TESIS DOCTORAL

PREPARACIÓN ATENCIONAL BASADA EN EXPECTATIVAS TEMPORALES: ESTUDIOS COMPORTAMENTALES Y ELECTROFISIOLÓGICOS

Attentional preparation based on temporal expectancy:

Behavioural and electrophysiological studies

DOCTORADO EUROPEO

Ángel Correa Torres

Directores

Juan Lupiáñez Castillo

Pío Tudela Garmendia

Departamento de Psicología Experimental y Fisiología del Comportamiento

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PREFACIO

La *Preparación atencional basada en expectativas temporales*, también denominada *Orientación de la atención en el tiempo*, constituye un mecanismo que los seres inteligentes emplean para conseguir comportamientos eficaces y adaptativos. En general, este mecanismo implica la orientación o focalización de la atención hacia determinados instantes en el tiempo, es decir, consiste en prepararse para el instante específico en que se anticipa la ocurrencia futura de un evento relevante, con objeto de optimizar las tareas que se realicen con tal evento.

La investigación experimental acerca del mecanismo atencional de orientación temporal, en concreto, de los determinantes, atributos y procesos cognitivos que subyacen a su funcionamiento, así como la investigación de los efectos que este mecanismo ejerce sobre el procesamiento de estímulos visuales, constituyó la motivación primordial de la tesis que se presenta a continuación.

La exposición de la tesis se estructura en tres partes: introducción, investigación experimental y discusión general. La *Introducción* se estructura en torno a los dos conceptos elementales que conforman nuestro objeto de estudio, atención y tiempo, y consta de cuatro capítulos que progresivamente van alcanzando un mayor nivel de especificidad hasta llegar al objeto de estudio en sí mismo. En primer lugar presentamos el concepto de tiempo, centrándonos en el estudio de cómo el tiempo es percibido y representado en el cerebro. Conocer estos aspectos es esencial para nuestra investigación, pues la habilidad que tenemos las personas para orientar la atención a diferentes intervalos temporales no sería posible sin un mecanismo que represente dichos intervalos de tiempo. El segundo capítulo está dedicado a la atención; ahí esbozamos el modelo teórico que subyace a nuestra investigación, y explicamos los mecanismos automáticos y controlados de la orientación de la atención en el espacio, dado que representan la analogía más cercana a nuestro objeto de estudio. En el tercer capítulo, describimos cuatro aproximaciones posibles para investigar las relaciones entre atención y tiempo, lo que nos lleva al último capítulo introductorio, donde se expone una revisión de la investigación relacionada con la orientación de la atención en el tiempo.

Fruto de dicha revisión son las preguntas que motivaron nuestra *Investigación Experimental*. Esta parte comienza con el planteamiento de las preguntas y objetivos que han guiado, y proporcionan el hilo conductor que articula las cuatro series de experimentos que luego se describen. Las series experimentales a su vez incluyen un total de seis capítulos que se corresponden con artículos independientes, publicados o en proceso de revisión. Finalmente, la *Discusión General* pretende la integración del conocimiento alcanzado a partir de cada uno de los artículos, mediante un resumen global de los resultados y aportaciones más relevantes de la tesis, y poniéndolo en relación con las ideas centrales de la introducción. La tesis culmina en un conjunto de reflexiones personales acerca del mecanismo de orientación temporal.

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INTRODUCCIÓN

I. El Tiempo

1.1. Filosofía del tiempo: Breves nociones

El tiempo es un concepto que fácilmente desborda nuestra comprensión y que adquiere un valor trascendental que lo sitúa en el ámbito de la metafísica, lo cual ha dificultado a lo largo de la historia un acercamiento científico al mismo. No obstante, entender el fenómeno del tiempo siempre ha preocupado a los filósofos, astrónomos, físicos, psicólogos o neurocientíficos, entre otros. ¿Por qué nos fascina de esta manera? La respuesta podría estar en el hecho de que posee la característica de la ubicuidad. El tiempo es tan intrínseco a cada uno de los sucesos que ocurren en la naturaleza que podemos encontrar ritmicidad o periodicidad tanto a niveles macroscópicos como microscópicos, por ejemplo en las órbitas de los planetas, los equinoccios, años solares, los periodos de día y noche, la fotoperiodicidad de las plantas, los ritmos circadianos en los animales, los ciclos en la división de las células, la frecuencia de las ondas electromagnéticas, las órbitas de los electrones en los átomos, etcétera. Realmente, sería difícil imaginar como podría desarrollarse la vida al margen de la dimensión de tiempo.

En la mitología griega, encontramos la figura de *Cronos*, el dios del tiempo. Cronos devoró a sus hijos para conseguir la inmortalidad. El tiempo también parece consumirlo todo, permaneciendo indestructible.

Desde la filosofía, Aristóteles creía en la existencia de un tiempo absoluto. Es decir, dos observadores, sean cualesquiera que sean sus circunstancias, obtendrían una misma medida de un intervalo de tiempo entre dos sucesos con la única condición de que tuvieran un reloj lo suficientemente preciso. El tiempo se consideraba como un marco de referencia fijo, inmutable, sobre el que van sucediendo los acontecimientos. De este modo, era lógico pensar que el tiempo había existido desde siempre.

Sin embargo, Kant (1781, véase Kant, 1966) niega al tiempo esa realidad absoluta que le concedía Aristóteles. Según Kant, “el tiempo es únicamente una condición subjetiva de nuestra intuición humana (que es siempre sensible, es decir, en la medida en que somos afectados por objetos), y en sí mismo, fuera del sujeto, no es nada” [p. 32][1]. Además, “el tiempo es la forma de la intuición de nosotros mismos y de nuestro estado interior. El tiempo no puede ser una determinación de los fenómenos externos, no pertenece ni a la figura ni a la situación, etc., sino que determina la relación de las representaciones en nuestros estados internos. Como esta intuición interior no tiene figura alguna, procuramos suplir esta falta por analogía y nos representamos la sucesión del tiempo con una línea prolongable hasta lo infinito, cuyas diversas partes constituyen una serie que es de una sola dimensión, y derivamos de las propiedades de esta línea todas las del tiempo excepto una: que las partes de las líneas son simultáneas, mientras que las del tiempo son siempre sucesivas” [p.31]. En resumen, el tiempo existe como forma *a priori* de la perceptibilidad, es decir, como condición de la posibilidad de nuestra percepción y previa a ella. La subjetivación del tiempo de Kant constituye una aproximación muy importante para el estudio científico del tiempo, pues nos obliga a indagar en una de las estructuras básicas del aparato perceptual.

Desde la física, las ideas que han dominado el panorama científico durante cuatro siglos surgen en el contexto de la mecánica clásica. Newton, al igual que Aristóteles, era fiel defensor de la existencia de un tiempo y un espacio absolutos, de la misma manera que creía en la existencia de un dios absoluto. No obstante, la teoría de la relatividad ha supuesto una gran revolución en la concepción científica sobre el tiempo. Pero, ¿cómo repercute esto en la aproximación psicológica al estudio del tiempo? Básicamente, con la teoría de la relatividad se introduce un concepto que impulsa una definición del tiempo más ligada a los fenómenos naturales que a los metafísicos, que es la “flecha del tiempo” (Hawking, 1992). El concepto de tiempo siempre va ligado a la idea de cambio, por ejemplo, en el estado de la materia. Este cambio siempre ocurre en la dirección que apunta la flecha del tiempo, es decir, de “atrás” hacia “delante”, de “antes” a “después”. En principio, se postulan tres flechas del tiempo. La flecha termodinámica es la dirección del tiempo en la que el desorden o entropía aumenta. La flecha cosmológica es la dirección del tiempo en la que el universo está expandiéndose en lugar de

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[1] La cita de Kant se basa en la traducción inglesa de la *Crítica de la Razón Pura*, realizada por F. Max Müller (1966). De acuerdo con esta edición, la cita correspondería a la página 33 de la 1ª edición (1781) y página 50 de la 2ª edición (1787).

contrayéndose. La flecha psicológica es la dirección en la que sentimos que pasa el tiempo, la dirección en la que recordamos el pasado pero no el futuro.

La flecha psicológica pone de manifiesto que la psicología tiene mucho que decir en el estudio del tiempo, como apuntaba Kant, al considerarlo como un fenómeno resultante de nuestra percepción del mundo. Al respecto, Bertrand Russell (1992) considera que la memoria es esencial en la percepción del cambio, o sea, del tiempo: “Cuando miramos el reloj, podemos ver moverse el segundero, pero sólo la memoria nos dice que las manecillas de los minutos y las horas se han movido” [p. 220].

Por otro lado, la teoría de la relatividad también aporta el concepto de la dimensión “espacio-tiempo”, lo que manifiesta la necesidad de considerar conjuntamente ambos aspectos en el estudio de la cognición, ya que nuestro sistema cognitivo, como cualquier elemento de la naturaleza, está constantemente influido y limitado por la dimensión espaciotemporal del contexto. Así, del mismo modo que tradicionalmente se han estudiado procesos cognitivos ligados al espacio (percepción del espacio, atención, memoria o aprendizaje espacial), también es necesario estudiarlos en relación con el tiempo porque ambas dimensiones se influyen de forma recíproca. De este modo, para comprender profundamente el fenómeno general de la percepción no sólo es importante la percepción del espacio sino también la percepción del tiempo, ya que espacio y tiempo son dos atributos indispensables de la percepción (Kubovy, 1981). En consecuencia, en el próximo apartado se profundiza en las aproximaciones psicológicas al estudio experimental de la percepción del tiempo.

1.2. Psicología y percepción del tiempo

Desde un nivel computacional de explicación (Marr, 1982), es posible justificar el estudio del fenómeno de la computación del tiempo, siguiendo una aproximación evolucionista. Desde esta perspectiva, la coordinación temporal en cuanto a secuenciación y cronometraje de los elementos constituyentes de procesos cognitivos o acciones motoras complejas, la representación coherente de los patrones temporales que presenta la sucesión de elementos en la naturaleza, o la anticipación temporal de la ocurrencia futura de acontecimientos, son aspectos de vital importancia para una adaptación exitosa al medio. De otra manera, escapa de nuestra comprensión imaginar un organismo cuyas interacciones con el ambiente no queden enmarcadas en las coordenadas espaciotemporales por las que se rigen los acontecimientos naturales. Por tanto, la evolución de un sistema que sea sensible a la dimensión temporal parece un requisito básico para la supervivencia.

La preocupación por el tiempo desde la psicología se remonta práctimente a los orígenes mismos de la disciplina. Por ejemplo, en el siglo XIX Külpe formuló los atributos fundamentales de la sensación: la cualidad, la intensidad y la duración eran atributos de todos los sentidos, mientras que la visión y el tacto además incluían la extensión como atributo. Por otro lado, Mach intentó aplicar la ley de Weber a la percepción del tiempo (véase Boring, 1942). Más recientemente, Block (1990) distingue tres campos de investigación en la psicología del tiempo: los ritmos biológicos, las experiencias de duración y el estudio del tiempo histórico-cultural. Aquí nos centraremos en la experiencia psicológica de duración, que se refiere a cómo los individuos realizan estimaciones temporales de la duración de los eventos.

La existencia de regularidades temporales, tanto en los sucesos externos del ambiente como en los procesos cognitivos internos al individuo, conduce a plantearnos si existe un mecanismo especializado en la representación del tiempo. Una posibilidad es asumir la existencia de un reloj o cronómetro interno que computa el tiempo de manera explícita y que es independiente de la modalidad sensorial. Por otro lado, el procesamiento del tiempo puede considerarse como una propiedad emergente del modo en que los eventos se organizan de forma implícita en una modalidad sensorial. En realidad, estas dos concepciones no son necesariamente excluyentes, sino que ponen de manifiesto la distinción entre dos formas de cronometraje o computación del tiempo: cronometraje implícito y explícito.

El cronometraje implícito conlleva un procesamiento temporal, una serie de ajustes temporales que son fundamentales para representar y actuar de forma coherente sobre los aspectos cambiantes que estructuran nuestro medio ambiente dinámico. Algunas actividades cotidianas en las que el *input* perceptual se organiza en patrones temporales son la segmentación en la percepción del habla, la percepción del movimiento o de la música (Jones, 1976). Otros ejemplos ilustran el papel del cronometraje para organizar el *output* motor, como la ejecución de habilidades complejas en los deportes, la conducción, la producción del habla o el alcance de objetos, en definitiva, en todo aquello que implique una secuenciación de elementos en la programación motora de un movimiento (v.g., Rosenbaum & Collyer, 1998). Un ejemplo de procedimiento para estudiar el cronometraje implícito es el condicionamiento parpebral, ya que la respuesta condicionada de cerrar el párpado debe ser cronometrada con exactitud para evitar eficazmente el soplo de aire.

El cronometraje explícito se relaciona con la tarea de discriminación de la duración, en la que los observadores han de realizar discriminaciones perceptuales sobre la duración de intervalos de tiempo. A continuación se describen con mayor detalle las tareas que se utilizan para estudiar estas dos formas de computar el tiempo.

1.2.1. Aproximación psicofísica a la computación del tiempo

Una de las tareas clásicas para el estudio de la computación del tiempo es la de producción temporal o golpeteo, en la que los participantes escuchan series de tonos a una tasa o ritmo determinado (por ejemplo a 1/550 ms) y deben simular dicho ritmo golpeando un botón. Es decir, los participantes estiman intervalos de 550 ms y dan un golpe por cada uno de estos intervalos. Al final se analiza la duración promedio y la desviación típica que presenta el intervalo estimado. Es decir, para determinar la precisión del mecanismo de cronometraje no sólo es importante fijarse en el grado de correspondencia entre el intervalo a estimar y el promedio general de todas las estimaciones, sino también en la cantidad de variabilidad o dispersión que presenta dicho mecanismo.

La tarea de percepción temporal, estimación de intervalos, o también conocida como discriminación de la duración, consiste en comparar intervalos de tiempo delimitados por pares de tonos auditivos. Primero se presenta el intervalo de referencia o estándar, que es un espacio vacío de tiempo, un silencio cuya duración queda delimitada por dos sonidos. A continuación se presenta el intervalo de comparación, que consiste en otro par de tonos de mayor o menor duración que el intervalo de referencia. El intervalo estándar suele presentarse antes del intervalo de comparación en cada ensayo, para que no haya que retenerlo en la memoria durante toda la tarea. Los individuos han de juzgar si el intervalo de comparación es más largo o más corto que el estándar. Este procedimiento psicofísico permite calcular el umbral diferencial y el punto de igualdad subjetiva (PIS). El umbral diferencial proporciona una medida de agudeza perceptual en el sentido de que valores altos indican una mala discriminación, una resolución perceptual baja, porque las diferencias entre intervalos de tiempo han de ser más gruesas para ser percibidas. El PIS nos da indirectamente el valor que los sujetos consideran que coincide con el estímulo estándar, ya que este valor tiene la misma probabilidad (.50) de ser juzgado como mayor o menor que el estándar.

Esta tarea se puede adaptar para aplicarla a animales, realizando un entrenamiento para que aprendan a esperar un intervalo de tiempo concreto, que comienza con una señal y termina con la respuesta operante del animal. Sólo se refuerzan las respuestas que se emiten en el instante correspondiente al intervalo temporal que queremos que el animal aprenda a cronometrar. Después de esta fase de adquisición se introducen algunos ensayos clave en los que no se proporciona el refuerzo. Analizando la tasa de respuestas de picoteo o de pulsación de una palanca a lo largo del tiempo se puede inferir que el intervalo estimado por el animal corresponde al momento en que ocurre la tasa máxima de respuestas.

Si realizamos un análisis cognitivo de esta tarea, encontraremos que intervienen procesos de cómputo temporal o cronometraje de intervalos (hay que “medir” la duración del intervalo de referencia y de comparación), procesos de almacenamiento (hay que memorizar el intervalo de referencia para que pueda ser comparado con otros intervalos) y procesos de decisión (hay que comparar la duración de los intervalos). Justamente, este tipo de procesos son los que se postulan desde los modelos cognitivos de percepción del tiempo.

1.2.2. Modelos cognitivos sobre percepción del tiempo

Los modelos sobre percepción del tiempo se diferencian en el tipo de información que utilizamos para computar el paso del tiempo. Podemos clasificarlos en modelos cronobiológicos, basados en la información del medio ambiente (por ejemplo, la luz del sol) y modelos cognitivos, basados en la cantidad de información bien atendida o bien acumulada en memoria. Los modelos cognitivos atencionales sobre la percepción del tiempo tratan de explicar cómo influye en las estimaciones temporales la asignación de recursos atencionales al procesamiento del tiempo. En los modelos de almacenamiento en memoria se considera que el número de estímulos que son codificados durante un periodo de tiempo influye en la estimación del mismo (Ornstein, 1969). No obstante, parece que lo que mejor explica la magnitud de la duración recordada no es la cantidad de información almacenada, sino el número de cambios que ocurren en un periodo de tiempo. Así, los modelos de cambio en la memoria asumen que a mayor cantidad de cambio en los estímulos interoceptivos y en el contexto psicológico que ocurre durante un intervalo, mayor es la duración recordada del mismo.

En último lugar, se encuentran los modelos cuya característica fundamental es la existencia de un reloj interno. En líneas generales, estos modelos consideran la contribución de procesos atencionales y de memoria en la percepción del tiempo.

Modelo del oscilador temporal interno (M. Treisman, 1963)

El modelo consta de cinco componentes: marcapasos, contador, almacén, comparador y mecanismo verbal selectivo. El marcapasos a su vez se compone del oscilador temporal, que emite una serie regular de pulsos con una frecuencia determinada. Los pulsos son transmitidos a la unidad de calibración, que controla la tasa final de pulsos que emite el marcapasos multiplicando la frecuencia inicial por un factor de calibración. Por ejemplo, dicha tasa puede aumentar debido a incrementos en el arousal. El contador va registrando el número de pulsos que le llegan durante cierto tiempo y el resultado es almacenado, o bien se manda al comparador. El mecanismo verbal selectivo es un almacén a largo plazo que contiene etiquetas verbales tales como “20 segundos”, “1 minuto”, etc.

Modelo de Cronometraje Escalar (Gibbon, Church, & Meck, 1984)

Este modelo surge en el contexto del aprendizaje animal. Contempla cinco componentes que se distribuyen en los tres procesos siguientes: cronometraje (marcapasos e interruptor), almacenamiento (memoria de trabajo-acumulador y memoria de referencia) y decisión (comparador). El cronometraje comienza con el marcapasos, que produce pulsos a una tasa determinada en un rango que puede oscilar de segundos a minutos. El interruptor es activado por la señal de comienzo del intervalo (v.g., el tono auditivo) y envía los pulsos al acumulador de la memoria de trabajo mientras dura el intervalo. El acumulador va registrando el número de pulsos. Cuando acaba el intervalo, ese valor de tiempo pasa de la memoria de trabajo para ser almacenado más permanentemente en la memoria de referencia. Por último, en el proceso de decisión se establece una comparación entre el valor de tiempo del ensayo actual almacenado en la memoria de trabajo y el valor almacenado en la memoria de referencia. El sistema emite una respuesta en función de la comparación entre esas dos duraciones. En este modelo también se contemplan procesos atencionales, que cumplen la función de controlar la acumulación de pequeños intervalos de tiempo caracterizados como pulsos, de manera que si un organismo retira la atención, se va a perder la cuenta de algunos de estos pulsos dando lugar a una subestimación del intervalo temporal (Brown, 1985).

Siguiendo la aproximación de los niveles de explicación de Marr (1982), podemos situar estos modelos teóricos en el nivel *algorítmico*, que estaría basado en explicaciones acerca de cómo se lleva a cabo la función de la percepción temporal. Por último quedaría, para un análisis completo del fenómeno, el nivel de *realización*, cuya principal preocupación es describir cómo el cerebro realiza dicha función. En el próximo apartado se describen tres aproximaciones de las neurociencias hacia el estudio de cómo se representa la dimensión temporal en el cerebro.

1.3. Representación del tiempo en el cerebro

La representación del tiempo es una de las grandes cuestiones que aún tiene la neurobiología por resolver. Los primeros modelos computacionales sobre la representación de información temporal están basados en mecanismos de demora de la conducción neural a lo largo de las fibras nerviosas. Braitenberg (1967) utilizó este modelo para explicar la función de control temporal del cerebelo. El tiempo sería medido en función de la distancia recorrida por un impulso nervioso a lo largo de las fibras paralelas entre la señal de entrada y la señal de salida. Aunque sugerente, esta propuesta no se sostiene a la luz de investigaciones posteriores, que indican que las representaciones en el cerebelo se extienden sobre distancias demasiado cortas como para poder computar tiempos útiles (cientos de milisegundos), dada la gran velocidad de la conducción neural.

Otros modelos consideran que la codificación temporal se basa en la actuación de procesos fisiológicos oscilatorios que ocurren en un único mecanismo central, el reloj interno, que sirve a la función *universal* de cronometrar un rango amplio de intervalos de tiempo. En cambio, hay otra serie de modelos conocidos como *modelos espectrales*, en los que los códigos temporales son trasladados a códigos espaciales. En concreto, intervalos de diferente duración serían representados por distintos circuitos neuronales que no se solapan y que presentan demoras temporales específicas causadas por procesos fisiológicos lentos (véase Buonomano & Karmarkar, 2002; Ivry & Spencer, 2004). Es decir, los procesos fisiológicos particulares de un circuito neuronal presentan una demora característica que posibilita el cronometraje de intervalos de tiempo en el rango de dicha demora. Por ejemplo, Buonomano (2003) ha observado en la corteza auditiva de la rata una sincronización en la ocurrencia de potenciales de acción con un estímulo hasta 300 ms después del inicio de su presentación. En esta línea, algunos proponen que determinados mecanismos fisiológicos como los potenciales post-sinápticos inhibitorios lentos podrían ser una pieza elemental en el procesamiento temporal, ya que éstos ocurren de forma generalizada en todo el sistema nervioso (Ivry & Spencer, 2004).

El estudio de la representación temporal en el cerebro además plantea la cuestión de si es realizada por una estructura neural especializada (que sería la sede del cronómetro interno de los modelos cognitivos), o por un circuito cerebral distribuido entre diferentes estructuras. También cabe la posibilidad de que esta función se realice de manera local en diferentes áreas en función de las demandas específicas de cronometraje que implica una tarea. Los estudios que se presentan más abajo persiguen aclarar esta cuestión mediante la búsqueda de las áreas cerebrales implicadas en la computación del tiempo.

1.3.1. Estudios neurofisiológicos con animales

Los modelos en psicología animal han atribuido al cerebelo una función de cronometraje. La evidencia más robusta procede de los estudios de condicionamiento de la membrana nictitante (para una revisión, véase Thompson, 1990). Un aprendizaje adaptativo implica no sólo la predicción del estímulo incondicionado (soplo de aire) a partir del estímulo condicionado, sino la adquisición de la relación temporal precisa entre ambos. Mediante estrategias de lesión y de estimulación de la corteza neocerebelar del conejo se ha demostrado que esta estructura es clave para cronometrar el intervalo entre el estímulo (un tono) y la respuesta condicionada de cerrar el párpado (es decir, la membrana). Los pacientes con lesión en el cerebelo replican este resultado, mostrando un deterioro en la adquisición del condicionamiento parpebral.

En el campo de la neurofarmacología (véase Meck, 1996, para una revisión), se ha descubierto que el uso de neurolépticos como el haloperidol (un antagonista dopaminérgico) disminuía la velocidad del reloj interno en ratas, mientras que la metanfetamina (agonista dopaminérgico) la incrementaba. Estos dos fármacos tienen en común la actuación sobre receptores de vías dopaminérgicas, que abundan en los cuerpos estriados de los ganglios de la base y en regiones del mesencéfalo como la sustancia negra (SN). En otra serie de experimentos se encontró que las lesiones en la SN, en los ganglios de la base o en la corteza frontal deterioraban la discriminación temporal de intervalos en ratas (Meck, 1996).

1.3.2. Estudios neuropsicológicos

En la neuropsicología se conocen dos síntomas principales cuando el cerebelo se encuentra dañado: la disdiadoquinesia, que consiste en la incapacidad de alternar rápidamente entre dos movimientos que involucran músculos antagonistas y la dismetría, que consiste en un fallo en el cálculo de la distancia en los movimientos (v.g., acción de agarrar un objeto antes de llegar a alcanzarlo). Estos síntomas se han interpretado como un deterioro en la habilidad para coordinar temporalmente el inicio y final de los músculos antagonistas, de modo que un movimiento hipermétrico sobrepasaría el objeto debido a que no se concluyó a tiempo la actividad del músculo agonista. Posteriormente, Ivry y Keele (1989) encontraron que los pacientes con lesión en el cerebelo muestran ejecuciones deterioradas respecto a un grupo control tanto en una tarea de golpeteo como en una tarea de estimación de duración de intervalos. Este resultado proporciona un buen apoyo al papel del cerebelo en el cronometraje y sugiere que éste no se limita al dominio motor sino que también se extiende al dominio de la percepción temporal.

En relación con el papel de los ganglios basales en el cronometraje, la investigación neuropsicológica se ha focalizado en los pacientes afectados de Corea de Huntington y de enfermedad de Parkinson. Los estudios revelan que ambos tipos de pacientes tienen mayor variabilidad que los controles en tareas de golpeteo o producción de intervalos (véase Pastor & Artieda, 1996). Parece que la percepción de duración en pacientes con Parkinson también es anormal, lo cual es importante para concluir que el deterioro en tareas de golpeteo no se debe exclusivamente a un déficit general de la ejecución motora. Más bien, sugiere que las operaciones de cronometraje son reguladas a través de vías dopaminérgicas en los ganglios de la base. En otro estudio (Harrington, Haaland, & Knight, 1998) encontraron que los pacientes que mostraron un déficit específico a una tarea no demorada de percepción de duración (intervalos estándar de 300 y 600 ms) presentaban lesiones en el córtex prefrontal, incluyendo los campos orbitales frontales (FEF o ‘f*rontal eye fields*’) y el córtex dorsolateral prefrontal.

Como conclusión provisional, la evidencia neuropsicológica sugiere una relación entre los procesos que postulaban los modelos cognitivos y estructuras específicas. El proceso de cronometraje se relaciona con una estructura subcortical que puede ser el cerebelo, los ganglios de la base o la interacción entre ambos. Los procesos de memoria de trabajo para la representación y comparación entre intervalos temporales se asocian con áreas de la corteza prefrontal. La pregunta que surge entonces es ¿cómo se relacionan estas estructuras para cumplir la función de percibir un intervalo corto de tiempo? Los estudios que se presentan a continuación aportan información en este sentido.

1.3.3. Estudios con neuroimagen

El número de estudios con neuroimagen sobre la percepción del tiempo ha sufrido un crecimiento espectacular en estos últimos años, de modo que se pueden contar hasta 20 estudios publicados desde el año 2000 (Lewis & Miall, 2003). En la primera investigación con neuroimagen que conocemos (Jueptner et al., 1995), se empleó la técnica de tomografía por emisión de positrones (PET) para localizar la función de cronometraje mediante una tarea de percepción de duración. Principalmente, observaron activaciones significativas en el cerebelo y en los ganglios basales. Uno de los estudios posteriores más influyentes es el de Rao, Mayer y Harrington (2001), quienes encontraron con RMf relacionada con eventos activaciones en la vermis del cerebelo y en los ganglios de la base (putamen derecho y caudado bilateral) específicas para la tarea de percepción de duración. A nivel de la corteza, encontraron una activación temprana bilateral en el área premotora, seguida de la activación más tardía del córtex dorsolateral prefrontal derecho (DLPF). Los autores relacionaron la activación del área premotora con la función de repaso de lazo articulatorio, que mantendría activa en la memoria de trabajo la representación del intervalo estándar, mientras que la corteza DLPF aportaría la función ejecutiva de manipular la información activa en la MT (comparar los intervalos) y de seleccionar una respuesta.

Una revisión reciente (Ivry & Spencer, 2004) encuentra activaciones comunes a varios estudios de estimación temporal en áreas prefrontales, premotoras, área motora suplementaria (AMS), corteza parietal, ínsula, cerebelo y ganglios de la base. En el siguiente apartado veremos el modelo que proponen los autores para explicar dicho patrón de activaciones.

Obsérvese la gran implicación del circuito motor en las tareas de cronometraje. El trabajo siguiente aclara en gran medida este hecho. Lewis y Miall (2003) realizan una excelente revisión que aporta bastante coherencia al campo de investigación. Mientras que otras revisiones, basadas en la concepción de un cronometro interno general, han considerado que las características específicas de la tarea de cronometraje no afectan al patrón cerebral observado (Macar et al., 2002), Lewis y Miall defienden que es precisamente el agrupamiento inapropiado de estudios en las revisiones lo que ha propiciado la ambigüedad que existe actualmente acerca de las áreas importantes para el procesamiento del tiempo. Así, los autores realizan un interesante análisis cognitivo de las tareas, que se relaciona con las funciones de cronometraje implícito y explícito explicadas anteriormente. En función de este análisis, los estudios quedan agrupados según tres características básicas de tarea: el rango de duración que ha de ser estimado, el uso de movimientos o procesos motores para realizar la estimación temporal y la predictividad que presenta la tarea.

Estas características son importantes porque definen el carácter implícito/explícito, o dicho en sus términos automático/controlado, de los procesos de cronometraje. Así, el cronometraje de intervalos breves del rango de cientos de milisegundos en tareas que además demandan movimiento (v.g., tarea de golpeteo) implica la actuación de procesos motores automáticos. Por otro lado, algunos autores consideran que las estimaciones en rangos inferiores al segundo son automáticas mientras que en rangos superiores éstas requieren cierta atención (véase Lewis & Miall, 2003). Además, la realización de tareas sobreaprendidas que presentan un patrón predecible no requiere atención, de modo que podría estar basada en un plan o programa motor sobreaprendido. En conclusión, la hipótesis principal de los autores consiste en que las tareas de cronometraje implícito o automático implican la actuación de circuitos motores automáticos al margen de la atención, mientras que las tareas de cronometraje explícito implican la actuación de procesos controlados de atención y memoria de trabajo.

El agrupamiento de estudios de neuroimagen en función de procesos de cronometraje implícito y explícito reveló una clara disociación de circuitos cerebrales. En particular, las tareas de cronometraje implícito mostraron la activación del AMS, áreas premotoras, corteza sensoriomotora izquierda, corteza auditiva (lóbulo temporal superior), cerebelo derecho y ganglios de la base. Aunque la activación de la corteza auditiva podría considerarse como un confundido debido a la utilización de estimulación auditiva, algunos estudios encuentran activación similar aún en ausencia de dicha estimulación (v.g., Coull, Frith, Büchel, & Nobre, 2000). Análogamente al procesamiento motor, las representaciones temporales en la modalidad auditiva cumplen un papel esencial para el procesamiento. En conclusión, este sistema automático de cronometraje podría utilizar las capacidades de computación temporal que presenta tanto el cerebelo como los circuitos motores o auditivos.

En cambio, el cronometraje explícito se relaciona con la corteza parietal y prefrontal preferentemente del hemisferio derecho y cerebelo izquierdo. Así, a la actuación de estructuras del sistema automático como el cerebelo, se añade la implicación de áreas prefrontales relacionadas con procesos de memoria de trabajo, así como de áreas parietales relacionadas con funciones atencionales, dando lugar a un sistema versátil que en este caso se ocupa de la función de control sobre la representación temporal.

Conclusiones

La convergencia entre los estudios animales, neuropsicológicos y de neuroimagen pone de manifiesto que el cerebelo es una estructura fundamental implicada en la función de realizar cómputos temporales que son importantes para un conjunto de tareas. Algunas de las tareas que se conocen son el condicionamiento parpebral, sincronización temporal de movimientos, percepción de intervalos temporales o percepción de la velocidad relativa entre varios objetos.

Desde un punto de vista evolucionista, Ivry y colegas (v.g., Ivry & Keele, 1989) plantean la hipótesis de que las computaciones temporales del cerebelo que evolucionaron originariamente para el control motor podrían haberse generalizado a otros contextos, volviéndose accesible para la ejecución de otras tareas que también requieren cómputos de tiempo. Siguiendo esta lógica, estos autores consideran que la función de cronometraje es una manifestación específica de una capacidad predictiva más general del cerebelo. Podemos citar tres ejemplos de procesos independientes en los que el cerebelo actúa como un dispositivo de predicción temporal. El condicionamiento clásico implica anticipar el comienzo del estímulo incondicionado con el objeto de emitir adaptativamente la respuesta condicionada. En procesos motores, la copia eferente es predictiva en el sentido de que la información sobre el siguiente movimiento a realizar en un programa motor (la copia eferente) llega antes al cerebelo que la información aferente que procede de la realización de dicho movimiento. En las tareas de producción y percepción temporal, para un buen cronometraje se requiere la habilidad de predecir cuando ocurrirá el siguiente evento, ya sea el próximo golpeteo o el tono final del intervalo estándar, respectivamente. En este sentido, los sujetos realizan juicios prospectivos sobre intervalos de tiempo. En resumen, los estudios revelan la implicación del cerebelo en tareas que requieren una representación precisa de la información temporal, como el aprendizaje de secuencias motoras, golpeteo rítmico, discriminación perceptual de la duración, percepción de fonemas y anticipación atencional (Ivry & Spencer, 2004).

Por otra parte, los datos además convergen en la idea de que las operaciones de cronometraje son reguladas por otra estructura subcortical, los ganglios de la base, a través de vías dopaminérgicas en el estriado (núcleos caudado y putamen). No obstante, actualmente no hay datos que permitan la elección de una estructura y la exclusión de la otra como sustrato neural de la computación del tiempo. Al contrario, hay varios modelos que contemplan una conexión entre cerebelo y ganglios de la base para formar una red neural distribuida. A favor de estos modelos está el hecho de que la mayoría de la investigación sobre el papel de los ganglios basales en cronometraje ha utilizado intervalos temporales de varios segundos o minutos, es decir, más largos que en las investigaciones sobre el cerebelo, que suelen utilizar intervalos de varios cientos de milisegundos. Así, podría ser que estas estructuras actuaran interconectadas para cubrir diferentes rangos temporales.

En cuanto a la implicación de la corteza prefrontal, parece ser que lleva a cabo una función típica de la memoria de trabajo. Se encargaría del mantenimiento activo, la monitorización y organización de las representaciones de tipo temporal, en este caso. Parece lógico pensar que el papel de la corteza prefrontal en la percepción del tiempo es más bien de tipo general: estaría desarrollando las mismas funciones para cualquier tarea cognitiva en la que esté implicado con la particularidad de que la información que se procesa es de tipo temporal. Sin embargo, también hay varias hipótesis que defienden el papel específico de esta región en el cronometraje. Por ejemplo, se ha asociado con la función de contar los pulsos que va acumulando del marcapasos, con un mecanismo atencional (interruptor) que manda los pulsos al acumulador, con un mecanismo de memoria específico implicado en el almacenamiento y recuperación de información temporal, o incluso se ha propuesto como la sede del mecanismo de cronometraje (Zackay & Block, 1996).

Otra área que también muestra activación en algunos estudios es la corteza parietal. Aunque se ha relacionado con procesos atencionales generales implicados en la percepción del tiempo, Leon y Shadlen (2003) encuentran una correlación entre la actividad de neuronas en la corteza parietal inferior del mono y procesos de estimación temporal. Por otro lado, la corteza parietal está implicada en la codificación espacial y en el procesamiento de cantidades numéricas. Esto condujo a Walsh (2003) a proponer la hipótesis de que la corteza parietal está implicada en el procesamiento de cantidades en general, ya sean expresadas en distancias espaciales, duraciones temporales o valores numéricos. De hecho, es común encontrar la metáfora de la línea mental tanto para cómputos numéricos como temporales.

1.3.4. Modelos de computación temporal basados en los datos de la neurociencia

Una vez determinadas las estructuras cerebrales implicadas y sus funciones específicas, es deseable contar con un modelo integrador que explique como se coordinan todas esas áreas para hacer posible la percepción del tiempo. En este contexto, los modelos cognitivos anteriormente comentados cobran una gran importancia, pues sirven de base para lograr dicha integración.

El grupo de Ivry (Ivry & Spencer, 2004) sugiere que la percepción del tiempo se realiza mediante una red neural formada por estructuras corticales y subcorticales: el cerebelo, los ganglios de la base y el córtex prefrontal. Considera que el cerebelo cronometra y genera las representaciones temporales de milisegundos de duración, y estas representaciones son mantenidas y manipuladas por la corteza prefrontal, que sirve a una función general de la memoria de trabajo. Los ganglios de la base en conexión con la corteza prefrontal intervendrían en procesos de actualización de la memoria de trabajo mediante un mecanismo de umbral. La función de cronometraje de esta estructura se lograría controlando el número de actualizaciones que se producen en la memoria de trabajo, que acumula los valores de tiempo. Así, los agonistas de la dopamina disminuyen el umbral de los ganglios de la base produciendo actualizaciones con mayor frecuencia, dando lugar a sobrestimaciones temporales en comparación con las estimaciones bajo los efectos de antagonistas dopaminérgicos.

En el modelo neurofarmacológico de Meck (1996) se contemplan cinco componentes, de los cuales los tres primeros forman el mecanismo de cronometraje: la sustancia negra, el estriado (caudado-putamen), el globo pálido, el tálamo y el córtex prefrontal. En términos de los modelos cognitivos, la sustancia negra es el *marcapasos*, que manda pulsos regularmente a través del estriado (*interruptor* o puerta de entrada) al globo pálido que actúa de *acumulador* de pulsos. Estos tres componentes constituyen el “reloj interno” y forman un circuito dependiente de la dopamina, a diferencia del siguiente circuito colinérgico (tálamo y prefrontal) implicado en atención y memoria. Entonces, el acumulador manda la información temporal, pasando por el tálamo, a la corteza prefrontal, donde se encuentra almacenada la duración del intervalo estándar y donde se realiza la comparación.

En el modelo del grupo de Harrington (Rao et al., 2001) se contemplan cinco estructuras principalmente del hemisferio derecho: ganglios basales (caudado y putamen), tálamo, córtex parietal, área premotora y córtex dorsolateral prefrontal. Los ganglios de la base subyacen a la función de *marcapasos*, interaccionando con procesos de *atención* localizados en el parietal derecho vía tálamo. De la interacción surge la *acumulación* de los pulsos, que es mantenida en la *memoria de trabajo* mediante un repaso ejercido por el área premotora, y esta representación manipulada (*comparación*) en el córtex DLPF. A continuación se describe cómo el modelo explicaría la tarea de percepción de duración.

Cuando aparece el intervalo estándar, es medido por los ganglios basales que actúan como un cronómetro generador de pulsos. Los procesos atencionales (córtex parietal derecho) actúan estrechamente con el cronómetro regulando la acumulación de pulsos. La conexión entre las dos estructuras es mediada por el tálamo derecho. Antes de llegar a la fase de comparación es necesario mantener activo en la memoria de trabajo el intervalo estándar: esta función la realiza el área premotora, implicada en el circuito de repaso del lazo articulatorio. La última fase requiere una manipulación de la información mantenida en la memoria de trabajo: se han de comparar los dos intervalos y seleccionar una respuesta. En esta función ejecutiva interviene el córtex dorsolateral prefrontal derecho. En este modelo, no hay lugar para el cerebelo en la percepción del tiempo.

En conclusión, parece haber un relativo acuerdo en considerar que estructuras subcorticales como los ganglios de la base y en especial el cerebelo cumplen una función de cronometraje automático de valores de tiempo inferiores al segundo. Las conexiones de estas estructuras con áreas corticales podrían integrar circuitos especializados en los que el cronometraje implícito es esencial para el procesamiento motor o auditivo. Además, las conexiones con áreas parietales y prefrontales podrían servir a procesos de cronometraje de carácter más controlado o explícito necesario para tareas de discriminación perceptual de intervalos de diversa duración.

II. Atención

2.1. Un breve repaso histórico a través de las metáforas de la atención.

La riqueza de fenómenos y de mecanismos englobados bajo el término ‘atención’ queda bien patente si hacemos un breve recorrido por algunas de las formas de entender la atención que han tenido los psicólogos a lo largo de nuestra historia reciente. La atención llegó a ser considerada como un simple reflejo de orientación de los receptores sensoriales hacia la estimulación (Sokolov, 1963), se ha comparado con un filtro que selecciona la vasta cantidad de información que recibimos continuamente (Broadbent, 1958), se ha relacionado con una política de distribución de recursos energéticos en la ejecución de una tarea (Kahneman, 1973), se ha conceptuado como un proceso de control de la memoria a corto plazo (W. Schneider & Shiffrin, 1977), como un “pegamento” para la integración de características perceptuales de los objetos (A. Treisman & Gelade, 1980), un foco de linterna (Tsal, 1983), una “puerta” hacia la consciencia (Reeves & Sperling, 1986) o el zoom de una lente (Eriksen & Yeh, 1985).

Fernández-Duque y Johnson (1999) realizaron un análisis de algunas de las metáforas más influyentes en el estudio de la atención en términos de cómo estructuran las teorías atencionales y cómo guían la investigación basada en esas teorías. En particular, examinaron las metáforas de la atención como filtro, como foco de linterna y como visión. En la metáfora del filtro, la atención se concibe como una estructura que actúa seleccionando el flujo de información, con el fin de evitar la sobrecarga del sistema perceptual de capacidad limitada (Broadbent, 1958). Esta metáfora ha inspirado debates e investigación acerca del *locus* en que se produce la selección de información, es decir, si el filtro atencional actúa a niveles tempranos o tardíos del procesamiento, acerca del carácter de dicha selección (si ésta es completa, de carácter todo o nada, donde todos los atributos de la información, físicos o semánticos, serían filtrados; o si es una selección parcial, en la que algunos atributos son procesados), o acerca de los procesos implicados en la selección de información (potenciación de lo atendido o inhibición de lo no atendido).

En la siguiente de las metáforas, se considera que la atención funciona como un foco de linterna que puede moverse e iluminar un área del espacio. El procesamiento de la información que cae bajo el foco atencional se ve selectivamente potenciado respecto a la información que cae fuera de dicho foco. La investigación se ha dirigido a estudiar las características del foco atencional, tales como su tamaño, forma y movimiento, y se plantea si la selección de información estaba basada en el espacio o en los objetos.

En la metáfora de la atención como visión, el foco de atención se corresponde con la fóvea (el lugar de la retina que tiene la mayor sensibilidad) y los cambios de atención con los movimientos sacádicos (movimientos oculares muy rápidos de carácter balístico). Esta metáfora es la base de la teoría premotora de la atención, la cual considera que los mecanismos implicados en la atención espacial son los mismos que los implicados en la programación de los movimientos sacádicos (v.g., Rizzolatti, Matelli, & Pavesi, 1985). Un ejemplo de investigación bajo esta metáfora es la cuestión de si la atención es unitaria, ya que los humanos tenemos una sola fóvea, o si puede ser dividida.

Como conclusión, Fernández-Duque y Johnson (1999) proponen la siguiente lista en la que enumeran algunas de las características atribuidas a la atención comunes a las metáforas anteriores. La atención mejora la ejecución de un amplio rango de tareas, tales como la percepción, actividades motoras y operaciones cognitivas. La atención minimiza la distracción. La atención potencia los procesos en el área atendida. La atención implica alguna forma de selección de estímulos. La atención facilita el acceso a consciencia. No obstante, los autores reconocen que esta lista es incompleta, que está lejos de ser una definición apropiada de la atención y que carece de la estructura conceptual necesaria para proporcionar explicaciones adecuadas sobre qué es la atención y cómo funciona.

Esta diversidad de concepciones sobre la atención nos revela la gran complejidad de este constructo. En consecuencia, en el próximo apartado presentamos nuestra postura teórica, pero antes esbozaremos una serie de características generales que ayudan a su definición. En primer lugar, destacamos la función adaptativa de la atención. En un medio ambiente cambiante, aquellos organismos que presenten una mayor flexibilidad en su comportamiento tendrán mayor probabilidad de lograr adaptaciones exitosas. El aprendizaje y la memoria son procesos cognitivos que aportan gran plasticidad a nuestro comportamiento, lo que proporciona un gran valor adaptativo a situaciones cotidianas. Del mismo modo, la función adaptativa de la atención es clara si tenemos en cuenta que el sistema atencional permite reconfiguraciones del procesamiento de información que proporcionan un ajuste prácticamente instantáneo a las demandas de una situación nueva.

Por otro lado, la capacidad para orientar la atención en el espacio es una característica que seguramente nos ha aportado ciertas ventajas en la evolución. En un medio ambiente complejo y dinámico resulta imprescindible para la supervivencia poder atender selectivamente a los estímulos que son relevantes para la especie (v.g., una presa, un depredador, un obstáculo en el camino, un aullido lejano o el llanto de un bebé). En este sentido, nuestro sistema atencional potencia el procesamiento de estímulos relevantes. Por una parte, parece que estamos sesgados hacia la detección de la novedad, ya que un objeto nuevo en una escena visual suele capturar poderosamente nuestra atención mediante procesos de captura automática.

Sin embargo, hay numerosas ocasiones en las que los estímulos por sí mismos no son una condición suficiente para atraer la atención. Es necesario que también entren en juego las interpretaciones que se dan a esos estímulos en función de las necesidades del organismo. En otras palabras, la atención puede estar controlada por los estímulos del ambiente o por las metas del individuo. Siguiendo la distinción de William James (1890), la atención puede ser involuntaria (exógena) o voluntaria (endógena). Así, las expectativas, metas, intenciones y motivaciones del individuo se convierten en un potente orientador de la atención, de manera que ésta no sería sólo un acto reflejo controlado por los estímulos (componente exógeno) ni tampoco un acto enteramente voluntario (componente endógeno); más bien se trataría de un mecanismo que funciona de acuerdo a la interacción entre el medio ambiente y las metas que dirigen nuestro comportamiento.

Otra característica relevante en el estudio de la atención es la distinción general que se realiza en psicología cognitiva entre procesamiento automático y controlado (Posner & Snyder, 1975; W. Schneider & Shiffrin, 1977). En estos estudios se argumenta que la atención es esencial para el procesamiento de carácter controlado, constituyendo así un sistema de control del procesamiento. La implicación del control atencional en actividades complejas o que no están muy practicadas es beneficiosa y mejora la ejecución de dichas actividades. Pero funcionar continuamente en ese estado sería altamente costoso, supondría un gran esfuerzo cognitivo, nos impediría desarrollar varias acciones al mismo tiempo y cualquier proceso se vería tan enlentecido que no resultaría adaptativo. Por eso también es importante la consecución de los automatismos a través del aprendizaje. La acción de andar la podemos realizar con poco control atencional, de forma que podemos dedicar nuestra atención a otras actividades, lo que permite realizar varias tareas en paralelo.

Por otra parte, las desventajas mencionadas respecto al procesamiento controlado (requiere gran esfuerzo, más tiempo y dedicación a una sola tarea) ponen de manifiesto el carácter limitado de la atención. La capacidad limitada de la atención es un rasgo que ha estado presente prácticamente en todas las teorías atencionales (v.g., Broadbent, 1958; James, 1890; Kahneman, 1973). Una multitud de efectos experimentales apoyan esta idea de la limitación, por ejemplo, los obtenidos mediante el paradigma de escucha dicótica (Broadbent, 1958), el periodo psicológico refractario (véase Pashler, 1998), el enmascaramiento atencional (Enns & Di Lollo, 1997), la ceguera por inatención (Mack & Rock, 1998) o el parpadeo atencional (Shapiro, Arnell, & Raymond, 1997).

Un factor común a estos experimentos es que se enfrenta a los individuos con la realización simultánea de más de una tarea, y al menos una de ellas requiere control atencional. Los resultados muestran que la ejecución de los individuos queda muy deteriorada bajo esas circunstancias, lo cual llevó inicialmente a Broadbent (1958) a considerar que hay determinadas estructuras de procesamiento con capacidad limitada, que sólo permitían el procesamiento secuencial de la información. Este modelo plantea que la limitación tiene lugar en momentos bastante iniciales del procesamiento, por lo que se le conoce como modelo de filtro temprano. Sin embargo, la evidencia experimental que este modelo no explicaba satisfactoriamente, por ejemplo, el hecho de que en tareas de escucha dicótica se pudiera seleccionar información a partir de sus características semánticas (v.g., Cherry, 1953), impulsó el desarrollo tanto de modelos que postulaban que la selección se producía a niveles más tardíos, por ejemplo a nivel de selección de respuesta (Pashler, 1998), como de concepciones más flexibles y dinámicas (v.g., Kahneman, 1973).

Las propias limitaciones del sistema indujeron a pensar que existía un mecanismo que selecciona la información, compensando así dichas limitaciones. En este contexto, resaltamos otra característica de la atención: la atención es selectiva. Los experimentos que ponían de manifiesto ese carácter limitado, también revelan que la información ha sido seleccionada de alguna manera. Por ejemplo, en los experimentos de escucha dicótica, en los que se presentan dos mensajes a la vez, uno por cada oído (Broadbent, 1958; Cherry, 1953), el mensaje que los participantes eran capaces de repetir procedía del oído atendido mientras que el mensaje procedente del oído no atendido era olvidado o ignorado. Este resultado llevó a pensar que el mecanismo de selección actuaba mediante procesos de filtrado o bloqueo de la información distractora o irrelevante. Sin embargo, cuando posteriormente las personas fueron enfrentadas ante situaciones donde no era necesario que eliminaran información, salieron a relucir otros mecanismos de selección. En concreto, en una tarea de orientación visual (Posner, Snyder, & Davidson, 1980) la atención visual puede dirigirse hacia una posición espacial mediante la presentación de una señal que informa a los participantes sobre el lugar más probable de aparición del estímulo objetivo. En esta situación, el sistema no sufre una sobrecarga y no hay nada que inhibir porque el estímulo se presenta solo, sin distractores. Entonces, ¿cómo explicar que los participantes fueran más rápidos en detectar el estímulo cuando aparecía en los lugares señalados que en los lugares no señalados? De esta forma, se plantea que hay otro mecanismo de selección que potencia la información relevante.

En conclusión, los resultados anteriores sugieren que la atención selecciona la información o los procesos relevantes mediante activaciones de la información atendida, inhibiciones de la información ignorada o mediante la acción conjunta de ambos mecanismos. Desde un punto de vista fenomenológico, podemos intuir que los dos procesos de selección mencionados contribuirán a incrementar la *claridad* de aquello a lo que prestamos atención. James (1890) ya lo intuyó tiempo atrás: “no hay duda de que la atención aumenta la claridad de todo lo que percibimos” [p. 426]. Así, podemos considerar que el beneficio fundamental que aporta la atención al comportamiento consiste en aumentar la cantidad y/o la calidad de la información que nuestro sistema cognitivo es capaz de procesar.

2.2. Modelo de atención

La postura teórica sobre atención que subyace a este trabajo de investigación se basa en la perspectiva de Tudela (1992), quien considera la atención como "un mecanismo central de capacidad limitada cuya función primordial es controlar y orientar la actividad consciente del organismo de acuerdo con un objetivo determinado" [p. 138], y se basa en la teoría atencional de Posner (v.g., Posner & Raichle, 1994). Se trata de una concepción vertical de la atención, la cual no es considerada como un sistema más de procesamiento. Más bien, concebimos la atención como un mecanismo de control sobre el procesamiento que realizan otros módulos, ya sean perceptuales, motores, de memoria, etc.

De este modo, nuestro gran objetivo en esta investigación persigue el estudio de las consecuencias que produce el mecanismo atencional de control sobre el procesamiento de los estímulos. En concreto, exploraremos si el atender a un estímulo puede potenciar o facilitar el procesamiento perceptual y motor que requiere dicho estímulo. A continuación, se describe uno de los paradigmas clásicos para el estudio de esta cuestión, y veremos cómo se ha adaptado para estudiar los efectos de focalizar la atención sobre diversos rasgos específicos que definen a un estímulo.

2.3. Atención visual selectiva al espacio: Orientación de la atención en el espacio

Los seres inteligentes han desarrollado a lo largo de la evolución la capacidad para la atención selectiva, que consiste en priorizar el procesamiento de aquellas características de los estímulos que son más relevantes para nuestras metas o necesidades. El espacio es una de las características estimulares esenciales que ha sido estudiada a fondo desde los inicios de la investigación sobre atención visual selectiva (v.g., Posner, 1978), dada la importancia de la información espacial para el sistema visual. Así, la capacidad para orientar selectivamente la atención hacia distintas zonas del espacio en la escena visual donde pueden aparecer a los objetos tiene un importante valor adaptativo, pues nos permite interactuar de forma efectiva con el medio.

Para su estudio, previamente debemos diferenciar dos tipos de orientación de la atención: abierta y encubierta. La atención abierta implica la orientación de los receptores sensoriales. Sin embargo, en el contexto de la visión hay evidencia de que las personas pueden mover su foco atencional sin mover los ojos (Posner et al., 1980). A este caso, donde se orienta la atención pero no los receptores, se le denomina atención encubierta, en la cual nos centraremos en este trabajo.

El procedimiento clásico para el estudio de la orientación de la atención en el espacio fue desarrollado por Posner y colaboradores y se conoce como el paradigma de Costes y Beneficios (Posner, Nissen, & Ogden, 1978; Posner et al., 1980). Consiste en que los participantes deben responder a un estímulo, llamado “objetivo”, que aparece en la periferia de la pantalla, a izquierda o derecha de un punto de fijación central. Al objetivo le precede una señal que, dependiendo de los ensayos, dirige la atención hacia el mismo lugar donde aparecerá éste (ensayos válidos) o hacia otra posición (ensayos inválidos). Normalmente se mide la latencia de respuesta o tiempo de reacción (TR) y la precisión (número de errores). El efecto de orientación atencional se manifiesta en el comportamiento a través de una disminución del TR y/o de los errores en relación con los estímulos que aparecen en el lugar atendido o esperado (válidos) cuando se compara con el procesamiento de estímulos que aparecen en lugares no atendidos o inesperados (inválidos). Este beneficio atencional se conoce como “efecto de validez o facilitación”.

Pero no sólo es posible estudiar los efectos de la atención espacial a partir de la ejecución comportamental en tareas cognitivas, sino que también podemos explorar sus efectos sobre el funcionamiento fisiológico cerebral. Los estudios fisiológicos revelan que la orientación espacial produce incrementos del flujo sanguíneo en la corteza del sistema visual (v.g., Heinze et al., 1994), e incrementos en la amplitud de los potenciales electrofisiológicos relacionados con procesamiento visual de los estímulos en electrodos localizados en zonas occipitales del cuero cabelludo (véase Mangun, 1995, para una revisión sobre estudios electrofisiológicos). Estos resultados convergen en la idea de que el procesamiento de los estímulos que aparecen en las posiciones indicadas por la señal es potenciado de alguna manera por el mecanismo atencional.

Las ventajas de este procedimiento, en cuanto a su simplicidad y a la posibilidad de incorporar infinidad de modificaciones, han propiciado una explosión de investigaciones en el campo de la atención que comparten el estudio de los efectos que la atención ejerce sobre la ejecución de tareas cognitivas, y en general, sobre el procesamiento de la información. Por ejemplo, es posible extender el estudio de la atención visual hacia otras modalidades sensoriales como la auditiva o la táctil, mediante instrucciones o mediante la presentación de señales y estímulos objetivos en dichas modalidades (v.g., Spence & Driver, 2004). Además, se puede estudiar el efecto de dirigir la atención selectivamente sobre otros atributos fundamentales de los objetos, aparte de su localización espacial. Así, se han utilizado señales que adelantan información sobre atributos como el color, la forma, identidad, velocidad, significado semántico, valencia emocional, etc., que definen al estímulo objetivo sobre el que se realizará la tarea (v.g., Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990). Llama la atención que entre los atributos básicos que se han investigado se encuentran el espacio y la velocidad pero no el tiempo. Insistimos una vez más, en la idea de que en nuestro medio ambiente dinámico los eventos no sólo tienen una extensión espacial sino también temporal, lo que justifica el objeto de estudio de la presente tesis: la atención temporal, es decir, la capacidad de anticipar y de atender al momento en el que sucederá un evento importante.

Volviendo a los estudios comentados, una conclusión común que puede extraerse es que la atención es un mecanismo flexible que puede dirigirse tanto a diferentes modalidades sensoriales como a diferentes rasgos o representaciones de los estímulos, asignando recursos adicionales para procesar los aspectos relevantes para la tarea, ya sea sobre una modalidad sensorial específica, ya sea sobre áreas cerebrales encargadas del procesamiento de las características relevantes del objetivo. Esta asignación de recursos es la que produciría la potenciación del procesamiento implicado. Llegados a este punto surge una cuestión clave que iremos retomando a lo largo de la tesis: ¿En qué consiste específicamente esa potenciación atencional sobre el procesamiento? Es decir, ¿es la velocidad del procesamiento o la calidad de las representaciones lo que se ve mejorado por la atención?

Consecuencias de la atención sobre el procesamiento y las representaciones de los estímulos

Una aproximación interesante para estudiar los efectos atencionales sobre la calidad de las representaciones visuales consiste en la combinación de un procedimiento de orientación espacial con tareas diseñadas para evaluar diferentes aspectos del procesamiento visual, como la sensibilidad al contraste o la resolución espacial. Nos centraremos en la resolución espacial, que se relaciona con la agudeza del sistema visual para disciminar detalles finos en una imagen. Carrasco y colaboradores (v.g., Yeshurun & Carrasco, 1999) han estudiado los efectos de la atención espacial sobre la resolución espacial utilizando una tarea de agudeza visual en la que había que detectar la presencia de un pequeño orificio en uno de los lados de un cuadrado. Los resultados muestran que la resolución espacial para percibir la presencia del orificio es mayor en zonas del espacio atendidas que en zonas no atendidas. Los autores interpretan que la atención mejora la calidad de la representación del estímulo incrementando la resolución espacial de la visión y lo relacionan con una reducción del tamaño de los filtros espaciales, en definitiva, con una reducción del campo receptivo de las células.

En relación con los efectos de la atención sobre la velocidad de procesamiento, una aproximación clásica se basa en combinar un procedimiento de orientación espacial con una tarea de juicios de orden temporal (JOT, véase Shore & Spence, 2005, para una revisión). En esta tarea se presentan dos estímulos separados por un intervalo corto de tiempo y el observador realiza un juicio ordinal, es decir, decide cuál de los dos se presentó primero. La manipulación del intervalo de tiempo entre ambos estímulos da lugar a una función psicofísica que permite el cálculo de índices como el PIS o el umbral diferencial. Los resultados muestran que la atención espacial modifica el PIS, produciendo un sesgo sobre los participantes en la percepción de orden de ocurrencia de dichos estímulos. En general, el estímulo que aparece en la posición espacial atendida tiende a ser percibido en primer lugar. Esto sugiere que la atención influye sobre la tasa de integración temporal de los estímulos. Según la ley de priorización de entrada (Titchener, 1908), ante dos eventos que se presentan simultáneamente el evento atendido es el que se percibe que ha aparecido primero. Así, la velocidad de procesamiento sería superior para los estímulos que aparecen en posiciones espaciales atendidas, de manera que acceden antes a consciencia.

El umbral diferencial es una medida de especial relevancia para nuestros objetivos, pues nos da una idea de la resolución temporal o agudeza de la percepción temporal y nos permite investigar cómo este aspecto de la percepción es influido por manipulaciones atencionales. En particular, valores bajos de umbral diferencial implican buena resolución temporal, indicando que el observador es capaz de discernir con exactitud el orden de comienzo de dos eventos prácticamente simultáneos, es decir, separados por escasos milisegundos. Aunque resulte lógico esperar que la atención pueda incrementar la resolución temporal del mismo modo que incrementa la resolución espacial, los resultados no son concluyentes en este sentido (Shore & Spence, 2005).

En resumen, los datos sugieren que es posible encontrar potenciaciones atencionales sobre el procesamiento basadas en aumentos tanto de la velocidad de los procesos como de la calidad de las representaciones relevantes para la tarea. Una vez conocidas las tareas para el estudio del mecanismo de orientación atencional, así como de sus efectos sobre el procesamiento, otra pieza fundamental para una comprensión global de este mecanismo es conocer sus bases cerebrales.

Bases neuroanatómicas de la orientación espacial de la atención

La orientación espacial se relaciona principalmente con áreas de la corteza parietal, con los núcleos pulvinar y reticular del tálamo y con los colículos superiores. Esta red ha sido fraccionada más finamente mediante disociaciones neuropsicológicas, dando lugar a tres operaciones elementales en el mecanismo de orientación: enganche, movimiento y desenganche de la atención. El enganche atencional se asocia con el núcleo pulvinar del tálamo, el movimiento de la atención con los colículos superiores (Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988) y el desenganche con la unión temporoparietal (Posner, Walker, Friedrich, & Rafal, 1984).

Estudios más recientes con técnicas de neuroimagen (v.g., Gitelman et al., 1999) sugieren la actuación de un circuito frontoparietal para la atención espacial que consta de tres elementos principales. Según los autores, las áreas frontales (FEF) y la corteza premotora circundante proporcionan una representación motora (*motor map*) para la distribución de conductas exploratorias abiertas. La corteza parietal posterior sustenta una representación sensoriomotora del espacio extrapersonal, mientras que la corteza del cíngulo se encargaría de la representación para la distribución espacial de las expectativas y de aspectos motivacionales.

No obstante, el patrón de activaciones cerebrales observado depende del procedimiento específico empleado para orientar la atención en el espacio. En concreto, a continuación veremos que hay dos mecanismos básicos de control de la orientación espacial de la atención, exógeno y endógeno, que se ponen en marcha específicamente según el tipo de señal espacial que se utilice, y que manifiestan propiedades diferenciales. Esta distinción es fundamental para este trabajo, dado que se centra en el estudio del mecanismo de orientación de tipo intencional o endógeno, es decir, basado en las expectativas o estrategias que genera el propio individuo. Así, en lugar de estudiar el mecanismo mediante el cual las personas atienden a diferentes localizaciones basándose en una expectativa espacial, estudiaremos el mecanismo para atender a diferentes instantes en el tiempo, de acuerdo a una expectativa temporal sobre el momento de ocurrencia de los estímulos. Veamos con más detalle las diferencias entre la orientación atencional exógena y endógena.

2.4. Disociación de los componentes automáticos (exógenos) y controlados (endógenos) de la atención.

Como se ha comentado anteriormente, el control de la atención puede ser efectuado por factores cognitivos (de arriba-abajo) o por propiedades sensoriales del estímulo (de abajo-arriba). Así, la atención puede dirigirse a diferentes localizaciones espaciales de una manera reflexiva o automática (orientación exógena) mediante la presentación de estímulos con características físicas salientes (v.g., señales periféricas), o de manera intencional (endógena) mediante la presentación de señales simbólicas cuyo significado induce la generación de estrategias o expectativas espaciales. Estos dos modos de controlar la atención espacial presentan unas características distintivas, que inducen a postular la existencia de dos mecanismos relativamente independientes.

La orientación espacial exógena es producida por señales periféricas que se presentan en los lugares donde posteriormente puede aparecer el estímulo objetivo. Por ejemplo, la aparición abrupta de un *flash* a la derecha o izquierda del punto de fijación central. La orientación espacial exógena se ha estudiado mediante paradigmas de captura atencional (para una revisión, véase Ruz & Lupiáñez, 2002) o de costes y beneficios (Posner et al., 1980). Las características principales que se le han atribuido se resumen en las siguientes:

1) La atención es orientada de forma involuntaria o automática por la aparición brusca de la señal. 2) La orientación no depende del valor predictivo de la señal, es decir, de la probabilidad con que la señal indica correctamente el lugar donde aparecerá el objetivo (normalmente se obtienen efectos atencionales con señales no predictivas, o sea, con una validez del 50%). 3) Los efectos facilitadores son resistentes a la interferencias por la realización de una tarea concurrente (Jonides, 1981). 4) Los efectos ocurren relativamente pronto, alcanzando un máximo alrededor de los 150 ms después de la presentación de la señal (Müller & Rabbitt, 1989). 5) Posteriormente a esta facilitación en los ensayos válidos el efecto se invierte, de forma que los TR llegan a ser mayores en este tipo de ensayos comparados con los ensayos inválidos. Este efecto se conoce como Inhibición de Retorno (Posner & Cohen, 1984).

La orientación endógena es producida por señales, llamadas simbólicas o centrales, que no indican directamente el lugar donde aparecerá el objetivo. Estas señales han de ser interpretadas, es decir, se requiere la decodificación de su significado simbólico. Por ejemplo, cuando aparece una flecha o un número en el centro de la pantalla que indican si el objetivo aparecerá a la derecha o a la izquierda. Sus características son: 1) La atención es orientada voluntariamente una vez que se ha procesado el significado de la señal. Esta orientación también puede ser inhibida de forma voluntaria. 2) Es sensible a las manipulaciones del valor predictivo de la señal, de manera que las señales altamente predictivas motivan a los sujetos a utilizar la señal, orientando voluntariamente su atención. 3) Resulta deteriorada cuando se sobrecargan las demandas cognitivas, por ejemplo, al realizar tareas duales. 4) Los efectos ocurren más tardíamente, alcanzando un máximo cuando el objetivo se presenta 300 ms después de la señal, en tareas de detección. 5) No se produce efecto de inhibición de retorno.

La revisión de Corbetta & Shulman (2002) aporta evidencia que apoya esta disociación a nivel neural. El sistema de control atencional endógeno incluye un circuito frontoparietal dorsal formado por áreas de la corteza intraparietal y frontal superior, mientras que el sistema de control exógeno se relaciona con un circuito frontoparietal ventral, formado por la corteza temporoparietal y frontal inferior del hemisferio derecho.

III. Atención y Tiempo

El interés por el estudio de las relaciones entre la atención y el tiempo puede ilustrarse con una anécdota que ocurrió en el observatorio de Greenwich en 1796 (Mollon & Perkins, 1996). El astrónomo real despidió a su ayudante por discrepancias de 800 ms en las estimaciones de los tiempos de tránsito de las estrellas. Para realizar estos juicios, el observador tenía que relacionar información espacial-visual (distancia entre las marcas en las lentes del telescopio) con información temporal-auditiva (contar los tic-tac de un reloj). La discrepancia en los juicios de ambos observadores se ha atribuido a dos factores.

A un fenómeno de atención selectiva que puede explicarse por la ley de priorización de entrada (Titchener, 1908). Como se ha comentado, ante dos eventos que nos llegan simultáneamente, percibimos que ha aparecido primero aquel que llega por el canal al que estamos atendiendo. Así, la diferencia entre observadores se debía a que estuvieran atendiendo a la información visual o a la auditiva. La otra explicación posible se basa en el cambio de la atención. El tiempo que se tarda en cambiar la atención de un canal a otro produciría esa discrepancia, de aproximadamente 300 ms (Reeves & Sperling, 1986). Es posible que estuvieran influyendo ambos factores, pero en cualquier caso, no son suficientes para dar cuenta de los 800 ms que separaban al aprendiz de su maestro. Al parecer, el joven no reunía grandes cualidades como observador para desempeñar el oficio de astrónomo.

Este fenómeno se estudió en el laboratorio de Wundt mediante los llamados “Experimentos de Complicación” (Wundt, 1887). Los sujetos observaban la aguja de un metrónomo y tenían que estimar su posición justo en el momento en que sonaba un timbre. Se encontró que las personas tendían a anticipar la localización espacial de la aguja, que era precisamente el canal atendido. Wundt propuso una explicación del fenómeno en términos atencionales. Este tipo de fenómenos ponían de manifiesto diferentes aspectos temporales de la atención como que acelera el procesamiento de los estímulos consiguiendo que entren antes en consciencia, o el hecho de que la atención está sujeta a limitaciones temporales y requiere algunos cientos de milisegundos para cambiar de un elemento a otro.

A continuación se presentan brevemente cuatro campos posibles de investigación experimental sobre las relaciones entre atención y tiempo: las limitaciones temporales de la atención, la influencia de la atención sobre la percepción del tiempo, la influencia de la estructura temporal sobre la dinámica de la atención y la orientación de la atención en el tiempo.

3.1. Limitaciones temporales de la atención: La atención *consume* tiempo

Una primera aproximación consiste en el estudio de las limitaciones temporales de la atención. Se trata de determinar cuánto tiempo consume la atención para el procesamiento controlado de los estímulos. Las tareas de búsqueda visual (A. Treisman, 1988) o la presentación visual serial rápida (RSVP, Shapiro et al., 1997) se han empleado para estimar el tiempo que se tarda en dejar de atender a un objeto y atender a uno nuevo. En esta última tarea se estudian los efectos del procesamiento de dos estímulos que se suceden rápidamente en el tiempo y que compiten por recursos atencionales limitados. El efecto más característico se conoce como ‘parpadeo atencional’ y consiste en un deterioro en el procesamiento del segundo estímulo como consecuencia de atender al primero. Entonces, la estimación del tiempo de demora de la atención sobre el primer estímulo puede realizarse manipulando la separación temporal entre ambos estímulos para estudiar qué efecto produce sobre el procesamiento del segundo estímulo.

Los resultados muestran que las estimaciones de los tiempos de demora de la atención divergen en función del paradigma empleado. Así, con una tarea de búsqueda visual basada en la conjunción de rasgos se calculan unos 50 ms por cada estímulo, mientras que con otros paradigmas se calcula alrededor de unos 500 ms. Posiblemente las diferencias se deban a que los paradigmas no son comparables porque implican demandas y procesos atencionales distintos. Es más, dentro del procedimiento RSVP se obtienen tiempos de demora distintos en función de parámetros específicos como el tipo de estímulos o la tarea que se utilice.

3.2. Atención y percepción del tiempo: La atención *deforma* el tiempo.

Seguramente, todos hemos vivido la experiencia fenomenológica de que el tiempo se acorta drásticamente, o por el contrario, de que se alarga hasta la eternidad. Este último caso es típico de situaciones que implican una gran consciencia del paso del tiempo, tales como el aburrimiento, la impaciencia o la anticipación. En cambio, cuando nos encontramos muy involucrados en la realización de una actividad absorbente, a menudo tenemos la sensación de que el tiempo *vuela*. En última instancia, estos fenómenos sugieren que el grado de atención que prestemos al fluir del tiempo altera nuestra percepción de la duración. En otras palabras, la atención deforma nuestra percepción del tiempo. En este campo de estudio se analizan fenómenos como la ilusión de duración (Enns, Brehaut, & Shore, 1999), donde la aparición de un flash breve en una zona del espacio atendida se percibe que dura más tiempo que si aparece en una posición no atendida.

Otras investigaciones realizan diferentes manipulaciones de la atención que se presta a la duración de un intervalo, incluyendo tareas concurrentes que demandan más o menos recursos atencionales (véase Zackay & Block, 1996, para una revisión). En estos experimentos, las personas realizan una tarea de estimación de intervalos temporales y se mide cómo varían estos juicios de duración en función de las demandas de la tarea secundaria. El resultado habitual consiste en una subestimación del intervalo temporal como consecuencia de la retirada o sobrecarga de la atención (Brown, 1985). Para explicar este resultado, Zackay y Block (1996) proponen el modelo de compuerta atencional, que combina características del modelo de Treisman (1963) y de cronometraje escalar (Gibbon et al., 1984) comentados anteriormente. El elemento principal es la compuerta, que consiste en un mecanismo cognitivo que está controlado por la asignación de recursos atencionales al procesamiento temporal. Cuanta más atención se asigne al procesamiento del tiempo, la compuerta se abre más o con mayor frecuencia, permitiendo un mayor trasvase de pulsos desde el marcapasos al contador o acumulador. Los juicios sobre la duración de un intervalo se basan en la cantidad de pulsos acumulados en el contador. Así, cuando los recursos atencionales no están disponibles para ser asignados al procesamiento temporal, debido a la competencia con una tarea concurrente, la compuerta se estrecha y permite la acumulación de un menor número de pulsos, lo que resulta en una subestimación temporal.

Recientemente, se ha publicado un interesante estudio de neuroimagen en este campo de investigación (Coull, Vidal, Nazarian, & Macar, 2004). El grado de atención asignado al procesamiento, bien de la duración temporal o bien del matiz del color (tarea control) de pares de estímulos, fue manipulado de forma paramétrica. Los participantes eran instruidos a atender únicamente al tiempo, al tiempo más que al color, a ambas dimensiones por igual, al color más que al tiempo o únicamente al color. Los datos comportamentales mostraron que los juicios sobre la duración (o el color) eran más exactos conforme más atención se prestaba al tiempo (o al color). Esta relación entre atención y ejecución también quedó patente en activaciones cerebrales de las áreas parietal inferior, temporal superior, prefrontal, premotora (preAMS) y ganglios de la base. Los autores concluyen que éstos son los sustratos neuroanatómicos del cronometraje del comportamiento. Nótese la gran coincidencia entre este patrón de activación y los comentados previamente para los estudios sobre percepción del tiempo.

Sin embargo, las relaciones entre atención y tiempo no son unidireccionales, de modo que la atención no sólo influye sobre la percepción del tiempo, sino que el propio cronometraje de la estructura temporal o rítmica de los acontecimientos del ambiente puede determinar asimismo la dinámica o curso temporal del proceso atencional. Esta es la idea fundamental que se defiende desde los modelos dinámicos de la atención que se describen a continuación.

3.3. Estructura temporal y dinámica atencional: El tiempo *deforma* la atención

En el medio ambiente continuamente acontecen eventos de los que es posible extraer cierta coherencia o estructura temporal basada en comienzos y finales distintivos así como en ritmos y cadencias reconocibles. Ejemplos de estos eventos naturales son la música, el habla o los patrones de movimiento característicos de habilidades motoras complejas como las deportivas. Jones y colaboradores han propuesto un modelo dinámico de la atención para explicar cómo las personas captan las regularidades temporales del contexto y cómo utilizan esta estructura temporal para atender a eventos que cambian en el tiempo (Barnes & Jones, 2000; Jones, Moynihan, MacKenzie, & Puente, 2002; Large & Jones, 1999). Una concepción dinámica de la atención resulta esencial a la hora de explicar los procesos atencionales que se ponen en juego ante presentaciones dinámicas de estímulos (v.g., procedimiento RSVP) y complementa las concepciones dominantes sobre la atención que están fundamentalmente basadas en investigación que utiliza presentaciones estáticas de estímulos visuales (v.g., Posner et al., 1980).

El ritmo atencional es el concepto central del modelo. La atención se concibe como un mecanismo oscilatorio interno que emite rítmicamente pulsos de energía. La frecuencia con la que ocurren las oscilaciones internas se relaciona con el periodo, que es el intervalo de tiempo entre los picos de dos pulsos atencionales consecutivos. Estas oscilaciones son la base para generar expectativas temporales que permiten la anticipación de eventos futuros. El pulso es caracterizado como el foco atencional en el tiempo.

La idea fundamental que se defiende es que los ritmos externos del ambiente dominan o capturan los ritmos internos atencionales. Es decir, ante la presentación rítmica de una serie de tonos auditivos el componente oscilatorio responde adaptativamente de manera que cambia su estado habitual previo, definido por la fase y el periodo, para entrar en sincronía con el ritmo externo. La fase es la diferencia entre el comienzo de un tono y el pico de un pulso atencional. Así, la expectativa temporal surge de la modulación flexible que ejerce la imposición de un ritmo externo sobre los parámetros que definen el ritmo atencional interno (fase y periodo). Como resultado de esta adaptación, el pulso o foco atencional queda perfectamente alineado con el momento relevante de la ocurrencia de los eventos.

La evidencia empírica que apoya el modelo se basa en la presentación regular de secuencias isócronas (idéntica duración temporal) de tonos auditivos para inducir de manera exógena una expectativa temporal (v.g., Barnes & Jones, 2000). La tarea consiste en una estimación temporal de intervalos como la comentada en el apartado 1.2.1. El intervalo que se ha de juzgar podía aparecer antes de lo esperado, en el momento esperado o después de lo esperado, en función del ritmo de la secuencia auditiva. Los resultados revelan que las estimaciones son más exactas cuando el intervalo a juzgar aparecía en el momento esperado. La explicación consiste en que el oscilador interno responde a la inducción rítmica externa mandando pulsos atencionales periódicos que acaban por acoplarse al ritmo externo. Como la atención está selectivamente dirigida al momento en que ocurrirá el intervalo a juzgar, el periodo del oscilador expresará su duración con mayor precisión. En cambio, un oscilador con un periodo distorsionado por la aparición inesperada del intervalo a juzgar produce estimaciones temporales más inexactas.

Obsérvese el parecido entre este modelo y el modelo oscilatorio de Treisman (1963) para la percepción del tiempo. De hecho, este modelo también puede aplicarse para explicar la percepción del tiempo, aunque su característica más importante aquí quizás sea la concepción dinámica de la atención. Además, éste es un modelo que nace en la investigación sobre la modalidad auditiva, dado que la selección de información en el campo de la audición básicamente opera en el dominio del tiempo. No obstante, los autores consideran que puede extenderse a la modalidad visual.

3.4. Orientación temporal de la atención: La atención se orienta en el tiempo

Este enfoque de estudio se interesa en determinar si las personas pueden utilizar información temporal para dirigir su atención a un punto concreto en el tiempo, con objeto de optimizar su comportamiento. En este ámbito de investigación, conocido como "orientación de la atención en el tiempo", se estudia el mecanismo de asignación endógena de recursos atencionales hacia un momento temporal determinado. Aunque presenta un gran paralelismo con los estudios sobre orientación espacial, es posible encontrar aspectos que los distingan, con lo que el estudio de la orientación en el tiempo supone un enriquecimiento para el campo general de la atención selectiva más que una simple extensión de conocimientos previos a la dimensión temporal.

De hecho, para obtener una visión comprehensiva del mecanismo atencional, el estudio de su dimensión temporal se hace necesario si tenemos en cuenta que ésta es tan importante como la dimensión espacial a la hora de representar la estructura dinámica de los estímulos que ocurren en nuestro medio ambiente (Fraisse, 1963). Por tanto, la presente tesis se centra en estudiar el fenómeno de la orientación de la atención en el tiempo que se produce como consecuencia de la generación de una expectativa temporal. La gran diferencia con respecto a los estudios sobre atención dinámica está en la fuente de información que da lugar a la generación de la expectativa. Mientras que en los estudios anteriores se enfatizaba el control que la estructura temporal del ambiente ejerce sobre los procesos atencionales del individuo (es decir, la generación exógena de expectativas temporales), en los estudios sobre orientación temporal se enfatiza el control que el individuo ejerce activamente sobre la dinámica de su proceso atencional (generación endógena de expectativas temporales). En el próximo apartado, desarrollaremos una revisión de los estudios concernientes a este tema.

IV. La Orientación de la Atención en el Tiempo:

Una Revisión

4.1. Estudios sobre preparación atencional.

4.1.1. Primeros acercamientos al estudio de la preparación atencional.

Los primeros experimentos de TR (Wundt, 1887) ya ponían de manifiesto los beneficios derivados de la preparación atencional. En uno de estos experimentos se presentaban sonidos de intensidad fuerte o débil ante los que había que dar una respuesta rápida de discriminación. Los sonidos se presentaban siguiendo dos tipos de secuencia, que podía ser regular o aleatoria (sonidos fuertes y débiles mezclados al azar). En la condición de secuencia regular los participantes podían predecir los estímulos, de modo que sus TR fueron menores que en la condición de secuencia aleatoria, donde la predicción no era posible. Este patrón de resultados se interpretó como que los participantes habían anticipado la intensidad de los sonidos. Posteriormente, William James (James, 1890) sugirió que "la concentración de la atención aceleraba la percepción" [p. 429]. Este autor concibió la preparación atencional ante un estímulo como un "preprocesamiento" del mismo, que reducía la cantidad de procesamiento necesaria para el momento en que dicho estímulo ocurriera. Experimentos posteriores en el laboratorio de Wundt demostraron que no sólo era posible anticipar la percepción de un estímulo. La preparación atencional también podía dirigirse hacia procesos motores, acortando así el tiempo en ejecutar una respuesta. Según James, las personas se preparaban imaginándose la aparición del estímulo o las sensaciones musculares implicadas en la ejecución de la respuesta.

Los hallazgos anteriores sugieren que la preparación atencional aporta un beneficio consistente en que los individuos pueden reaccionar más rápidamente a un evento cuando éste es esperado. El incremento en la velocidad de procesamiento se asume que se debe al preprocesamiento en áreas perceptuales, motoras o ambas (LaBerge, 1995). Según LaBerge, la preparación ante un estímulo o una acción consiste en un incremento de actividad en la correspondiente área perceptual o motora que acelera el procesamiento de estímulos o acciones cuando ocurre el evento desencadenante.

Una vez establecido que las personas podían desarrollar procesos de preparación atencional, los investigadores se interesaron por determinar cuánto tiempo se necesitaba para desarrollar dichos procesos. Es decir, se comenzó a investigar cuál era el intervalo óptimo para alcanzar el estado de preparación máxima (Woodrow, 1914). Para ello se realizaron varios experimentos en los que comparaban los tiempos de reacción ante la presentación de estímulos precedidos por intervalos de preparación con diferente duración. El intervalo de preparación se definió como el tiempo que transcurría desde la presentación de una señal de aviso hasta la aparición del objetivo. En un principio se pensaba que la preparación constituía un proceso más bien rígido y que dicho intervalo tenía un valor constante. Sin embargo, estudios posteriores observaron que el proceso de preparación no seguía un curso temporal fijo, sino que podía variar en función de factores como el tipo de tarea (Bertelson, 1967). Así, el intervalo de preparación óptima solía ser menor en tareas de TR simple que en tareas de elección de respuesta. De este modo, la investigación se centró en explorar el curso temporal de la preparación.

Bertelson (1967) realizó un experimento en el que manipuló de forma más sistemática la duración del intervalo de preparación. Los experimentos anteriores habían recibido la crítica de que el intervalo de preparación no era determinado con la suficiente precisión, ya que sólo manipulaban su duración a dos o tres niveles. Así, cuando Woodrow (1914) utilizó intervalos de preparación que duraban 1, 2 y 4 segundos, los resultados únicamente le permitieron concluir que se tardaba entre 2 y 4 segundos en alcanzar la "atención plena". Por tanto, el curso temporal de la preparación aún estaba por determinar. Sin embargo, Bertelson (1967) utilizó un rango más amplio de intervalos de preparación (0, 20, 50, 100, 150, 200 y 300 ms), observando que el tiempo necesario para desarrollar la preparación era mucho menor que el valor obtenido por Woodrow (1914). En concreto, los TR más bajos ocurrieron en intervalos de preparación que duraban entre 100 y 150 ms. La función que se observaba al representar los TR en función de la duración del intervalo de preparación tenía forma de "U". De este modo, se consideró que en los intervalos menores de 100 ms aún no se había completado el proceso de preparación. La explicación al incremento de los TR conforme el intervalo se alejaba de los 150 ms se basaba en un proceso de "incertidumbre temporal" (Klemmer, 1956). Cuanto mayor era el intervalo de preparación, más imprecisas eran las estimaciones del momento en que debía aparecer el estímulo, de acuerdo con la teoría escalar del cronometraje (Gibbon et al., 1984). En conclusión, estos experimentos indican que un factor fundamental que afecta al desarrollo de un estado de preparación anticipatoria es la duración del intervalo de preparación.

4.1.2. Principales variables que modulan la preparación atencional.

Las revisiones sobre los estudios de preparación atencional (Niemi & Näätänen, 1981) han añadido multitud de variables relacionadas con el procedimiento de presentación tanto de intervalos de distinta duración como del estímulo objetivo. A continuación se describen algunos de los experimentos que manipulan aquellos factores que están más directamente relacionados con el presente trabajo, a saber: la regularidad de la presentación de intervalos (intervalos de duración constante versus duración variable), la distribución de probabilidades condicionadas de aparición de cada uno de los intervalos, el orden secuencial de presentación de intervalos de distinta duración y la probabilidad de ocurrencia del objetivo.

La *presentación regular de intervalos* se refiere a que la manipulación de su duración se realizaba por bloques (o por sesiones). Es decir, los bloques experimentales estaban homogéneamente formados por ensayos con intervalos de preparación de duración constante. Un bloque con un intervalo de preparación determinado se alternaba con bloques de intervalos con otra duración diferente. El resultado habitual con este tipo de manipulación es un incremento en el TR con el incremento de la duración del intervalo de preparación (Klemmer, 1956). Como se ha dicho, la interpretación se basaba en que la incertidumbre o imprecisión temporal era mayor en los intervalos de preparación más largos.

La presentación irregular o variable de intervalos se refiere a que la duración de los intervalos de preparación variaba de forma aleatoria ensayo a ensayo. Es decir, en los bloques experimentales se entremezclaban ensayos con intervalos de diferente duración. El resultado habitual consiste en que los TR para intervalos de preparación cortos son mayores que para intervalos largos (Klemmer, 1956; Woodrow, 1914). En los intervalos cortos, la incertidumbre acerca de la duración del intervalo próximo podría haber deteriorado el ajuste temporal de la preparación. En intervalos largos, no obstante, la incertidumbre podía ser reducida por la información que aporta el flujo de tiempo en sí mismo (Elithorn & Lawrence, 1955). Es decir, parece que los individuos eran sensibles al hecho de que el flujo de tiempo contiene información en sí mismo sobre la futura ocurrencia del estímulo. Así, cuanto más tiempo pasara sin que apareciera el objetivo su probabilidad de ocurrencia era cada vez mayor, de manera que los sujetos aprendían a utilizar este conocimiento para prepararse.

Lo interesante de la presentación variable de intervalos es que permitía el estudio de los efectos secuenciales, que son los efectos debidos al orden de presentación de dichos intervalos. En particular, el *efecto secuencial* consiste en que el TR incrementa cuando el intervalo de preparación previo es más largo que el intervalo de preparación actual (Granjon & Reynard, 1977). Se dice que los efectos secuenciales son asimétricos porque un intervalo de preparación corto no incrementa el TR del intervalo subsiguiente si éste es más largo. Estos datos se explican considerando que los participantes predicen la duración del intervalo actual basándose en la duración del intervalo anterior (Drazin, 1961). Si el intervalo anterior fue largo, los participantes esperan que el intervalo actual también lo sea, pero si el intervalo actual es corto el objetivo aparece antes de lo esperado y al no encontrarse preparados su TR aumenta. Si el intervalo anterior fue corto los participantes esperan que el intervalo actual también lo sea. Sin embargo, si el intervalo actual es más largo de lo esperado, en este caso los TR no incrementan porque se supone que los participantes utilizan una estrategia de repreparación (Karlin, 1959).

La hipótesis de la repreparación fue estudiada a nivel comportamental por Alegria (1975) y a nivel fisiológico por Loveless y Sanford (Loveless & Sandford, 1974). La repreparación implica que, tan pronto como los participantes se dan cuenta de que el objetivo no aparece en el momento crítico para el cual estaban inicialmente preparados (el intervalo corto), utilizan el resto de intervalo de preparación que les queda para "reprepararse" para el momento crítico posterior. De este modo, la repreparación explicaría la asimetría de los efectos secuenciales, es decir, el porqué un intervalo actual largo no enlentece el TR cuando es precedido por un intervalo corto. Se ha demostrado que la repreparación tiene un consistente correlato fisiológico que se relaciona con el aspecto intencional del proceso de preparación, la variación contingente negativa (CNV). Loveless y Sanford (1974) utilizaron una presentación variable de intervalos de preparación (0.5, 1, 3, 6 y 15 segundos) mientras registraban los potenciales cerebrales. El hallazgo más sorprendente fue que en la condición de 15 segundos se observaron incrementos en los componentes negativos tardíos de los potenciales que coincidían exactamente con periodos de aparición posible del objetivo. Es decir, se observaron dos picos en los componentes característicos de la CNV a los 3 y a los 6 segundos posteriores a la presentación de la señal de aviso. Los autores interpretaron que los participantes desarrollaban voluntariamente un estado de preparación para cada uno de los intervalos de posible aparición.

La *distribución de probabilidades de aparición de los intervalos* con diferente duración era otra variable que influía sobre el proceso de preparación. Baumeister y Joubert (1969) encontraron que los TR en un intervalo de preparación corto eran más rápidos cuando el intervalo más frecuente era corto que cuando el más frecuente era largo. Interesantemente, la interpretación se realizaba en términos de expectativa temporal. Así, una alta probabilidad de intervalos cortos inducía una expectativa temprana, de modo que el proceso de preparación se ajustaba a una aparición temprana del objetivo. Entonces, los TR eran menores cuando el objetivo aparecía en el intervalo esperado, es decir, el más frecuente.

Otro factor que afectaba al proceso de preparación era la *probabilidad de ocurrencia del objetivo*, que podía ser manipulada incluyendo una proporción de ensayos en los que no se presentaba el objetivo (conocidos como "*catch trials*"). Un experimento clásico es el de Drazin (1961), quien observó que un aumento en la proporción de catch trials producía incrementos en el TR, especialmente en intervalos de preparación largos. Näätanen (1972) también encontró un incremento lineal en los TR de acuerdo a un incremento en la probabilidad de no ocurrencia del objetivo. Este autor propuso que los participantes iban abandonando progresivamente su expectativa de aparición del objetivo a medida que transcurría el tiempo en un ensayo y el objetivo seguía sin aparecer. Evidentemente, el decremento de la expectativa era más potente conforme mayor fuera la proporción de *catch trials* empleada en el experimento. Adicionalmente, los altos TR que se obtenían cuando finalmente sí se presentaba el objetivo en un intervalo largo parecían indicar que los participantes se encontraban completamente desprevenidos. Es decir, los *catch trials* incrementaban los TR en intervalos de preparación largos, probablemente debido a un efecto de relajación o de abandono de la preparación atencional como consecuencia de una ruptura de la expectativa de ocurrencia del objetivo.

A partir de la revisión sobre los estudios sobre preparación atencional, podemos concluir que la presentación de señales de aviso que habitualmente se emplean en los experimentos, produce una preparación □atch□patorio basada en una expectativa acerca del momento de ocurrencia del objetivo como consecuencia de la información temporal que ofrece dicha señal. Lo que inicialmente se postuló como un proceso rígido, sucesivamente se ha ido comprobando que puede ser modulable por factores que dependen fundamentalmente de diversos tipos de expectativas que los individuos son capaces de generar a partir de las condiciones particulares del experimento. Cuando la situación experimental genera incertidumbre temporal, como es el caso de la presentación aleatoria de intervalos, los individuos tratan de compensar esa incertidumbre mediante la creación de expectativas temporales que se basan en la duración del intervalo anterior. En el caso de que se desconfirme esa expectativa, por ejemplo cuando se sobrepasa la duración de un intervalo corto esperado, los individuos son capaces de utilizar una estrategia de repreparación y generar una nueva expectativa de aparición más tardía. Además, hemos comprobado que los participantes utilizan otras estrategias de preparación basadas en el cálculo de probabilidades condicionadas. Por otra parte, los datos también muestran los costes atencionales derivados de la ruptura de este tipo de expectativas. Cuando la situación experimental genera una incertidumbre respecto a la ocurrencia del objetivo, como ocurre en presencia de *catch trials*, los individuos parece que forman una expectativa de no ocurrencia que va creciendo conforme esperan más tiempo. Esto se traduciría en un abandono progresivo del estado de preparación, tal y como sugiere la subida de los TR cuando el objetivo finalmente aparece en el intervalo largo.

En conclusión, la evidencia que aquí se recoge pone de manifiesto el funcionamiento de un mecanismo atencional basado en la generación de expectativas temporales mediante el cual las personas obtienen un beneficio en el comportamiento que se refleja en una disminución de los TR. Probablemente, la evidencia aportada por estos estudios no sea suficiente para afirmar que este mecanismo tiene un carácter intencional. En este sentido, surgen una serie de cuestiones que merecen ser abordadas. ¿Es posible facilitar de una forma más directa la puesta en marcha de las estrategias que los individuos parecen utilizar de forma espontánea para anticipar el momento crítico de aparición de un estímulo? ¿Qué pasaría si informamos a los individuos de forma explícita acerca del tiempo que han de esperar hasta la llegada del estímulo? ¿Serían capaces de aprovecharse de esta información para ajustar de forma voluntaria y flexible su estado de máxima preparación a intervalos de tiempo de diferente duración? Este tipo de preguntas son las que se pretendía abordar en los estudios sobre orientación de la atención en el tiempo que se exponen a continuación.

4.1.3. Estudios sobre orientación endógena temporal

De forma análoga a la orientación de la atención en el espacio, en los estudios sobre orientación endógena temporal se examina la posibilidad de que la atención pueda focalizarse de forma intencional hacia un punto en el tiempo donde se anticipa que ocurrirá un evento (Coull & Nobre, 1998; Kingstone, 1992). No hay que olvidar que la dimensión temporal es un elemento importante en la percepción, de manera que para interactuar de forma adaptativa con nuestro medio dinámico no sólo consideramos información espacial, sino también información temporal.

Según Coull y Nobre (1998), la orientación temporal de la atención es la habilidad para asignar y focalizar los recursos hacia un momento dado en el tiempo con la finalidad de optimizar nuestro comportamiento. A nivel comportamental, se observa una disminución en el TR como consecuencia del beneficio que supone el tener una expectativa temporal adecuada sobre el momento en que ocurrirá un determinado evento. Esta definición pone de manifiesto una idea que ya se conocía en los experimentos sobre preparación atencional, en los que se obtenía sistemáticamente una mejora en la ejecución consistente en una disminución de los TR. La explicación se basaba en que los participantes podían anticipar cuándo aparecería el estímulo objetivo, ya que utilizaban la señal de aviso como una clave temporal. En consecuencia, realizaban determinados “ajustes preparatorios” en adelanto a la ocurrencia del estímulo (Bertelson, 1967)

Coull y Nobre postulan que el efecto que se observa en estos estudios no estaría causado por un mecanismo rígido, sino que los recursos atencionales pueden asignarse de forma flexible a una variedad de intervalos de tiempo. Es decir, se trataría de un mecanismo endógeno de orientación, donde la asignación de recursos se realiza de forma voluntaria o controlada. Las autoras demostraron que la información explícita sobre la duración de un intervalo temporal puede utilizarse de forma flexible para dirigir la atención visual (Coull & Nobre, 1998) En su estudio utilizaron el paradigma de costes y beneficios (Posner et al., 1980) adaptado al dominio temporal, donde presentaban una señal temporal que indicaba si el estímulo que debía ser detectado aparecería tras un intervalo corto (300 ms) o tras un intervalo largo (1500 ms; SOA, del inglés, *Stimulus Onset Asynchrony*, que se refiere al intervalo de tiempo que transcurre entre la presentación de la señal y el objetivo). Posteriormente, el objetivo aparecía en el intervalo indicado por la señal en el 80% de los casos (ensayos válidos), mientras que en los ensayos restantes el objetivo aparecía en el intervalo no señalado (ensayos inválidos). Los resultados que obtienen son análogos a los hallados en los estudios de orientación espacial, de manera que los estímulos que aparecen en los intervalos indicados por la señal temporal son detectados más rápidamente que aquellos estímulos que fueron erróneamente señalizados.

Las autoras concluyen que la orientación temporal se produce porque los participantes son instruidos sobre el tipo de información que aporta la señal y además comprueban que su validez predictiva es alta. En consecuencia, decodifican su significado simbólico y utilizan esta información para generar una expectativa temporal, orientando intencionalmente su atención al intervalo concreto apuntado por la señal. Esta orientación ha de ser dinámica y flexible, ya que la duración del intervalo puede variar de un ensayo a otro.

En definitiva, el efecto de orientación endógena de la atención en el tiempo consiste en un descenso en el TR cuando hay una concordancia entre la expectativa temporal de aparición del objetivo (temprana o tardía) y el intervalo en el que éste aparece realmente (corto o largo), en comparación con los TR típicos de una situación donde no hay tal concordancia. Por ejemplo, el efecto de orientación para una expectativa temporal tardía consiste en que los TR son más bajos cuando el objetivo aparece en el intervalo indicado por la señal (largo), que cuando aparece en el intervalo no indicado (corto). En el caso de la expectativa temprana, los TR más bajos se obtienen cuando el objetivo aparece en el momento esperado por los participantes, o sea, en el intervalo corto.

A partir de una revisión de los experimentos sobre orientación endógena temporal comprobamos que únicamente se obtuvieron efectos de orientación temporal para las dos expectativas, temprana y tardía, en dos de los estudios (Milliken, Lupiáñez, Roberts, & Stevanovski, 2003; Miniussi, Wilding, Coull, & Nobre, 1999) mientras que el resto sólo consiguió el efecto con la expectativa tardía. Obtener el efecto con ambas expectativas es importante para argumentar que el mecanismo de orientación que subyace es de tipo endógeno y flexible. Coull y Nobre (1998) han propuesto un proceso de reorientación o repreparación para explicar por qué no se obtuvo el efecto de orientación con la expectativa temprana. El efecto con la expectativa temprana que se esperaría teóricamente es un TR menor cuando el objetivo aparece en el intervalo corto (situación de concordancia) que cuando aparece en el intervalo largo (situación de no concordancia). Sin embargo, lo que realmente se observa es que este efecto desaparece porque los TR en el intervalo largo también son bajos. Parece que, si los participantes tienen una expectativa temprana y el objetivo no aparece en el intervalo corto, predicen que lo hará en el largo, de modo que reorientan su atención a este intervalo más tardío. En otras palabras, el proceso de reorientación de la atención consigue eliminar el coste atencional que cabría esperar en el intervalo largo cuando los participantes se encuentran ante un ensayo inválido, es decir, cuando tienen la expectativa temprana. Sería interesante encontrar un procedimiento para prevenir ese proceso de reorientación, con el fin de obtener efectos de orientación con la expectativa temprana. Como veremos a continuación, este fue uno de los objetivos iniciales de nuestra investigación.

El proceso de reorientación se ha estudiado con más detalle mediante técnicas de neuroimagen (Coull, Frith, Büchel et al., 2000). En este trabajo se pretendía disociar los componentes exógenos y endógenos de la orientación temporal. La orientación endógena se identificó con el citado proceso de reorientación, en tanto que implica que los participantes realizan de forma voluntaria un cambio de una expectativa inicial temprana a otra expectativa tardía. La condición experimental relevante para el estudio de este proceso está formada por los ensayos inválidos de expectativa corta-intervalo largo. Según los autores, la orientación exógena se pondría en marcha con la aparición inesperada del objetivo, provocando una orientación refleja o exógena. La condición experimental relevante fue la de ensayos inválidos de expectativa tardía-intervalo corto. Los resultados mostraron que en la condición de orientación exógena se activaron zonas de la corteza visual extraestriada. Se interpreta que representa el funcionamiento de un mecanismo de orientación atencional guiado por un evento sensorial, es decir, de tipo “abajo-arriba”. En la condición de orientación endógena se activaron zonas de la corteza prefrontal ventrolateral y dorsolateral derecha, zonas del lóbulo parietal superior izquierdo y regiones motoras y premotoras. Este circuito se piensa que está a la base de la orientación atencional guiada por expectativas temporales, es decir por influencias de “arriba-abajo”.

Por otro lado, la activación de estructuras frontales y parietales es consistente con la idea de una red frontoparietal que está a la base de la orientación atencional tanto espacial como temporal. La activación de regiones motoras replicó patrones de activación específicamente observados para la condición de orientación temporal en estudios de neuroimagen previos (Coull & Nobre, 1998) y son consistentes con datos de potenciales evocados en los que encuentra una modulación de la atención temporal sobre componentes electrofisiológicos tardíos relacionados con procesamiento motor (Miniussi et al., 1999). Este resultado sugiere que el efecto de la orientación temporal tiene un carácter eminentemente motor. Una observación en la que basan su argumentación es que la orientación temporal no ejerció un efecto sobre los componentes electrofisiológicos comparable a lo que se ha descrito en la literatura sobre orientación espacial visual (para una revisión, consúltese Mangun, 1995), de lo que deducen que la atención temporal y espacial son cualitativamente diferentes. En concreto, en este estudio de orientación temporal (Miniussi et al., 1999) no se replicó la modulación típica de la orientación espacial sobre los componentes relacionados con procesamiento visual temprano (componentes P1 y N1). Consecuentemente, concluyen que la orientación temporal no implica modulación perceptual temprana sino la preparación de procesos motores de respuesta.

No obstante, cabe la posibilidad de que la activación que se observa en áreas motoras y premotoras no sea producto de una potenciación atencional del procesamiento motor, sino que, como hemos visto en apartados anteriores, la intervención del circuito motor podría estar cumpliendo una función de cronometraje (Lewis & Miall, 2003), que es necesaria para la orientación temporal. De hecho, en su estudio previo (Coull & Nobre, 1998) también observan activación de estructuras importantes para el cómputo temporal como el cerebelo. Otro posible confundido en relación con estos estudios está en la utilización exclusiva de tareas de detección, que implican un sesgo en las demandas de procesamiento motor sobre el procesamiento perceptual, de modo que no resultan tareas muy sensibles para medir la potencial contribución de efectos atencionales sobre procesos perceptuales.

Por tanto, la motivación que impulsó los primeros estudios que componen la presente tesis parte de dos cuestiones fundamentales surgidas a partir de los trabajos del grupo de Nobre. En primer lugar, nos preocupaba la idea de que sólo se obtuvieran efectos atencionales para un tipo de expectativa temporal, lo cual cuestionaba la idea de un mecanismo flexible, capaz de orientarse a diferentes puntos en el tiempo. Pero más nos preocupaba aún el hecho de que la orientación temporal no pudiera mejorar el procesamiento perceptual de los estímulos. Intuitivamente, parecía lógico pensar que los estímulos que ocurren en el momento que los esperamos se perciben mejor que los estímulos que ocurren inesperadamente. Por otra parte, desde la concepción teórica sobre la atención que hemos defendido más arriba, teníamos razones para esperar que el procesamiento perceptual de los estímulos atendidos resultara facilitado. La demostración empírica de esta hipótesis forma el eje central de los experimentos que hemos llevado a cabo, y que se presentan más abajo. Pero antes, desarrollaré los objetivos principales que motivaron cada una de las cuatro series experimentales de las que se compone esta tesis. Dado que el apartado de motivación de la investigación constituye el hilo conductor de los artículos que se incluyen en la tesis, y dado que estos artículos están escritos en la lengua inglesa, el siguiente apartado se ha escrito en inglés.

INVESTIGACIÓN EXPERIMENTAL

V. Aims of the Research

The main general aim of the present thesis is to investigate the consequences on stimulus processing of attending to the moment in time at which the stimuli will occur. In particular, the fundamental question of the present research is whether temporal attention can enhance early perceptual processing.

An important previous step to that end was to obtain a more complete understanding on the temporal orienting of attention. We first focused on exploring relevant attributes of this mechanism, such as its *endogenous* and *exogenous* components, the *flexible* ability to commit attention to different moments in time, its *generality* across tasks, and the *controlled* nature of the processes involved in temporal orienting.

Once we achieved a comprehensive knowledge regarding this attentional mechanism, as well as the experimental conditions that determine robust endogenous temporal orienting effects, we followed different approaches that converged in our primary aim. That is, to test the potential role of temporal attention in enhancing perceptual processes, we used different tools: Behavioural studies in which RT was the main dependent variable, psychophysical, and electrophysiological methodologies, in Series I, II and III, respectively. In Series IV, we conducted behavioural and electrophysiological experiments to explore the *applicability* of the temporal orienting mechanism to tasks simulating realistic situations, in order to explore how could be the real functioning of the temporal orienting mechanism in natural environments involving dynamic stimuli.

The general procedure followed in the present thesis consisted of a temporal analogue to the costs and benefits paradigm developed by Posner and colleagues to study the spatial orienting of attention (Posner et al., 1978). Temporal information was explicitly provided to the participants by presenting in advance predictive temporal cues, which indicated with high probability when a visual target stimulus would appear (i.e., *early*, after a short interval of 400 ms, or *late*, after a long interval of 1400 ms). Then, the target could appear either at the short or the long interval. Temporal orienting effects were defined as the attentional benefit given by the difference between the processing of targets appearing at the attended moment in time (valid condition) and the processing of targets appearing at the unattended moment (invalid condition), as indexed by behavioural or physiological measures.

Series I. Factors involved in building attentional preparation and temporal expectancy: Behavioural experiments with RT as dependent variable.

Our starting point was to obtain a more complete picture of temporal orienting. The two main aims here were: a) to test its *endogenous* nature by isolating experimentally automatic (exogenous) and strategic (endogenous) contributions to temporal orienting effects, and b) to test its *flexibility* by finding temporal orienting effects across different intervals.

We reviewed the literature on attentional preparation and foreperiod, which revealed decisive factors presumably involved in temporal orienting. In fact, both foreperiod and temporal-orienting procedures have in common the manipulation of time intervals. Thus, many factors found in studies of preparation, such as the automatic sequential effects produced by the duration of the interval of the previous trial, could play an important role in temporal orienting effects, in addition to the role of predictive cues. However, the research on endogenous temporal orienting had not considered the influence of such factors (e.g., see Nobre, 2001, for a review). Then, an automatic view of sequential effects could account for temporal orienting effects, thus questioning its *endogenous* character as argued by Los & Van den Heuvel (2001).

Therefore, the fields of research on preparation and temporal orienting should be further connected. The first experimental series (Chapters I and II) consisted of a comprehensive study including important factors involved in preparation according to the review, and the main factor manipulated in temporal orienting research, that is, cue validity. In these experiments, the potential contribution of automatic sequential effects was isolated by manipulating the duration of the preceding interval. If temporal orienting were not merely due to automatic sequential effects, but to endogenous predictive cues, we should observe a main effect of cue validity and no interaction between cue validity and the duration of the preceding interval.

In Chapters I and II, the *flexibility* to focus attention to temporal intervals involving different durations was also tested. Whereas early research had concluded that the preparation process had a fixed temporal course (e.g., Woodrow, 1914), Coull and Nobre (1998) recently showed that it could be modulated according to the expectancy induced by a predictive temporal cue. However, temporal orienting effects have been rarely observed at a long interval (but see, Griffin, Miniussi, & Nobre, 2001; Milliken et al., 2003), presumably due to a reorienting process from short to long intervals triggered in the invalid condition (i.e., early cue-long interval condition). Despite the existence of physiological evidence supporting the reorienting of attention (e.g., Coull, Frith, Büchel et al., 2000; Loveless & Sandford, 1974), this process had not been directly manipulated to study its influence on temporal orienting.

Considering that reorienting makes sense only when the certainty about target occurrence is high, we expected to manipulate the reorienting process by varying the probability of target occurrence. In Chapter I, three exploratory experiments included a proportion of trials in which the target was not presented, that is, a 25% of catch trials (Experiments 1.1, 1.2, 1.3). Chapter II (Experiment 2.1) included a broader range of catch-trial proportions, allowing this systematic manipulation a finer exploration of the reorienting process. Our prediction was that the inclusion of catch trials would increase uncertainty on target occurrence, thus impairing reorienting. As a result, in the groups with catch trials we expected to observe significant validity effects at both the short and the long interval. Then, the simultaneous finding of temporal orienting effects not only at short intervals, but also at long intervals, would provide stronger support to the flexibility of temporal orienting.

Moreover, the *generality* of temporal orienting across different tasks was tested by comparing performance in simple-RT detection tasks with choice-RT discrimination tasks. From a view of a general mechanism of attentional orienting, we expected to replicate the results observed in detection tasks (Coull & Nobre, 1998) by using discrimination tasks. The task consisted of discriminating between the 'X' and 'O' letters. Given that discrimination tasks demand a detailed visual analysis, the finding of temporal orienting effects in the discrimination task might open the possibility of perceptual processing enhancement by temporal attention. Finally, the manipulation of the task demands could also provide information regarding the *controlled* versus *automatic* nature of the processes involved in temporal orienting.

In sum, the factors that showed to modulate the preparation process in RT experiments were included within a temporal-orienting procedure to investigate its influence on endogenous temporal orienting. In addition, we investigated other factors that seemed to influence temporal orienting effects, such as the task (e.g., Griffin et al., 2001) or the blocking of temporal expectancy (see Milliken et al., 2003). Importantly, this series specified the experimental conditions suitable to observe robust temporal orienting effects in our subsequent experiments.

Series II: Does temporal attention modulate psychophysical indexes of perceptual processing?

Once we found evidence supporting a flexible and endogenous mechanism of temporal orienting, and specified the appropriate experimental conditions to observe clear temporal orienting effects, our next goal was to explore the locus at which temporal attention operates. In the case for spatial attention, the enhancement of both early perceptual and late motor stages of processing has been consistently reported in event-related potentials studies (ERPs) and neuroimaging (e.g., Heinze et al., 1994; Mangun, 1995).

However, it remains unclear so far whether temporal orienting effects are produced by perceptual preparation, motor preparation or both. In contrast to spatial attention, physiological data revealed selective activations in left premotor cortex in neuroimaging studies (e.g., Coull & Nobre, 1998), and modulations of late electrophysiological components linked to decision and motor response processing in ERP studies (Miniussi et al., 1999). Thus, the current evidence mainly suggests a late post-perceptual locus for the effects of temporal attention rather than perceptual enhancement. However, an alternative explanation might be that the detection task typically used in such studies was insensitive to measure perceptual modulations, as simple-RT detection tasks might mainly tap motor processes, due to their high demands on speeded motor responses. Then, the observed activations over motor areas could be merely reflecting task demands, rather than temporal attention effects *per se*.

Hence, we carried out the second experimental series to investigate whether temporal attention could enhance perceptual processes. Rather than the detection task commonly used in temporal orienting research, we used a perceptually demanding task, such as letter discrimination. Indeed, our previous findings of temporal orienting effects in the discrimination task (Series I) might suggest a perceptual preparation. Thus, attention may facilitate perceptual processes involved in analysing object features, which are essential to accomplish discrimination tasks.

However, the evidence exclusively based on RT measures could not rule out the motor account. For instance, Nobre (2001) suggested that temporal orienting effects in discrimination tasks could be just due to a motor preparation of the two possible responses involved. Consequently, our results could be explained in terms of facilitation of later post-perceptual processes, such as decision or motor response execution, which are also demanded in choice-RT discrimination tasks. Thus, behavioural data based on classic RT experiments did not address this question appropriately, as perceptual and motor contributions to RT are not easily isolable.

Therefore, the strategy we followed to design the subsequent experiments was the use of psychophysical measures to track perceptual processes. Moreover, we aimed to minimise the contribution of motor processes to temporal orienting by emphasising accuracy instead of speeded responses, that is, participants responded without time pressure. Also, we maximised the perceptual demands of the task.

In Experiments 3.1 and 3.2 (i.e., Experiments 1 and 2 of Chapter III), the perceptual demands were increased by using a rapid serial visual presentation procedure (RSVP) in which the perception of the target was masked by a fast succession of distracting stimuli. However, we expected that focusing attention to the moment of target onset could override such masking effects (Enns & Di Lollo, 1997). The psychophysical measures used in these experiments were the perceptual sensitivity (d’) and the response criterion (beta). According to the signal detection theory, the perceptual processing indexed by d’ can be dissociated from other post-perceptual processes related to decision and response bias that are indexed by beta (Green & Swets, 1966). Then, if temporal orienting facilitated perceptual processing, we would expect perceptual sensitivity to be enhanced for targets appearing at validly rather than invalidly cued temporal intervals.

However, the strength of our conclusions depended on the ability of d’ to isolate pure perceptual processing. It might be argued that d’ can be affected by post-perceptual factors (e.g., participants' encoding strategies of sampling more evidence from the cued versus uncued time interval, see Hawkins et al., 1990). Consequently, the finding of temporal orienting effects in the measure of perceptual sensitivity, though suggestive, could not be taken as unequivocal evidence of a perceptual preparation.

Experiment 4.1 aimed to provide additional evidence supporting the perceptual preparation hypothesis, by combining a temporal cuing procedure with the use of a temporal order judgment task (TOJ). In this task, two stimuli are presented very close in time and participants are asked to decide which one appeared first. The stimulus onset asynchrony (SOA) between the two stimuli is manipulated and the resulting psychophysical function is used to compute the just noticeable difference measure (JND, in milliseconds), which provides an index of the temporal resolution or acuity of temporal perception. Specifically, small JNDs mean high temporal resolution, indicating that observers are able to make a fine discrimination of the onset of two almost simultaneous events, namely, separated by few milliseconds.

Hence, the use of TOJ tasks could provide an appropriate index of perceptual processing, since TOJ tasks normally demand accurate unspeeded responses (Klein, Schmidt, & Müller, 1998). Interestingly, TOJ tasks also provide a direct index of the temporal resolution of perception. Hence, this experiment explored whether selective temporal attention modulates perceptual processing, and if so, whether such modulation improves the temporal resolution of vision.

In sum, the psychophysical methodology followed in this series of experiments afforded a stronger test of the perceptual account than the choice-RT experiments conducted in Series I. On the other hand, one might still argue that behavioural data *per se* are insufficient to confidently infer that temporal attention enhances early perceptual processing. More compelling evidence would be provided if we used a more direct measure of processing. Considering the high temporal resolution of the ERP methodology, this technique was especially appropriate to explore on line the dynamic modulations of temporal attention on the electrophysiological brain activity evoked by stimulus processing. Therefore, the follow-up experimental series made use of the advantages of the electrophysiological tools of research.

Series III: Does temporal attention modulate electrophysiological indexes of early perceptual processing of visual stimuli?

To continue with our endeavour of exploring the locus at which temporal attention operates, in Experiment 5.1 we reviewed the current ERP research on temporal orienting, with special attention being paid to the differential characteristics between experimental procedures that might determine the finding of modulations at early stages of processing. Two main conclusions were drawn from this review. First, the components traditionally linked to late processes of decision and response execution, such as N2 and P300, are consistently modulated by the temporal orienting of attention. The latency modulation of the P300 component seems to be an idiosyncratic feature of temporal attention, and fits well with the function of synchronizing processes with the expected moment of occurrence of relevant events. Consequently, these findings provided strong support to the motor account.

On the other hand, the modulation of early perceptual processing by temporal attention is not a well-known phenomenon to date. Most of the studies have failed to find attentional effects on components linked to perceptual processing (i.e., P1 and N1), whereas some others have succeeded to find such effects. Furthermore, when the attentional effect is observed, it is not consistently reflected in a particular modulation of ERPs, so that some studies reported N1 enhancement for valid compared to invalid targets (Griffin, Miniussi, & Nobre, 2002; Lange, Rösler, & Röder, 2003), whereas others reported N1 attenuation (Doherty, Rao, Mesulam, & Nobre, in press).

Given that spatial attention modulates perceptual and motor processing, and that temporal attention mainly modulates motor processing, some authors have proposed that spatial and temporal attention modulates processing by different mechanisms (e.g., see Nobre, 2001). This could be a consequence of the differential nature of representations of space and time in the brain. Whereas space is accurately represented in retinotopic maps within the visual system, time implies a rather different way of representation, which might include the cerebellum and basal ganglia and cortical structures located in frontal-parietal areas (Ivry & Spencer, 2004). Thus, the neural representations of specific locations can be directly amplified by spatial attention, whereas the influence of temporal attention on visual processing seems less obvious. This fact could then explain why temporal attention experiments scarcely show influences at early perceptual levels of visual processing.

Interestingly, we found a common aspect in the studies that reported perceptual modulations. In particular, high demands in perceptual processing seemed to be a key factor. Thus, in Experiment 5.1, the task was similar to the letter discrimination task used in previous experiments. As mentioned above, this task demands more perceptual processing than detection tasks, as a finer analysis of the visual features is required. Hence, we expected that temporal attention would not only modulate late motor processing, but also early visual processing, when a discrimination task was used.

In addition to studying the processing triggered by target stimuli appearing at attended vs. unattended time intervals, this experiment aimed to study the brain mechanisms involved in the process of preparation triggered by the presentation of temporal cues. The contingent negative variation (CNV) was a good candidate on which focus the analysis, as it has been related both to processes of intentional preparation for the impending arrival of a target, and to processes of time estimation (Macar & Besson, 1985).

Finally, another goal of Experiment 5.1 was to test whether the system we used for ERP recording and analysis led to analogous results to those observed in temporal orienting research conducted with other systems.

To summarize, three experimental series were conducted using converging methods based respectively on RT, psychophysical and electrophysiological measures, in order to investigate whether people can improve visual perception of stimuli by attending to the specific moment at which a relevant event is expected to occur.

So far, the study of temporal orienting has normally included artificial displays in which explicit symbolic cues, empty intervals between cue and target, and stationary targets are presented. However, in order to attend to stimuli occurring in the spatiotemporal layout in real world scenes, we probably engage more dynamic processes of temporal orienting than those studied in artificial contexts. One example might be the building up of expectancy based on implicit information inherent in the way objects move. Then, the challenging issue of research for the last experimental series was to assess the extent to which procedures with dynamic and static displays involve the same processes of temporal orienting. This will hopefully provide more confident extrapolations and richer concepts about the real functioning of the attentional mechanism in natural environments.

Series IV: Temporal attention in natural environments: Behavioural and electrophysiological studies on temporal orienting to moving stimuli.

In the fourth series, we followed a novel approach to explore whether attention can flexibly build temporal expectancies based on moving objects across a wide range of speeds. Attention likely plays a key role in everyday situations, for example, when someone anticipates the upcoming location of a moving object, especially when it is temporary occluded by other objects in a visual scene. In fact, situations like this frequently occur in ball-sports. In order to study the role of attentional orienting in such situations, Nobre and colleagues have recently developed a novel task that simulates the attentional demands involved in dynamic displays more realistically than the traditional spatial/temporal orienting tasks that use static artificial displays (Doherty et al., in press).

The task consisted of a stimulus (a ‘ball’) that moved across the screen from left to right before disappearing under an occluding band. Upon the ball’s reappearance, participants discriminated the presence of a black dot in its centre. Then, the way the ball moved before the occlusion served to induce temporal expectancy, spatial expectancy or no expectancy, which allowed participants to predict the moment or the location of the ball’s reappearance.

The behavioural results revealed attentional benefits analogous to those observed in classical studies on both spatial orienting (Posner et al., 1978) and temporal orienting of attention (e.g., Nobre, 2001). In particular, participants were faster when the stimulus movement before the occlusion followed a trajectory either spatially predictable (i.e., a straight line) or temporally predictable (i.e., a pace with constant speed), compared to when the pattern of movement could not be predicted (i.e., random trajectories or paces). This suggests that the attentional orienting mechanism can be applicable to real world situations involving dynamic stimuli.

However, the temporal condition in the Doherty et al. study only included a single temporal expectancy derived from movements with the same speed for all the trials, so that the flexibility of this mechanism to build several temporal expectancies based on moving objects remained to be investigated. Then, the present experiments aimed to extend the Doherty et al.'s results by using a broader range of stimulus speeds to induce temporal expectancy.

Experiment 6.1 manipulated the pace of movement to induce temporal expectancy (regular/predictable pace) or neutral expectancy (random/unpredictable pace). Experiment 6.2 manipulated the time for which the object was occluded. This manipulation afforded to compare valid and invalid conditions, which is central in studies of attentional orienting. Then, we could further explore attentional effects in a more refined way than in the previous experiment by holding a regular pace of movements during the pre-occlusion period, while varying the occlusion time to create valid and invalid trials. Thus, the valid and invalid conditions were equated in terms of perceptual stimulation (e.g., the random pace of the neutral condition in Experiment 6.1 could have generated more alertness than the temporal condition). The temporal condition included valid trials in which the ball appeared at the expected moment according to the regular speed of the ball before the occlusion, invalid trials in which the ball appeared earlier than expected (early-invalid condition), and invalid trials in which the ball appeared later than expected (late-invalid condition). However, late-invalid was not an appropriate condition of non attention, as could imply temporal predictability (e.g., engagement of temporal reorienting processes). Hence, the analyses focused on the valid versus early-invalid comparison to study the effects of attention.

Once the task was refined to observe a robust attentional effect on behaviour, Experiment 6.3 aimed to study the cerebral correlates of the ability to build up temporal expectancy by attentive tracking to moving objects across a range of speeds. Moreover, the results were compared with those observed in Experiment 5.1 (Series III), in which the classic procedure of static displays was used, to identify the aspects of the orienting mechanism that were common to both static and dynamic contexts.

VI. Experimental Studies

Series I. Factors involved in building attentional preparation and temporal expectancy:

Behavioural experiments with RT as dependent variable.

Chapter 1. Endogenous temporal orienting of attention in detection and discrimination tasks.

Ángel Correa, Juan Lupiáñez, Bruce Milliken[*] and Pío Tudela

Universidad de Granada, España.

* McMaster University, Canada

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Abstract

Endogenous temporal-orienting effects were studied using a cuing paradigm in which the cue indicated the time interval during which the target was most likely to appear. Temporal-orienting effects were defined by lower reaction times (RTs) when there was a match between the temporal expectancy for a target (early or late) and the time interval during which the target actually appeared than when they mismatched. Temporal-orienting effects were found for both early and late expectancies with a detection task in Experiment 1.1. However, catch trials were decisive in whether temporal-orienting effects were observed in the early-expectancy condition. No temporal-orienting effects were found in the discrimination task. In Experiments 1.2 and 1.3, temporal-orienting effects were observed in the discrimination task; however, they were larger when temporal expectancy was manipulated between blocks, rather than within blocks.

Focusing attention towards the location of an object in a visual scene is important for adaptive behaviour in many contexts. Some authors have proposed that processing the spatial location of stimuli has a special status for our cognitive system (e.g., Garner, 1987). Posner's Costs and Benefits paradigm has been used by many researchers to study the orienting of visual attention in space (see also Posner et al., 1978; Posner et al., 1980). Studies using this paradigm have shown that previously directing attention to a location benefits performance for a target that appears in that same location in a variety of tasks. This result suggests that processing of the target is modulated in some way by the orienting of attention to that location. This attentional modulation can be observed not only behaviourally, in faster and/or more accurate responses for attended targets, but also physiologically, in increased cerebral blood flow and altered electrical potentials in relevant areas of the visual system (e.g., Posner & Raichle, 1994). These findings are traditionally interpreted in terms of the *spotlight* metaphor. According to this view, stimuli that appear within an attentional spotlight are allocated more resources than stimuli that appear outside that attentional spotlight.

Analogous to the orienting attention in space, researchers have begun to consider the possibility that attention also can be focused to a specific moment in time (Coull & Nobre, 1998; Kingstone, 1992). The temporal dimension is clearly relevant in perception. Kubovy (1981) has argued that space and time are both "indispensable attributes" of perception. It seems likely that we take into account temporal information to fix ourselves in a particular context within our dynamic and complex environment. From this perspective, temporal expectancy about when an event will occur is also likely to benefit our behaviour.

According to Coull and Nobre (1998), attentional orienting in time is the ability to use information about time intervals "to direct attention to a point in time when a relevant event is expected, to optimise behaviour" [p. 7426]. Behaviourally, a temporal orienting effect can be defined as a decrease in reaction time (RT) as a consequence of a match between temporal expectancy for an event and the actual temporal occurrence of that event. In other words, RTs that are lower when the target appears at expected than at unexpected time intervals can be attributed to temporal orienting processes. This definition is consistent with effects that were found previously in the field of alertness. When a warning signal was presented in simple-RT (Woodrow, 1914) or choice-RT tasks (Bertelson, 1967), an improvement in RTs was found. This RT improvement was interpreted as being caused by participants' certainty about the moment when the target would appear, which they gained by using the warning signal as a temporal cue. Presumably, participants used the warning signal to make "preparatory adjustments" in advance of the occurrence of the stimulus (Bertelson, 1967).

However, Coull and Nobre (1998) claim that the alertness effect in the experiments with warning signals is not produced by a rigid mechanism. Rather, they propose that attentional resources can be allocated dynamically to a particular time interval. In this sense, the mechanism underlying temporal orienting of attention can be endogenous, that is, voluntarily controlled by the cognitive system. Thus, a warning signal could trigger two different processes at the same time: an alertness process and an attentional preparation process. The former involves a general increase of activation in organisms (i.e., an unspecific preparation, Posner, 1978). The latter involves, according to LaBerge (1995), "an elevation of activity in the corresponding perceptual or action brain area that speeds processing of stimuli or actions when the appropriate triggering event occurs" [p. 51], that is, a specific preparation based on a temporal expectancy. Recently, other authors have proposed another factor that may contribute to unspecific preparation: The warning signal could act as a conditioned stimulus that triggers a preparatory response, which is time locked to the *unconditioned* stimulus (i.e., the target) and learned by trace conditioning (Los & Van den Heuvel, 2001).

In this sense, some authors have differentiated between exogenous and endogenous processes in temporal orienting (Coull, Frith, Büchel et al., 2000; Milliken & Lupiáñez, 2000). Exogenous processes are related to a *rigid mechanism* of alertness (or trace conditioning), whereas endogenous processes are related to an attentional preparation process that can be modulated by strategic factors such as temporal expectancies.

In several studies of preparation that manipulated the foreperiod (see Niemi & Näätänen, 1981, for a review), one can find additional evidence supporting the idea that participants spontaneously use temporal expectancies to guess the moment at which a target will appear (Alegria, 1975). However, Coull and Nobre (1998) analysed directly how a temporal expectancy can modulate the process of preparation. They presented an endogenous cue that provided predictive temporal information, so that participants could anticipate whether the stimulus was likely to appear after a short (300 ms) or a long interval (1500 ms). Then, the target appeared either in the cued interval with a probability of .80 (valid trials) or in the uncued interval with a probability of .20 (invalid trials). The results were analogous to those from spatial orienting studies: stimuli that appeared in the cued time interval were detected faster than those that appeared in the uncued interval. This effect was attributed to temporal orienting as participants are presumed to have used the temporal information provided by the cue to predict the likely temporal onset of the target. They were encouraged to adopt this orienting strategy by the high predictability of the cue (.80). Presumably, participants decoded the symbolic meaning of the cue and used it to generate a temporal expectancy, directing attention voluntarily to the cued interval. This orienting process must be flexible and dynamic, since the time interval changed from trial to trial.

A review of the research literature on endogenous temporal orienting (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998; Coull, Nobre, & Frith, 2001; Milliken et al., 2003; Miniussi et al., 1999) reveals that orienting effects for both early and late expectancies are rarely found (Milliken et al., 2003; Miniussi et al., 1999). Instead, orienting effects are often reported only for the late expectancy. Yet, observing a temporal orienting effect for both early and late expectancies is important to argue that the underlying mechanism is endogenous in nature, as orienting effects for just a late expectancy could be explained by alertness processes.

Several authors (Alegria, 1975; Coull & Nobre, 1998; Karlin, 1959; Kingstone, 1992; Loveless & Sandford, 1974; Mc Auley & Kidd, 1998) have discussed a "reorienting" or "repreparing" process, which could explain why temporal orienting effects are often not observed for an early expectancy (but see Los & Van den Heuvel, 2001, for a different account to that of the reorienting). It is assumed that reorienting can occur when participants have an early expectancy, and the target fails to appear early. In response to this failed prediction, participants may reorient their attention to the long interval. Consequently, despite the cue indicating a highly probable early target, participants may be as well prepared for a target at the long interval as for a target at the short interval. This conclusion is supported by the fact that RTs are often not lower on ‘early expectancy-short interval’ trials than on ‘early expectancy-long interval’ trials.

The reorienting hypothesis is well supported by physiological (Loveless & Sandford, 1974) and neuroimaging studies (Coull, Frith, Büchel et al., 2000). However, the reorienting process has never been directly manipulated to study its influence on temporal orienting. In the present study, we examined whether it is possible to gain empirical control over this reorienting process. How might this empirical control be achieved?

A straightforward answer to this question is to gain control over whether participants act on the knowledge that: “if the target doesn’t appear at the short interval, it necessarily will appear at the long interval”. Methodologically, we can eliminate this contingency by including trials in which the target does not appear (i.e., catch trials). Indeed, in experiments in which temporal orienting effects have been reported for an early expectancy, catch trials have been part of the design (Milliken & Lupiáñez, 2000; Miniussi et al., 1999). According to our hypothesis, the presence of catch trials implies that the target cannot be confidently expected at the long interval when it does not appear at the short interval. This uncertainty may well be sufficient to prevent participants from confident predictions about the appearance of the target, which we presume to be the basis of the reorienting process. Thus, when an early expectancy is violated in the context of an experiment with catch trials, RTs may be high when the target appears at a long interval because the reorienting process is not engaged.

Thus, the primary aim of the present study was to examine whether the presence/absence of catch trials dictates whether reorienting occurs in the context of a temporal orienting study.

One difference between our procedure and that of Coull and Nobre (1998) was the inclusion of a third SOA (Stimulus Onset Asynchrony). This additional SOA was used to examine whether the orienting of attention produces effects on RT that depend on the difference between the cued (expected) temporal interval and the actual temporal interval. As this property holds for the orienting of spatial attention (Shulman, Sheehy, & Wilson, 1986), and given that this property has been observed in one other temporal orienting study (Milliken et al., 2003), we expected a progressive increase in RTs as the difference between expected and actual SOA became larger.

Finally, we examined whether temporal orienting occurs in discrimination tasks, since it has been fundamentally studied with simple-RT tasks (but see Griffin et al., 2001; Kingstone, 1992; or Los & Van den Heuvel, 2001). Thus, if temporal orienting effects are due to the orienting of attention in time, effects should be general and ought to be found across different tasks. In contrast, if the effects are due to a specific motor preparation, they should be more easily observed in those tasks in which a simple and direct stimulus-response mapping is used, as in simple detection tasks. Thereby, it could be interesting, in parallel with studies of spatial attention, to explore whether effects of attentional orienting generalize to choice-RT tasks such as our shape discrimination task.

Moreover, the use of shape discrimination tasks could be useful for future research with physiological measures to test more adequately the possibility that temporal orienting might modulate early visual processing, as such tasks demand a more detailed perceptual analysis than detection tasks. However, at the moment there is no neuroimaging research with other tasks different to detection tasks. Therefore, the studies that suggest that temporal orienting exclusively affects late stages of processing such as preparation of a motor response (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998; Miniussi et al., 1999) would be better contrasted with the use of shape discrimination tasks.

EXPERIMENT 1.1

In this experiment, the influence of uncertainty on endogenous temporal orienting was explored by manipulating the presence/absence of catch trials. In addition, temporal orienting was studied in both detection and shape discrimination tasks.

According to the definition of temporal orienting proposed above, temporal orienting processes ought to produce an interaction between Temporal Expectancy and SOA. Furthermore, we expected to observe a significant interaction between Temporal Expectancy and SOA in both detection and discrimination tasks. Concerning the effect of catch trials, we expected that it would modulate the influence of the temporal cue. In particular, without catch trials, we predicted that an expect-early cue would not necessarily produce faster responses for early than for late targets. This prediction is based on the notion that, when there are no catch trials, participants may re-orient to a late temporal interval when the target does not appear at the cued early temporal interval.

In contrast, with catch trials, participants ought to produce faster responses for early targets when given an expect-early cue. This prediction follows because participants will be less likely to re-orient to a long interval when such reorientation is often met with the absence of a target.

Method

Participants

Thirty-two students of Psychology took part in the experiment for course credits. There were four groups composed of eight participants each.

Apparatus and stimuli

MEL software (W. Schneider, 1988) controlled the presentation of stimuli and data collection. The experiment was run on a 486/33 processor connected to a 14 inch VGA monitor. All stimuli appeared in the centre of the screen. The stimuli that appeared on each trial included a fixation point (“+” symbol), an endogenous cue and a target. The endogenous cue was either a red or green square, 14 mm in width X 17 mm in height, subtending visual angles of 1.34° and 1.62° at a viewing distance of 60 cm, respectively. The target was either the letter ‘O’ or the letter ‘X’, 4 mm in width X 8 mm in height, subtending visual angles of 0.38° and 0.76° respectively. The two target letters appeared with a probability of .50. In the detection task group, participants pressed the ‘B’ key when either an ‘O’ or ‘X’ appeared. In the discrimination task group, participants pressed the ‘Z’ key for one target and the ‘M’ key for the other target. The assignment of targets to response keys was counterbalanced across participants within each group.

Procedure

Participants sat approximately 60 cm from the screen. Instructions concerning the task were displayed on the screen at the beginning of the experimental session. Participants were explicitly informed that the temporal cue would help them to predict when the target would appear. Half of participants were told that the green square indicated the target would appear “early”, while the red square indicated the target would appear “late”. The meaning associated to the colour of the cue was counterbalanced. So, for the remaining half of participants the red square indicated that targets were likely to appear early, while the green square indicated that targets were likely to appear late. Auditory feedback (a 400 Hz tone of 100 ms) was provided on error trials. Participants were encouraged to respond as quickly and accurately as possible. The group with catch trials was not informed about the presence of catch trials. A sketch of the sequence of events on a trial is depicted in Figure 1.1.

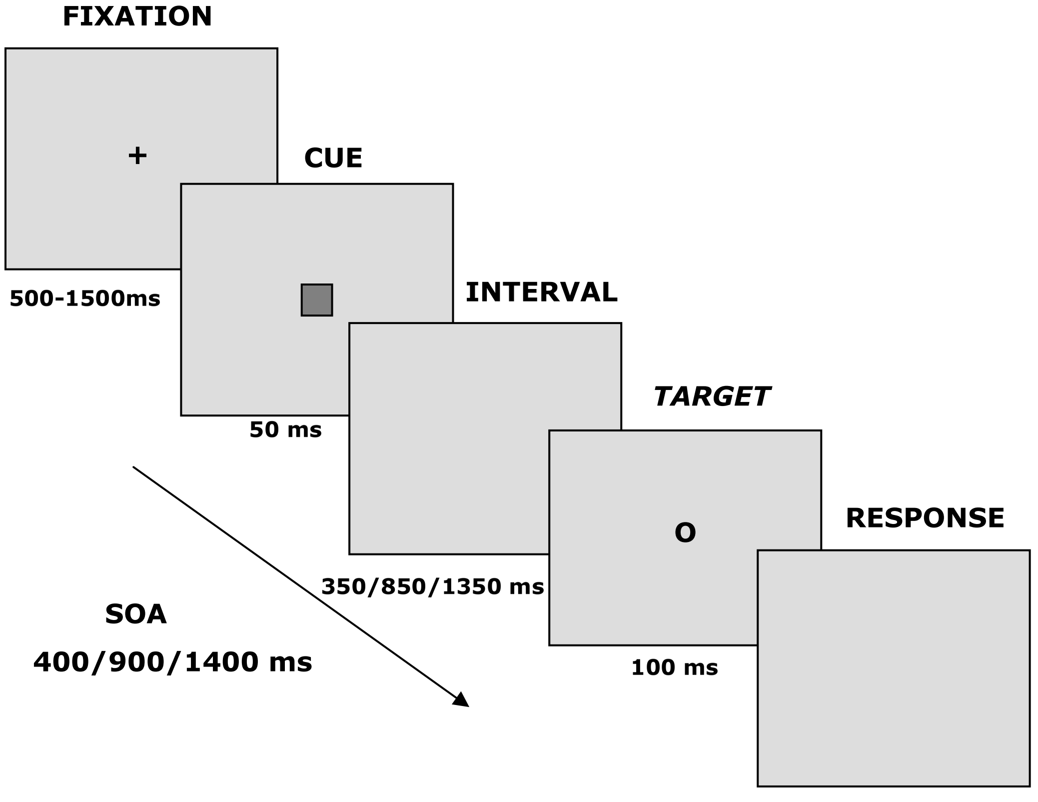

Figure 1.1. *Sequence of events on a trial in Experiment 1.1.*

The fixation point was displayed in black on a grey background for a random interval between 500 and 1500 ms. The endogenous cue, a red or green square, then appeared for 50 ms. The cue was then removed and the screen remained blank for a variable delay of 350, 850 or 1350 ms, depending on the SOA for that trial. Finally, the target was displayed for 100 ms and was then replaced by a blank screen until the detection or discrimination response. After response, the next trial began. When no response was made, the next trial began following a delay of 2000 ms.

The experimental session lasted about 30 minutes. Each session included one block of 64 practice trials and four blocks of 128 experimental trials. There was a 1-minute interruption to rest at the end of each block.

In the group with uncertainty (i.e., with catch trials), there were 32 trials without a target, and 96 trials with a target, thus producing a catch trial proportion of .25. The 96 target trials consisted of 72 validly cued trials and 24 invalidly cued trials, thus producing a validity proportion of .75. On half of the valid trials, the cue indicated that the target was likely to appear “early” and the target appeared 400 ms after cue onset. On the other half of the valid trials, the cue indicated that the target was likely to appear “late”, and the target appeared 1400 ms after cue onset. The invalid trials were equally distributed between the two uncued SOAs for both early and late cues. Thus, all the trials at the medium SOA were invalid. Therefore, the number of target trials within a block was as follows: 36 early cue-short SOA, 6 early cue-medium SOA, 6 early cue-long SOA, 36 late cue-long SOA, 6 late cue-medium SOA and 6 late cue-short SOA.

In the group without catch trials, a target was displayed on the 32 trials in each block that corresponded to catch trials in the other group. These trials were composed of the same proportions of cue validity and SOA conditions as the remainder of the block. However they were excluded from the analysis, so that the same number of trials were analysed in both groups. In other words, we analysed 96 trials in which a target appeared for both groups.

Design

The experiment consisted of a 2 (Task: detection / discrimination) X 2 (Target Uncertainty: without catch trials / with catch trials) X 2 (Temporal Expectancy: early / late) X 3 (SOA: 400 / 900 / 1400 ms) mixed factor design. Task and Target Uncertainty were between-participants variables. Temporal Expectancy and SOA were within-participant variables.

Uncertainty will also be referred to as “catch”, since uncertainty was induced by the presence of catch trials. Half of the participants completed the detection task and the remaining half completed the discrimination task. Each task group was divided into two subgroups, referred to as the “without catch trial” and “with catch trial” groups. The factorial combination of Temporal Expectancy and SOA factors defined six conditions that were randomly intermixed among trials within blocks. Reaction times and percentage of errors (misses and mistakes) were the dependent variables. Misses referred to target trials in which no response was made. Mistakes referred to incorrect responses in the discrimination task (e.g. the target was the letter ‘O’ and the key assigned to the target ‘X’ was pressed).

Results

Trials with correct responses faster than 100 ms (0.16%) or slower than 1000 ms (0.84%), as well as incorrect responses (misses and mistakes), were excluded from the RT analysis. This cut-off was held constant across the experiments. Mean RTs for correct responses and percentage of errors for each experimental condition are shown in Table 1.1. Only misses are shown for the detection task, as mistakes could not occur in this task.

Mean RTs for correct responses were submitted to a mixed factor analysis with Temporal Expectancy (early/late) and SOA (400/900/1400 ms) as within-participant variables, and Task (detection/discrimination) and Uncertainty (without/with catch trials) as between-participants variables. When the Expectancy X SOA interaction reached significance, temporal orienting effects were examined more specifically by applying two different analyses of the validity effects.

Table 1.1. *Mean correct response times (in milliseconds) and percentage of errors for each experimental condition in the detection task and the discrimination task, Experiment 1.1. In Brackets: Percentage of omissions (misses). In parenthesis: incorrect responses.*

		EARLY EXPECTANCY			LATE EXPECTANCY		
TASK	**CATCH**	**400 ms**	**900 ms**	**1400 ms**	**400 ms**	**900 ms**	**1400 ms**
DETECTION	**WITH**	358 [1,96]	395 [1,03]	411 [2,04]	376 [3,03]	378 [1,54]	385 [1,79]
	WITHOUT	345 [2,37]	335 [1,03]	324 [1,03]	371 [3,52]	329 [0,00]	318 [1,71]
DISCRIMINATION	**WITH**	561 (1,43) [0,00]	569 (1,46) [0,00]	591 (0,50) [0,00]	551 (1,50) [0,00]	565 (0,50) [0,00]	572 (1,77) [0,01]
	WITHOUT	506 (1,68) [0,68]	498 (2,79) [0,00]	491 (4,12) [0,00]	504 (4,64) [0,00]	488 (2,42) [0,51]	488 (3,34) [0,42]

The first analysis focused on how RTs for a given temporal expectancy change across SOA, referred to as “expectancy-fixed analyses” or SOA effect (e.g. Milliken *et al.*, in press). The second analysis focused on how RTs for a given SOA change across temporal expectancies, referred to as “SOA-fixed analyses” or temporal expectancy effect (e.g. Coull & Nobre, 1998). The former was accomplished by analysing the linear and quadratic trends in RT across SOA while holding constant the temporal expectancy. The latter consisted of planned comparisons between RTs for valid and invalid trials while holding constant the SOA at either 400 ms or 1400 ms. Thus, the medium SOA (900 ms) was excluded from the SOA-fixed analyses, but included in linear and quadratic trend analyses across SOA.

The main effect of task [F(1,28)=96.11; p<.001] confirmed that RTs were faster in the detection task than in the discrimination task. There was also a significant interaction between

Task, Expectancy and SOA [F(2,56)=3.97; p<.05]. To examine this interaction further, analyses were conducted for each task separately.

Detection Task. The main effect of catch trials [F(1,14)=4.38; p<.05] showed faster responses without catch trials than with catch trials. The interaction between Catch and Expectancy was significant [F(1,14)=5.39; p<.05], so that the slowing of responses with catch trials was more pronounced for the early expectancy than for the late expectancy.

The interaction between Catch and SOA was also significant [F(2,28)=18.31; p<.001], as shown in Figure 1.2. In the group without catch trials, RTs decreased as the SOA increased (referred to as a "reorienting effect"). In the group with catch trials, RTs increased as the SOA increased (referred to as a "dispreparation effect").

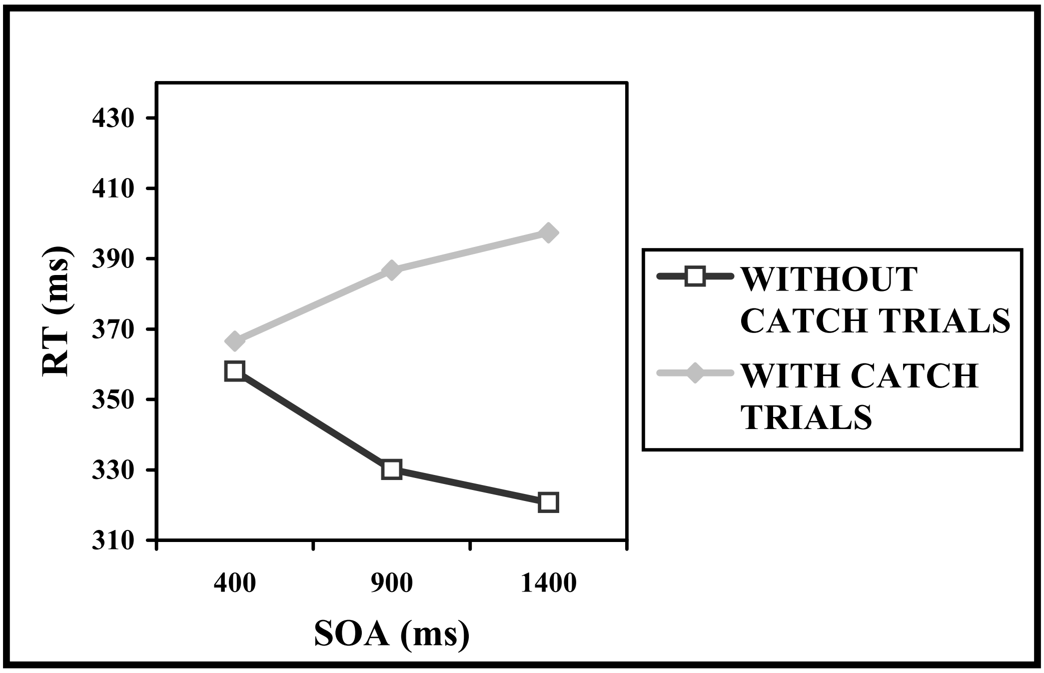

Figure 1.2. *Mean RTs in the detection task of Experiment 1.1 as a function of Catch and SOA. Note the effect of catch trials, reorienting and dispreparation effects for the groups without and with catch trials, respectively.*

More interestingly, the interaction between Expectancy and SOA was significant [F(2,28)=15.51; p<.001]. This interaction is depicted in Figure 1.3.

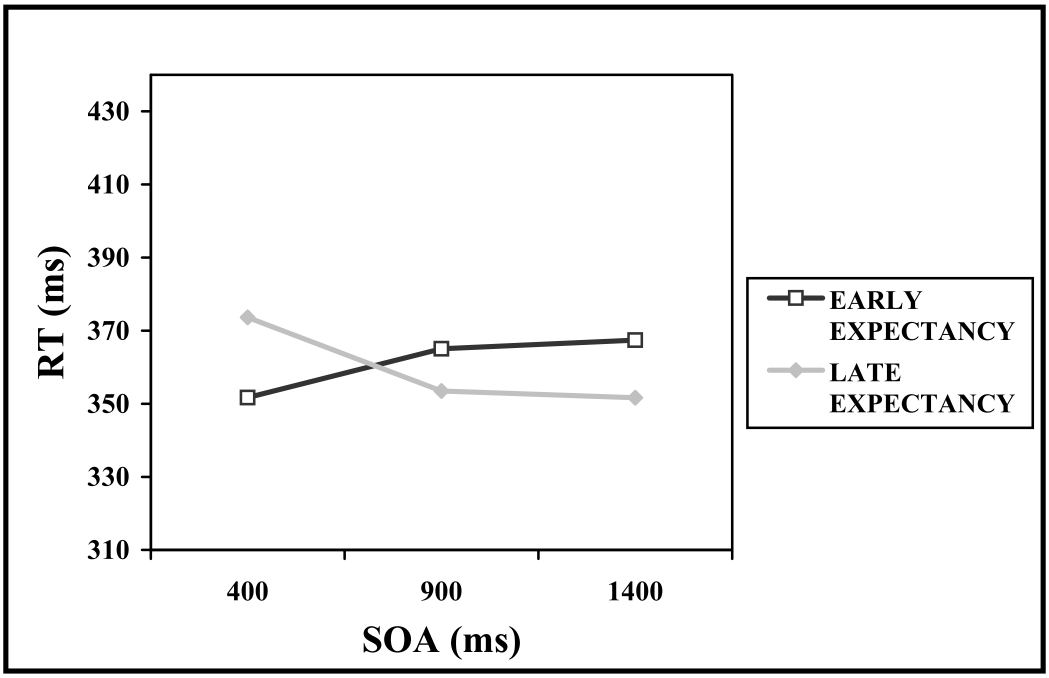

Figure 1.3. *Mean RTs in the detection task of Experiment 1.1 (with and without catch trials groups collapsed) as a function of Temporal Expectancy and SOA. Note the validity effects for both early and late expectancies, and at short and long SOAs.*

Note that the fastest RTs occurred when temporal expectancy and SOA matched (i.e., early expectancy-short SOA and late expectancy-long SOA). This observation was confirmed, first by significant linear trends across SOA for both early expectancy [F(1,14)=5.93; p<.05] and late expectancy [F(1,14)=5.93; p<.05]. The quadratic trend did not reach significance in either case (p>.08 and p>.2, respectively). As predicted (see Table 1.1), the early expectancy effect only appeared in the group with catch trials [validity effect: 53 ms; F(1,14)= 30.11; p<.001]. On the other hand, the late expectancy effect was only significant in the group without catch trials [validity effect: 53 ms; F(1,14)= 17.43; p<.001]. Second, planned comparisons between RTs for valid and invalid trials were significant at the short SOA [validity effect: 22 ms; F(1,14)=14.73; p<.01], as well as at the long SOA [validity effect: 16 ms; F(1,14)=14.56;

$p<.01$]. Importantly (see Table 1.1), catch trials also determined the appearance of validity effects at the long SOA, as they were only observed in the group with catch trials [validity effect: 26 ms; $F(1,14)=18.79$; $p<.001$ with catch trials; validity effect: 6 ms, $p>.30$, without catch trials].

To summarize, both the expectancy-fixed and the SOA-fixed analyses showed robust temporal orienting effects, although the effects, as predicted, were modulated by the presence of catch trials.

Analysis of error percentages (misses) revealed only a main effect of SOA [$F(2,28)=5.22$; $p<.05$]. Most of the misses occurred at the short SOA (2.66%).

Discrimination Task. Analyses of the RTs revealed only a significant main effect of Catch [$F(1,14)=7.2$; $p<.05$] and a significant interaction between Catch and SOA [$F(2,28)=5.69$; $p<.01$]. The pattern of results was similar to that of the detection task (reorienting and dispreparation effects in the groups without and with catch trials, respectively). Endogenous temporal orienting effects, revealed by the Expectancy X SOA interaction, were not found in this task.

The analyses of mistakes (ANOVA) revealed no significant effects. Misses were not analysed, as they were very rare. No miss rate was higher than 0.7% (see Table 1.1).

Discussion

The most important finding in this experiment is that people can direct their attention, voluntarily and flexibly, to specific moments in time. This finding is noteworthy in that it extends the use of attentional cueing procedures from the domain of space to the domain of time.

The pattern of results that suggests robust voluntary temporal orienting processes was the co-occurrence of a validity effect for the early and late expectancy conditions. The results from Experiment 1.1 that met this criterion were those in the detection task, and catch trials showed to be decisive to observe the validity effect for the early expectancy. This criterion is important because provides additional evidence for voluntary temporal orienting explanations over alertness explanations. Note that if performance had been faster for validly cued SOAs only in the late expectancy condition, as has occurred in various prior studies (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998; Coull et al., 2001), it could have been argued that presentation of the cue produced only an alertness effect. Such an alertness effect would be expected to facilitate performance in a rigid manner, with optimal performance occurring at a fixed temporal interval following the cue. However, the mentioned studies reported validity effects at the short SOA, which also points to endogenous effects.

Moreover, we further observed validity effects at both the short and the long SOA. Again, catch trials were a key factor to find such effects at the long SOA. This result would provide more evidence to the endogenous view, as it shows that temporal orienting is not limited to a fixed temporal interval. Rather, participants could flexibly focus their attention to different points in time according to their temporal expectancy.

Therefore, Experiment 1.1 suggests that uncertainty over whether a target will appear on a trial could dictate whether a validity effect occurs for early expectancy and long SOA conditions. Thus, the manipulation of uncertainty allowed us to discriminate whether there was a reorienting process that masked validity effects for the early expectancy and the long SOA or there was no temporal orienting at all for those conditions. It appears that reorienting of attention occurred in the group without uncertainty (i.e., without catch trials), whereas an effect we called “dispreparation” occurred in the group with uncertainty (i.e., with catch trials; see Figure 1.2). This finding helps to explain why cue validity effects are not always observed, as temporal orienting processes can be affected by factors other than the match between cue and target.

Specifically, a reorienting process tends to decrease RTs with increasing SOA. Thus, in the early expectancy condition, RTs in the long SOA condition were quite a bit lower than would be expected if RTs depended only on the match between expectancy and SOA. As Coull and Nobre (1998) suggested, participants appear to refocus their attention to the long interval when the target does not appear at the short interval. Indeed, this strategy makes perfect sense when there are no catch trials. Without catch trials, participants can confidently predict the later appearance of the target once the target has not appeared at the short SOA. As such, this reorienting process is likely to eliminate validity effects for the early expectancy and the long SOA conditions.

In contrast with the reorienting process, dispreparation produces an increase in RTs with increasing SOA. Dispreparation also makes perfect sense when there are catch trials, in that the conditional probability of target appearance becomes lower with longer SOAs[2]. Consequently, participants may have *relaxed* their state of readiness in anticipation of a catch trial. Surprise at the appearance of a target at the long SOA would then augment RTs sharply. Hence, the presence of catch trials prevented the reorienting effect, which in turn allowed us to observe validity effects for the early expectancy and the long SOA conditions.

In summary, cue validity is not the only factor that affects temporal orienting. An absence of catch trials appears to encourage a reorienting process that makes validity effects for expect-early cues and long SOAs difficult to observe. In contrast, the presence of catch trials encourages a relaxation of preparedness, which makes cue validity effects difficult to measure for expect-late cues.

Concerning the inclusion of the medium SOA (900 ms), it allowed us to examine the linearity of temporal orienting effects. In particular, there was an increase in RTs as the difference between expected and actual SOA became larger. Although statistical analyses revealed linear trends instead of quadratic trends in the expectancy functions, such an increment did not seem progressive, as RTs for the 900 ms and 1400 ms SOAs were quite similar. This result might suggest that both SOAs could have not been appropriately differentiated, so that, at the time of the medium SOA, participants achieved (or had already abandoned, in case of an early cue) the same preparation as for the long SOA.

On the other hand, temporal orienting effects were not sufficiently large to be observed in the discrimination task of Experiment 1.1. Endogenous temporal orienting effects in a shape discrimination task have been reported in only two prior studies (Griffin et al., 2001; Milliken et

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[2] In the groups with catch trials, the conditional probabilities for an early-cued target to occur at the short, medium and long SOAs are .56, .21 and .27, respectively.

al., 2003). This discrepancy could be explained by methodological differences: Milliken *et al.* manipulated temporal expectancy between-participants, whereas we manipulated temporal expectancy within-participant and within blocks. One possible explanation is that both endogenous temporal orienting (i.e., the voluntary process of attentional preparation in time) and the maintenance in working memory of an arbitrary stimulus-response mapping may interfere with each other. Our shape discrimination task is not demanding in perceptual terms (i.e., letters "X" and "O" can be easily discriminated), but in terms of the stimulus-response mapping (S-R mapping), which is arbitrary. Thus, some processes implied in voluntary temporal orienting could demand controlled processing (e.g., the endogenous generation of the expectancy, or time estimation processes, Brown, 1985), as well as tasks with complex S-R mappings. Hence, both demands at the same time could produce interference in central processing.

In brief, our explanation based on interference assumes that temporal orienting, as an endogenous process, demands controlled processing. Moreover, our discrimination task is more demanding than the detection task in that the S-R mapping is more complex (and arbitrary). Hence, the competition for central resources between both demands could result in impaired temporal orienting.

In fact, some participants in Experiment 1.1 mentioned that trying to follow the meaning of the cue distracted them for the discrimination task, so they ignored the temporal information and focused only on the discrimination task. This hypothesis was examined in Experiments 1.2 and 1.3.

EXPERIMENTS 1.2 and 1.3

Interference between demands to accomplish the choice-RT task (arbitrary mapping) and to focus attention in time could explain the absence of temporal orienting effects for the discrimination task in Experiment 1.1. Presumably, the resources required for maintaining the stimulus-response mapping for the discrimination task prevented simultaneous preparation for expecting a target at a particular temporal interval.

According to the interference hypothesis, we would expect to observe temporal orienting effects in choice-RT tasks if the processing demands of preparing for a particular temporal interval were eased. This prediction could be tested by several methods, as there are multiple ways to reduce interference.

For example, temporal expectancy might be manipulated between blocks rather than within blocks. With this method, participants would not need to generate a new temporal expectancy for each trial, since each experimental block would be composed of homogeneous trials in which expectancy does not change. We tested this possibility in Experiment 1.2, in which temporal expectancy was manipulated between blocks for one group of participants and within blocks for a separate group of participants. We expected to observe temporal orienting effects for the discrimination task in the group for which expectancy was manipulated between blocks, as occurred in Milliken *et al.* (in press). However, given the results of Experiment 1.1, we did not expect to observe temporal orienting effects for the discrimination task in the group for which expectancy was manipulated within blocks (or at least we expected them to be smaller). In terms of the design of the experiment, then, a significant interaction between Temporal Expectancy, SOA and Expectancy manipulation (within vs. between blocks) ought to occur.

Following the logic introduced above, another strategy that might be used to find endogenous temporal orienting effects in a discrimination task would be to facilitate the interpretation of the temporal cue. The cue used in Experiments 1.1 and 1.2 linked two different colours to two different time intervals. As the relation between colours and temporal intervals is arbitrary rather than intuitive, generation of a temporal expectancy using colour cues might be relatively resource demanding. By this view, a more easily interpretable cue would require fewer resources, and therefore might allow for the co-existence of preparation for temporal orienting and maintenance of the S-R mapping for the discrimination task. This way, the cue used in this Experiment 1.3 linked two concepts highly related: space and time. We used a line as a cue, the length of which represented the most likely duration of interval between cue and target. A short line indicated that the target was most likely to appear at an early interval, whereas a long line indicated that the target was most likely to appear at a late interval. Then, we would expect to enhance temporal orienting effects with this more intuitive cue if temporal orienting effects depend on cue-decoding processes.

We also tested a new measure in Experiment 1.3, temporal duration judgements (TDJ), to examine the relation between this measure and temporal orienting effects. Participants had to estimate the duration of the time interval between the cue and target. Judgements were retrospective, as participants were not informed about the estimation task until after they had finished the experiment (see Brown, 1985 for a distinction between retrospective and prospective paradigms of temporal estimation).

This measure could be useful to elucidate whether participants actually attended to the cue and generated temporal expectancies. Then we assumed that participants would have more accurate representations of time intervals if they endogenously generated temporal expectancies. Hence, we expected the accuracy of temporal duration judgments to vary directly as a function of temporal orienting effects in the on-line performance task.

In sum, Experiments 1.2 and 1.3 aimed to find temporal orienting effects in discrimination, choice-RT, tasks through two different strategies directed to the same goal, that is, to reduce the resources demanded by temporal orienting processes. In both Experiments 1.2 and 1.3, temporal expectancy was either blocked or mixed within blocks. In Experiment 1.3, a more intuitive temporal cue was used. According to the interference hypothesis, we expect to observe the effect of such manipulations in larger temporal orienting effects.

Method

Participants

Thirty-two students of the University of Granada took part in each experiment for course credit. There were four groups per experiment, each composed of eight participants. In

Experiment 1.2, however, data from four participants (one participant from each group) were lost for technical reasons.

Apparatus and stimuli

The only difference between Experiment 1.2 and Experiment 1.1 was that the ‘B’ key was not used, as all participants performed the discrimination task using the ‘Z’ and ‘M’ keys. The following were the changes introduced in Experiment 1.3:

The experiment was run on a computer with a 1000 MHz Pentium III processor. The cue appeared in the centre of the screen, and consisted of a red rectangle, 4 mm in height, subtending a visual angle of 0.38° at a viewing distance of 60 cm. Its width was either 10 mm or 22 mm (0.95° and 2.1° of visual angle, respectively).

A time scale printed on a piece of paper was used to collect the TDJ. A 20 cm line was divided into 20 identical parts. The scale ranged from 0 to 2000 milliseconds, in 20 steps of 100 ms.

Procedure

The discrimination task was identical to that in Experiment 1.1. However, for half of the participants, expectancy was manipulated between blocks. In the between blocks manipulation, there were one block of 64 practice trials, two blocks of 128 experimental trials with an expect-early cue and two blocks of 128 experimental trials with an expect-late cue. There was a 1-minute interruption to rest at the end of each block. The order of presentation of these four experimental blocks was counterbalanced.

In Experiment 1.3, there were two differences from the procedure of Experiment 1.2. First, the stimulus used as temporal cue was either a short or long red line, indicating respectively early (for the short line) or late (for the long line) appearance of the target.

Moreover, at the end of the Experiment 1.3, participants were asked to make an estimate of the duration of both the short (400 ms) and the long interval (1400 ms). Participants were asked to draw two marks, one for each interval, on the scale. Their estimates were constrained to be a multiple of 100 ms. In other words, 500 ms and 600 ms, but not 550 ms, were eligible estimates.

Design

Both Experiments 1.2 and 1.3 consisted of a 2 (Expectancy-Manipulation: between blocks / within blocks) X 2 (Target Uncertainty: without catch trials / with catch trials) X 2 (Temporal Expectancy: early / late) X 3 (SOA: 400 / 900 / 1400 ms) mixed factor design. Expectancy-Manipulation and Target Uncertainty were between-participants variables. Temporal Expectancy and SOA were within-participant variables. Moreover, we included the Type of Cue[3] (non-intuitive / intuitive) as between-participants factor. Experiment 1.2 used the non-intuitive cue (i.e., colour as cue), whereas Experiment 1.3 used the intuitive cue (i.e., length as cue).

In addition to RTs and percentage of errors, in Experiment 1.3 we collected temporal duration judgements about the duration of the short and the long interval, made by each participant at the end of the experiment.

Results

Trials with correct responses faster than 100 ms (0.02% and 0.01% for Experiments 1.2 and 1.3, respectively) or slower than 1000 ms (1.32% and 0.74% for Experiments 1.2 and 1.3, respectively), as well as incorrect responses, were excluded from the RT analysis. Mean RTs for correct responses and percentage of misses and mistakes for each experimental condition in Experiment 1.2 (Type of Cue: non-intuitive) and in Experiment 1.3 (Type of Cue: intuitive) are shown in Table 1.2.

Mean RTs for correct responses were submitted to a mixed factor analysis with Temporal Expectancy (early/late) and SOA (400/900/1400 ms) as within-participant variables, and Type of Cue (non-intuitive/intuitive), Expectancy-Manipulation (between blocks/within blocks) and Uncertainty (without/with catch trials) as between-participants variables.

The type of temporal cue did affect performance overall, as indicated by the main effect of Type of Cue [$F(1,52)=4.55$; $p<.05$]. RTs were faster when different length lines were used as

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[3] Although the two experiments were run independently, data are presented as a between-participants variable for the sake of simplicity. As can be seen, the data of the two experiments were quite similar.

temporal cues (overall RT in Exp. 1.3: 491 ms) than when squares of different colours were used (overall RT in Exp. 1.2: 520 ms). However, the type of cue did not modulate any interaction between variables, so that we did not make separated analyses for Experiments 1.2 and 1.3. Therefore, the following results included pooled data from Experiments 1.2 and 1.3.

Table 1.2. *Mean correct response times and percentage of errors (incorrect responses in parenthesis and percentage of omissions in brackets) of Experiment 1.2 (Type of Cue: Non-intuitive) and Experiment 1.3 (Type of Cue: Intuitive).*

EXPERIMENT	EXPECTANCY MANIPULATION	CATCH	EARLY EXPECTANCY			LATE EXPECTANCY		
			400ms	900ms	1400ms	400ms	900ms	1400ms
EXPERIMENT 1.2	WITHIN BLOCKS	WITH	489	505	532	484	521	514
			(3,67)	(2,29)	(3,61)	(3,30)	(5,30)	(3,96)
			[0,57]	[0,58]	[1,68]	[0,57]	[0,56]	[1,13]
		WITHOUT	501	515	516	513	504	503
			(4,04)	(4,69)	(5,08)	(4,12)	(5,10)	(3,29)
			[0,91]	[0,00]	[0,49]	[0,50]	[0,97]	[0,58]
	BETWEEN BLOCKS	WITH	510	557	574	552	545	555
			(3,03)	(3,51)	(6,67)	(3,08)	(5,71)	(3,82)
			[0,58]	[0,49]	[1,90]	[0,00]	[0,00]	[0,83]
		WITHOUT	481	486	515	574	531	513
			(2,86)	(1,14)	(1,71)	(2,46)	(4,20)	(3,33)
			[6,28]	[7,34]	[6,25]	[2,26]	[0,56]	[0,76]
EXPERIMENT 1.3	WITHIN BLOCKS	WITH	503	533	530	517	526	521
			(2,19)	(3,33)	(5,08)	(1,36)	(2,92)	(2,98)
			[0,49]	[0,00]	[0,48]	[0,00]	[0,00]	[0,41]
		WITHOUT	457	456	457	470	463	451
			(3,57)	(3,39)	(1,00)	(3,62)	(4,75)	(3,85)
			[0,58]	[0,50]	[0,51]	[0,00]	[0,00]	[0,25]
	BETWEEN BLOCKS	WITH	454	501	525	518	501	497
			(2,66)	(3,92)	(1,00)	(1,46)	(2,85)	(2,78)
			[0,17]	[0,50]	[0,51]	[3,94]	[0,00]	[0,50]
		WITHOUT	458	469	474	541	492	472
			(2,81)	(3,54)	(1,96)	(2,46)	(2,92)	(2,98)
			[0,08]	[0,00]	[0,00]	[1,50]	[0,50]	[0,08]

The main effects of Catch [F(1,52)=3.90; p<.05], Temporal Expectancy [F(1,52)=14.54; p<.001] and SOA [F(2,104)=3.85; p<.05] were significant, such that RTs for the groups without catch trials were faster than for the groups with catch trials, RTs for the early expectancy were faster than for the late expectancy, and RTs were faster for the short than for the long SOA, respectively.

Concerning this expectancy effect, it was modulated by Expectancy-Manipulation (Expectancy-Manipulation X Temporal Expectancy; F(1,52)=16.50; p<.001), such that the main effect of Temporal Expectancy was significant in the between blocks condition [F(1,52)=31.06; p<.001], but not in the within blocks condition (F<1). Moreover, the interaction between Catch and Temporal Expectancy [F(1,52)=7.55; p<.01] replicated that of the detection task in Experiment 1.1, which showed that the slowing produced by inclusion of catch trials was greater for the early expectancy than for the late expectancy condition.

Concerning the SOA variable, the interesting interaction between Catch and SOA found in Experiment 1.1 was replicated [F(2,104)=25.52; p<.001], reflecting the reorienting and dispreparation effects mentioned above. And more interestingly, the Expectancy X SOA interaction previously found in the detection task (Exp. 1.1) was now replicated in the discrimination task [F(2,104)=50.79; p<.001].

However, the Expectancy X SOA interaction depended on Expectancy-Manipulation [F(2,104)=20.65; p<.001]. This three-way interaction is depicted in Figure 1.4.

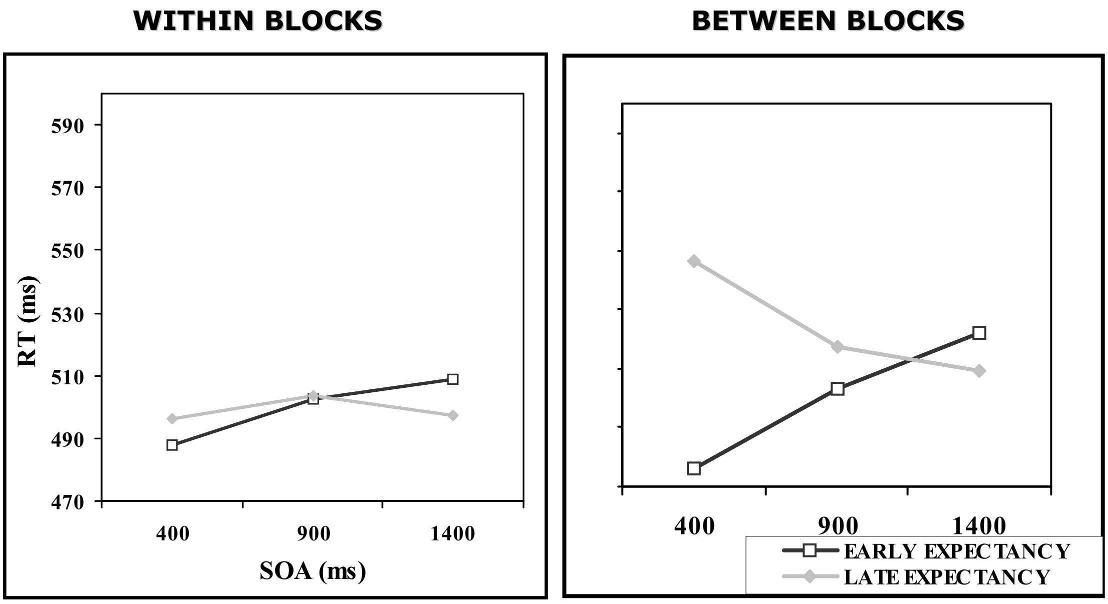

Figure 1.4. *Mean RTs in the discrimination task (Experiments 1.2 and 1.3 collapsed) as a function of Temporal Expectancy, SOA and Expectancy-Manipulation: within blocks (left panel) vs. between blocks (right panel). Each panel represents data collapsed from two groups: with and without catch trials.*

Note that the typical RTs pattern observed in temporal orienting experiments (i.e., a crossing between functions for both early and late expectancies) is more evident for the between blocks groups (right panel, with and without catch trials groups collapsed) than for the within blocks groups (left panel). According to our hypothesis, temporal orienting effects as revealed by the Expectancy X SOA interaction, although significant for both between and within blocks conditions [F(2,52)=72.88; p<.001, and F(2,52)=3.53; p<.05, respectively], were stronger in the former. Thus, we further analysed such an interaction for each condition separately.

Further analysis in the between blocks condition revealed significant linear trends across SOA for both early [F(1,26)=57.58; p<.001] and late expectancy [F(1,26)=26.04; p<.001]. Also, the quadratic trend was significant for the late expectancy [F(1,26)=5.26; p<.05]. Furthermore, comparisons between RTs for valid and invalid trials were significant at the short SOA [validity effect: 70 ms; F(1,26)=78.18; p<.001] and approached significance at the long SOA [validity effect: 13 ms, F(1,26)=3.35; p<.08].

Further analysis in the within blocks condition revealed a significant linear trend across SOA for the early [F(1,26)=11.75; p<.01] but not for the late expectancy (F<1). The quadratic trend was not significant in either case (p>.2 and p>.1, respectively). Comparisons between RTs for valid and invalid trials were near significance at the short SOA [validity effect: 8 ms; F(1,26)=3.52; p<.07] and were significant at the long SOA [validity effect: 12 ms, F(1,26)=4.61; p<.05]. As can be seen, validity effects were quite smaller than in the between blocks condition.

Another significant 3-way interaction was Expectancy-Manipulation X Catch X Expectancy [F(1,52)=6.16; p<.05], so that the Catch X Expectancy interaction was significant in the between blocks condition [F(1,26)=8.77; p<.01], but not in the within blocks condition (F<1).

The analyses of mistakes (ANOVA) revealed no significant effects. Misses were not analysed, as they were very rare.

Analysis of Temporal Duration Judgements. This measure was only collected in Experiment 1.3, so the following analysis only included data from this experiment. TDJ were submitted to a mixed factor analysis with Expectancy-Manipulation (between blocks/within blocks) and Uncertainty (without/with catch trials) as between-participants variables, and SOA (short/long) as a within-participant variable. The only significant effect was the main effect of SOA [F(1,28)=112.8; p<.001], such that estimates of the 400 ms interval (375 ms on average) were significantly different from estimates of the 1400 ms interval (1103 ms on average).

Our prediction was not supported, as estimates from the within blocks condition (419 ms and 1125 ms for the short and long interval, respectively) were not significantly less accurate than estimates from the between blocks condition (331 ms and 1081 ms for the short and long interval, respectively). Thus, the Expectancy-Manipulation X SOA interaction was far from significance (F<1).

Discussion

The most important finding in Experiments 1.2 and 1.3 was the observation of endogenous temporal orienting effects in a shape discrimination, choice-RT task, as revealed by significant interactions between Temporal Expectancy and SOA. This finding indicates that temporal orienting is not limited to simple-RT tasks and replicates previous studies that reported other temporal orienting effects with choice-RT tasks such as location discrimination (Kingstone, 1992; Los & Van den Heuvel, 2001).

Another interesting result concerns the specific experimental conditions in which temporal orienting effects are more clearly observed in discrimination tasks. The results of both experiments suggest that the way temporal expectancy is manipulated can be critical. In particular, temporal orienting effects were hardly found when expectancy was manipulated trial by trial, a result in line with the findings from the discrimination task in Experiment 1.1. However, as predicted, temporal orienting effects were remarkably enhanced when expectancy was manipulated between blocks. We suggest that the generation of expectancy for a target to occur within a specific temporal window while maintaining the arbitrary S-R mapping for our discrimination task is highly demanding to the attentional system. Consequently, we found smaller temporal orienting effects when temporal expectancy cues were manipulated on a trial-by-trial base that when temporal expectancy was constant within a block of trials, presumably because fewer resources were needed to generate the expectancy consistently across a block.

Concerning the manipulation based on the type of the cue, overall reaction time in Experiment 1.2 was faster than in Experiment 1.3. This result suggests that processes of symbolic decoding of the more intuitive cue demanded fewer resources in Experiment 1.3 than in Experiment 1.2, thus freeing resources for other aspects of task performance. However, the type of cue did not interact with any factor, suggesting that this manipulation was not decisive in observing temporal orienting in discrimination tasks. Then, reducing the resources required by using a more intuitive cue did not lead to larger temporal orienting effects. However, other methods could facilitate temporal orienting more successfully. For example, participants might be allowed more time to generate a preparatory set for a given time interval. Given that the cue was displayed for 50 ms in these experiments and the shortest SOA was 400 ms, it remains possible that temporal orienting effects were obscured in the discrimination task because participants had insufficient time to generate a temporal expectancy (see Kingstone, 1992 or Los & Van den Heuvel, 2001 for longer exposure times of the temporal cue). This is an issue that ought to be addressed in future research.

On the other hand, temporal duration judgements did not prove to be a reliable index of temporal orienting effects, given that this variable did not discriminate between the conditions that did (between blocks groups) and did not (within blocks groups) produce remarkable temporal orienting effects. In contrast to our hypothesis, estimations were not more accurate in the condition that showed stronger temporal orienting effects. However, this measurement probably was not reliable enough because we registered just one estimate from each participant. Other studies that have measured TDJs (Chen & O'Neill, 2001) have registered one estimate after each trial, so that the number of estimates per participant was considerable higher than in our study.

Isolating Endogenous from Non-Endogenous Influences on Temporal Orienting: an analysis of sequential effects.

So far, we have shown that temporal orienting of attention can be observed in both a detection, simple-RT task, and a discrimination, choice-RT task, both for early and late expectancies, and at short and long SOAs. These data point to the endogenous nature of our temporal orienting effects, in line with results observed by Nobre and co-workers (e.g. Coull et al., 2000; Coull & Nobre, 1998 or Miniussi et al., 1999). However, other researchers have studied similar temporal orienting effects, which are, according to them, non-endogenous (Los & Van den Heuvel, 2001).

Thus, it seems appropriate to disentangle endogenous from non-endogenous influences on our temporal orienting effects, in order to test thoroughly our main hypothesis that such effects are produced by an endogenous mechanism. Moreover, this analysis allows the link of studies on temporal orienting with the classical literature on foreperiod and preparation.

Studies on preparation that have manipulated the foreperiod duration usually find asymmetrical sequential effects (Niemi & Näätänen, 1981). Foreperiod is defined as the time interval between a warning signal and a target. Therefore, if we consider that foreperiod (FP) and SOA are practically the same variable, it makes sense to expect that our SOA manipulation additionally produced such effects. Asymmetrical sequential effects imply that RTs are lengthened when the previous FP was longer than the current FP. In other words, RTs at a short current SOA are slower when the previous SOA was long rather than short. Typically, this relation is not symmetrical because RTs at a long current SOA are not different when the previous SOA was either short or long.

Hence, our data could be contaminated by such effect, so that the Expectancy X SOA interaction might be due to asymmetrical sequential effects rather than to temporal cueing[4]. Thus, to distinguish between these two causes it is important to argue that there exists an endogenous mechanism of attention underlying our temporal orienting effects, since Los and Van den Heuvel (2001) presented evidence that sequential effects are produced by unintentional processes. Therefore, we will consider sequential effects as non-endogenous influences to put them in opposition to our account of temporal orienting effects based on endogenous influences (but see Alegria, 1975, or Niemi & Näätänen, 1981 for endogenous accounts of sequential effects).

In order to control for potential sequential effects, we made a reanalysis of the data of the reported experiments that included the SOA of the previous trial as a factor, namely “SOA_{n-1}” (the current SOA will be referred to as “SOA”). Thus, the contribution of automatic sequential effects on temporal orienting could be estimated.

The design was then modified to add the SOA_{n-1} factor. Given that catch trials can also contribute to sequential effects, the effect of a catch trial on the subsequent trial was considered in this factor[3]. However, data from the medium SOA and the medium SOA_{n-1} were excluded from the analyses due to insufficient observations. Moreover, only the groups with catch trials were analysed for two main reasons. First, the sequential effects of catch trials could not be

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[4] We thank Sander A. Los for his suggestions on this point.

analysed in the groups without catch trials. On the other hand, as shown by our results, validity effects for both SOAs are better observed in the groups with catch trials.

As stated above, asymmetrical sequential effects would imply an interaction between SOA_{n-1} and SOA such that RTs at the short SOA will be higher for the long than for the short SOA_{n-1}, whereas RTs at the long SOA would not be very different for the long and the short SOA_{n-1}. As said before, the interaction between Temporal Expectancy and SOA will be the hallmark of temporal orienting effects.

Again, analyses were conducted for each task separately. For the detection task, RTs for correct responses were submitted to a repeated measures analysis with SOA_{n-1} (short/long/catch trial), Temporal Expectancy (early/late) and SOA (400/1400 ms) as within-participants variables. For the discrimination task, the analysis also included the Expectancy-Manipulation (between blocks/within blocks) as between-participants variable.

Detection Task.

The detection task analysis included one group with catch trials in which temporal expectancy was manipulated within blocks (Experiment 1.1).

A significant interaction between SOA_{n-1} and SOA [F(2,14)=6.27; p<.01] showed the mentioned asymmetrical sequential effects. As expected, the interaction between Expectancy and SOA was also significant [F(1,7)=20.22; p<.01]. Crucially, the interaction between SOA_{n-1}, Expectancy and SOA was not significant [F(2,14)=1.27; p>.3].

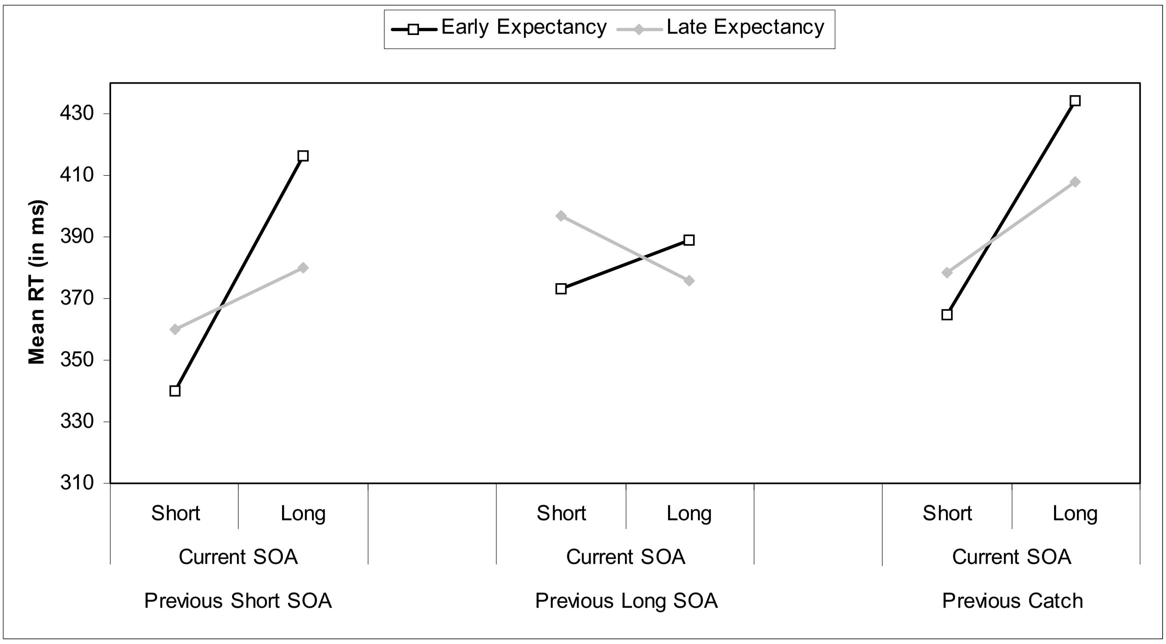

Figure 1.5. *Mean RTs in the detection task as a function of Temporal Expectancy, SOA and the previous trial SOA. Note that the temporal orienting effects were independent of the sequential effects produced by the previous trial SOA.*

As can be seen in Figure 1.5, the validity effects related to intentional temporal expectancies holds separately for the short, the long and the catch trial SOA_{n-1} condition. Therefore, although sequential and temporal orienting effects affected RT, both contributions appear to be independent of each other. This result suggests that endogenous temporal orienting cannot be reduced to explanations based on sequential effects.

Discrimination Task.

The discrimination task analysis included 3 within blocks groups (Experiments 1.1, 1.2 and 1.3) and 2 between blocks groups (Experiments 1.2 and 1.3). All the groups had catch trials.

A significant interaction between SOA_{n-1} and SOA [F(2,70)=13.65; p<.001] replicated the sequential effects obtained in the detection task. Moreover, temporal orienting effects were denoted by the interaction between Expectancy and SOA [F(1,35)=21.23; p<.001]. Importantly, the 3-way interaction between SOA_{n-1}, Expectancy and SOA was again not significant [F(2,70)=1.86; p>.16], as can be observed in Figure 1.6.

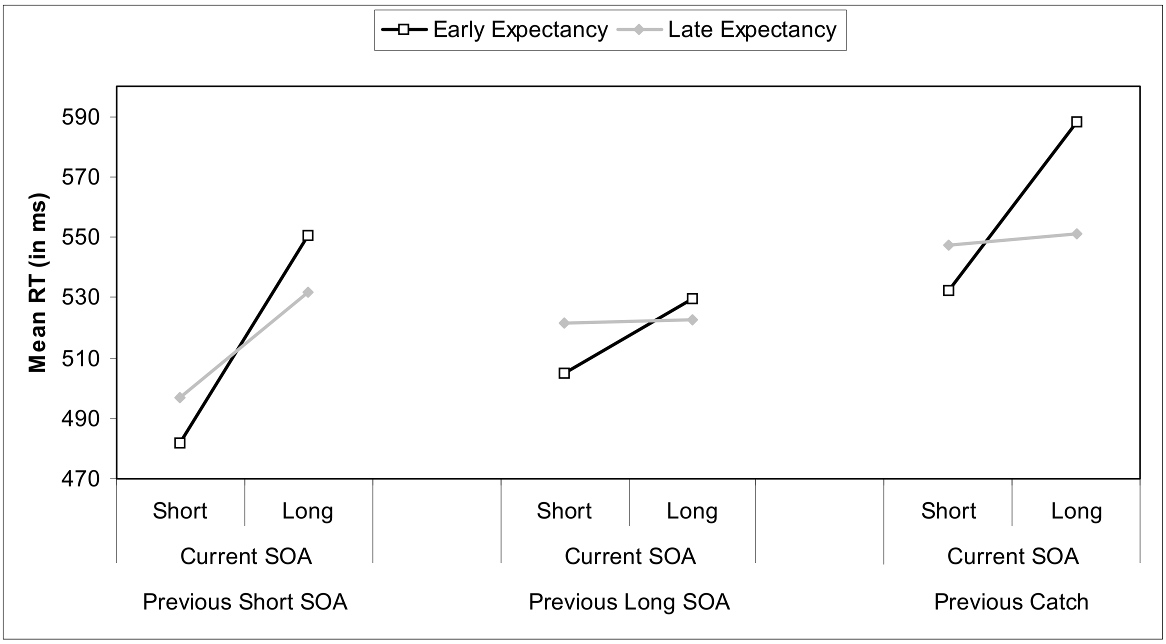

***Figure 1.6**. Mean RT in the discrimination task as a function of Temporal Expectancy, SOA and the previous trial SOA**.** Note that the temporal orienting effects were independent of the sequential effects produced by the previous trial SOA.*

Thus, the findings of the discrimination task replicated those of the detection task, in which temporal orienting effects were observed with independence of the effects produced by the SOA of the previous trial.

Interestingly, data from the discrimination task groups allowed exploring the effect of blocking. The marginally significant interactions between Expectancy-Manipulation, SOA_{n-1} and SOA [F(2,70)=2.79; p<.07], and Expectancy-Manipulation, Temporal Expectancy and SOA [F(1,35)=4.03; p<.05] revealed that the size of both sequential and temporal orienting effects depended on Expectancy-Manipulation. In particular, the size of both effects was larger in the between blocks than in the within blocks groups.

In conclusion, analyses from detection and discrimination tasks disentangled temporal orienting effects related to endogenous processes from other effects more related to automatic processes such as sequential effects. These results provide converging evidence suggesting that temporal orienting effects cannot be adequately explained by non-endogenous accounts based on sequential effects. Therefore, it seems also necessary to consider an endogenous mechanism of attention, which is guided by the participant's expectancies.

General Discussion

The results of the three experiments suggest that uncertainty over whether a target will appear is an important factor in determining whether temporal orienting effects occur for an early expectancy condition. When catch trials are present, they appear to prevent the reorienting of attention to longer intervals on invalid trials. Thus, for the groups without catch trials, the reorienting of attention seemed to eliminate validity effects for the early expectancy condition, and at the long SOA. In this sense, such groups replicated results from studies in which no temporal orienting effects were obtained for an early expectancy condition (Coull et al., 2000; Coull & Nobre, 1998; Coull et al. 2001). For the groups with catch trials, however, uncertainty induced a dispreparation effect, which allowed validity effects to be measured for the early expectancy and long SOA conditions. Thereby, the groups with uncertainty replicated results from studies that reported temporal orienting effects for an early expectancy (Milliken et al., 2003; Miniussi et al., 1999).

Together, the results indicate that uncertainty generated by catch trials modulates temporal orienting effects. Hence, an interesting question concerns exactly how uncertainty over the presence of a target affects processing. We proposed that a dispreparation process occurs when there are catch trials in the experiment and it prevents a reorienting process, thus allowing validity effects to be measured either for both the early expectancy and the long SOA.

With this framework in mind, it is worth considering the data from the late expectancy condition (see Table 1.1: detection task, catch trials group of Experiment 1.1). For the late expectancy, one would expect lower RTs at the long SOA (1400 ms) than at the short SOA (400 ms), if in fact endogenous temporal orienting processes underlie performance. However, note that the RTs were very similar across SOA (376, 378 and 385 ms for the short, medium and long SOA, respectively). This pattern was also observed in other groups with catch trials from

Experiments 1.2 and 1.3, as can be seen in Table 1.2 (between blocks and within blocks groups, respectively). How might this type of results be explained?

We propose that this result was the consequence of two antagonist processes, namely, an orienting process produced by a late temporal cue, which decreased RTs for the long SOA, and a dispreparation process produced by catch trials, which increased RTs. Together, these two processes would produce no effect of SOA in the late expectancy condition. Subsequent experiments that manipulate both temporal expectancy and uncertainty in a graded fashion (e.g., by varying the proportion of catch trials) might provide converging support for this proposal.

On the other hand, no significant temporal orienting effects were observed in the discrimination task of Experiment 1.1. We proposed that this result occurred because endogenous temporal orienting competes for central resources, which are also needed to accomplish the arbitrary S-R mapping used in the discrimination task. According to that, in Experiments 1.2 and 1.3 we eased the resource demands associated with the generation of temporal expectancy by manipulating it between blocks rather than in a trial-to-trial within block manner. Indeed, a more clearly temporal orienting effect was observed when temporal expectancy was manipulated between blocks. We conclude that endogenous temporal orienting in discrimination tasks can occur reliably, but the magnitude of such effects depends critically on how temporal expectancy is manipulated.

Therefore, other noteworthy result is the finding of a factor that clearly determined the size of the temporal orienting effects in our discrimination task. Experiments 1.2 and 1.3 showed that such effects are maximized when temporal expectancy is blocked. We have suggested that the dependency of temporal orienting effects on expectancy blocking might be due to the interference between expectancy generation (on each trial) and the maintenance in working memory of the discrimination task set (arbitrary S-R mapping). Hence, if the expectancy is manipulated within blocks, when the easy S-R mapping for the detection task turned more complex with the discrimination task, temporal orienting effects were not observed (discrimination task of Exp. 1.1) or at least, more difficult to observe (Exp. 1.2 and 1.3 collapsed). Thus, the use of discrimination tasks provided important information regarding the nature of the processes underlying temporal orienting. The fact that such processes could be impaired with increments in other simultaneous demands indicates their controlled nature. It appears that endogenously focusing attention to time is a demanding task in a within blocks context.

Moreover, the finding of temporal orienting effects in a shape discrimination task raises the theoretical question of whether temporal attention affects early or late stages of processing (i.e., modulation of perceptual or motor processing, respectively). Previous research with detection tasks suggest that temporal orienting mainly implies preparation of motor processes (Coull et al., 2000; Coull & Nobre, 1998; Miniussi et al., 1999), whereas the present findings with discrimination tasks might open the possibility that temporal attention also enhances perceptual processes. However, the motor account cannot be ruled out exclusively on the basis on our RT data.

Hence, the use of shape discrimination tasks could be useful to track physiological modulations of perceptual processing produced by temporal attention. It remains possible that cerebral activation patterns normally found in temporal orienting studies (Coull et al., 2000; Coull & Nobre, 1998; Miniussi et al., 1999) are partially due to the specific demands of the task at hand (i.e., detection). Thus, motor areas may be involved in detection tasks, whereas perceptual areas may be more involved in discrimination than in detection tasks.

As a final point, the analyses of sequential effects have revealed the contribution of unintentional factors to temporal orienting or preparation. However, these analyses have also revealed that temporal orienting can occur independently of sequential, unintentional, effects. Therefore, the temporal orienting effects reported here cannot be reduced to a non-endogenous preparation. In conclusion, it is likely that both endogenous and automatic factors contribute to temporal orienting and preparation. The primacy of one in particular might well depend on the specific demands in the context of the experiment.

Chapter 2. The attentional mechanism of temporal orienting: Determinants and attributes

Ángel Correa, Juan Lupiáñez and Pío Tudela

Universidad de Granada. Granada, Spain.

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Abstract

A review of traditional research on preparation and foreperiod has identified strategic (endogenous) and automatic (exogenous) factors probably involved in endogenous temporal-orienting experiments, such as the type of task, the way by which temporal expectancy is manipulated, the probability of target occurrence and automatic sequential effects, yet their joint impact had not been investigated. These factors were manipulated within the same temporal-orienting procedure, in which a temporal cue indicated that the target could appear after an interval of either 400 or 1400 ms. We observed faster reaction times (RTs) for validly versus invalidly cued targets, that is, endogenous temporal-orienting effects. The main results were that the probability of target occurrence (catch-trial proportion) modulated temporal orienting, such that whereas the attentional effects at the short interval were independent on catch trials, at the long interval the effects were only observed when catch trials were present. In contrast, the interval duration of the previous trial (i.e., exogenous sequential effects) did not influence endogenous temporal orienting. A flexible and endogenous mechanism of attentional orienting in time can account for these results. Despite the contribution of other factors, the use of predictive temporal cues was sufficient to yield attentional facilitation based on temporal expectancy.

Keywords

Attention, time perception, discrimination, reaction time, cognition

The ability to process in advance stimulus attributes that could be relevant for adaptive behaviour is a crucial feature of attention. The environment provides implicit and explicit information that can be used to anticipate such attributes. As a result, one can develop attentional preparation, which facilitates subsequent stimulus processing.

Early research searched for the time interval at which preparation was optimal, that is, how much time was necessary to develop a state of maximal preparation. For instance, Woodrow (1914) presented a warning signal to indicate the impending delivery of a target stimulus and manipulated the length of *foreperiod* or stimulus onset asynchrony (SOA), namely, the time interval between the onsets of the warning signal and target. The shortest reaction times (RTs) to detect the target were observed at foreperiod durations of between 2 s and 4 s, suggesting this interval as the optimal foreperiod to reach ‘full attention’.

However, later studies observed that the preparation process had not a fixed temporal course, which could be modulated by several factors such as the type of *task* (see Bertelson, 1967). Thus, simple-RT tasks led to shorter optimal foreperiods than choice-RT tasks, probably due to the fact that the former afforded more anticipatory responses before the target onset than the latter. More recently, Niemi and Näätänen (1981) made an extensive review of the factors involved in the effects of foreperiod on RT. The *between-blocks vs. within-blocks foreperiod manipulation*, *duration of the preceding foreperiod*, *probability of stimulus occurrence* and *frequency of foreperiods of different durations* are some factors on which the present work will focus.

The *between-blocks vs. within-blocks foreperiod manipulation* concerns the way by which foreperiods of different durations are presented in an experiment[5]. In a between-blocks manipulation, different foreperiods are presented in separated blocks of trials. The typical results consist of a lengthening in RTs related to increments in foreperiod duration (e.g., Klemmer, 1956). Klemmer suggested that, whereas short constant foreperiods allowed confident and accurate predictions on the temporal onset of the target, at the long foreperiod these predictions were less accurate, i.e., the time uncertainty was higher (see the scalar theory

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[5] In the experiments reviewed here, the foreperiod durations usually ranged from 0.5 to 16 s

in time perception, Gibbon et al., 1984). On the other hand, in a within-blocks manipulation, different foreperiods are randomly intermixed among trials within the same experimental block. In contrast, the results show that RTs are slower at short foreperiods compared to longer foreperiods (e.g., Klemmer, 1956; Woodrow, 1914). At short foreperiods, uncertainty regarding the forthcoming foreperiod duration could have impaired the accurate timing of the participants' preparation. At long foreperiods, however, the uncertainty produced by foreperiod variability could be reduced using the information provided by the flow of time itself (Elithorn & Lawrence, 1955). Thus, the longer the time for expecting a target, the higher is the probability of its occurrence.

Interestingly, the mixing of trials with different foreperiods led some researchers to investigate *sequential effects*, that is, the effects due to the order of presentation of such foreperiods. Then, the *duration of the preceding foreperiod* showed to be an important factor that modulated RTs in studies on preparation (e.g., Woodrow, 1914). For instance, Granjon and Reynard (1977) found asymmetrical sequential effects, so that RTs were lengthened when the previous foreperiod was longer than the current foreperiod. That is, RTs at a short current foreperiod were slower when the previous foreperiod was long rather than short. This relation was not symmetrical, as RTs at the long current foreperiod were unaffected by the previous foreperiod duration. Hence, sequential effects were also considered to explain the finding of long RTs at short foreperiods in the within-blocks manipulation mentioned above (Klemmer, 1956).

Two main accounts are discussed here to explain sequential effects. One possibility is that that sequential effects are produced by automatic or exogenous factors, i.e., a sort of inertia or repetition priming between the preceding and the current trial (see also Los & Van den Heuvel, 2001, for an explanation based on trace conditioning). In contrast, the strategic or endogenous account of sequential effects considers that participants use the duration of the previous foreperiod to build expectancy concerning the duration of the subsequent foreperiod (e.g., Drazin, 1961; Karlin, 1959; Niemi & Näätänen, 1981). That is, participants anticipate the current foreperiod by expecting a repetition of the previous foreperiod. Then, at the current short foreperiod, RTs are slower when the previous foreperiod was long rather than short, as the target actually appeared earlier than expected (i.e., the participants were "*caught napping*"; Karlin, 1959). At the current long foreperiod, however, RTs are not slower for targets appearing later than expected (i.e., when the previous foreperiod was short rather than long), as a process of repreparation is assumed to occur (e.g., Alegria, 1975; Karlin, 1959). Repreparation consists of developing an additional state of preparation tuned to a long foreperiod once participants realize that target failed to appear at the expected short foreperiod. This leads to similar levels of preparation at the current long foreperiod regardless the duration of the previous one. The repreparation hypothesis has been supported by physiological research (Loveless & Sandford, 1974). Moreover, as will be described below, recent studies concerning the strategic factors in building temporal expectancy have provided further evidence (Correa, Lupiáñez, Milliken, & Tudela, 2004; see also Coull, Frith, Büchel et al., 2000, for neuroimaging evidence).

In relation to the *probability of stimulus occurrence*, Drazin (1961) noted that including a proportion of trials in which the target was not presented (catch trials) could modulate the effects of foreperiod on RT. The use of catch trials in simple-RT experiments was a common practice to minimize the frequency of anticipatory responses. The main result was that increments in the catch trial proportion produced increments in RTs, especially at long foreperiods (Drazin, 1961; Näätänen, 1972). Näätänen suggested that the subjective probability of the expected target occurrence decreases as the foreperiod becomes longer in a context of a catch trial manipulation, which impairs the participants' preparation (i.e., catch trials induce a kind of '*dispreparation'*).

In the final set of studies reviewed here, the *relative frequency of foreperiods of different durations* was manipulated to explore the effects on RT (Baumeister & Joubert, 1969; Zahn & Rosenthal, 1966). In these experiments, short and long foreperiods were randomly presented within a block of trials and their relative proportion was changed across different experimental conditions. The most important finding was a significant interaction between foreperiod proportion and foreperiod duration. At the short foreperiod, RTs were faster when the most frequent foreperiod was short rather than long. However, the effect of foreperiod frequency was not significant at the long foreperiod.

Interestingly, the effect at the short foreperiod was interpreted in terms of variations of temporal expectancy (Zahn & Rosenthal, 1966). Thus, a high probability of short foreperiods induced an early expectancy, so that the preparation process was synchronized to the early target onset. On the other hand, the lack of effects at the long foreperiod could be due to a *floor* effect, in which the repreparation process was involved. That is, the RT enhancement in the condition of the frequent long foreperiod (late expectancy), was obscured by the RT enhancement in the condition of the frequent short foreperiod due to a repreparation to the long foreperiod (i.e., the original early expectancy was disconfirmed and replaced by a late expectancy).

Moreover, note that sequential effects could also be contributing to the results. In fact, the interaction between foreperiod proportion and foreperiod duration resembled the pattern of data described for asymmetrical sequential effects. However, Zahn and Rosenthal (1966) isolated both sequential and foreperiod probability effects by reanalysing the data, such that the duration of the previous foreperiod was held constant. The authors found main effects of the previous foreperiod and foreperiod probability, but no interaction between the two factors, which led them to assume different mechanisms influencing RT.

Taken together, these studies have revealed that several sources of information are used to build up temporal expectancy and to develop attentional preparation for the target arrival in RT experiments. The results suggest that participants are able to reduce uncertainty regarding temporal occurrence of the target by using, more or less explicitly, the available information. For instance, when the target always follows the warning signal after a constant interval (between-blocks manipulations, e.g., Bertelson, 1967; Klemmer, 1956), or the target appears with a high probability at a given interval (within-block manipulations, Baumeister & Joubert, 1969; Zahn & Rosenthal, 1966), the time course of preparation can be modulated to match the point of optimal preparation with the *inferred* moment of target arrival.

Furthermore, if this probabilistic information were not available, participants could use the interval duration of the previous trial to anticipate the actual target arrival (Drazin, 1961; Karlin, 1959). If this information were disconfirmed, for example, by a target appearing later than expected, a repreparation process tuned to that later moment could be triggered then (Alegria, 1975; Karlin, 1959). Finally, the manipulation of the catch-trial proportion also influenced preparation by inducing uncertainty regarding target occurrence. Thus, when participants perceive the target arrival as unlikely in conditions of a high catch-trial proportion, they tend to *relax* their state of preparation (Näätänen, 1972).

Although these observations apparently support the strategic view of preparation, they are not concluding to rule out explanations based on automatic views (Los & Van den Heuvel, 2001). This raises the question of whether temporal expectancy can be intentionally built. In other words, what if participants were explicitly informed about the time they have to wait for the onset of a relevant event? Could they voluntarily use temporal cues to attend to the moment at which an event is expected to occur? Recently, the studies on endogenous temporal orienting of attention have addressed such a question.

Studies on endogenous temporal orienting of attention

The endogenous ability to selectively attend to a particular time interval (i.e., the temporal orienting of attention, Coull & Nobre, 1998) has been studied using a temporal version of the Posner's spatial cuing procedure (Posner et al., 1980). Coull and Nobre presented symbolic cues to indicate with a high probability the temporal interval at which the target was most likely to appear, either '*early'* (after a short interval of 400 ms) or '*late'* (after a long interval of 1600 ms). The SOA was manipulated, such that the target actually appeared either at the validly cued time interval in 80% of trials (valid trials) or at the uncued interval in the remaining 20% of trials (invalid trials). The participants' task was to detect the target onset as fast and accurate as possible.

As observed for spatial attention, RTs were faster for targets appearing at expected intervals (valid trials) compared to unexpected time intervals (invalid trials). This validity effect (so-called 'temporal orienting effect') was restricted to the short SOA, such that RTs were faster for the early cue-short SOA condition compared to the late cue-short SOA condition (see also Kingstone, 1992). As suggested in studies on foreperiod and preparation (Karlin, 1959), the lack of effects at the long SOA was attributed to a process of repreparation (i.e., the reorienting of temporal attention, Coull & Nobre, 1998). The results revealed that participants can modulate the temporal course of preparation according to the temporal expectancy elicited by the cue, at least for a short interval. In contrast, validity effects at the long interval have been rarely observed (but see, Griffin et al., 2001; Milliken et al., 2003).

However, the finding of temporal orienting effects at both short and long intervals would provide more compelling evidence about the flexibility of the attentional orienting mechanism. Then, we conducted a temporal-orienting study (Correa et al., 2004), in which the probability of stimulus occurrence was manipulated by including a catch-trial proportion of .25. The results revealed temporal orienting effects at both the short and long intervals, supporting the flexibility of temporal attention. In particular, validity effects at the long interval were significant only in the group with catch trials (however, the catch x SOA x cue validity interaction was not significant in this study). In the group without catch trials, validity effects at the long interval were presumably obscured by the reorienting of attention. We proposed that the uncertainty regarding target occurrence induced by the presence of catch trials produced a dispreparation effect, similar to that reported in foreperiod studies (Näätänen, 1972). Thus, the reorienting of attention from short to long intervals was impaired as the probability of target occurrence decreased with time in the catch trial group.

From the automatic view of foreperiod sequential effects[6], another fact that could question the endogenous character of temporal orienting was the high similarity between the results of temporal orienting and the results of studies on preparation that manipulated the proportion of different foreperiods (Zahn & Rosenthal, 1966). Indeed, both temporal orienting and foreperiod studies have in common the manipulation of intervals with different durations. Thus, many factors found in studies on preparation (e.g., sequential effects) could play an

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[6] Although the strategic view could also account for sequential effects, we will consider here sequential effects as an automatic contribution to temporal orienting effects, in order to further isolate the endogenous contribution of other strategic factors, such as the role of predictive temporal cues.

important role in the observed temporal orienting effects, in addition to the role of predictive cues. However, the temporal orienting research had not considered the influence of such factors (e.g., see Nobre, 2001, for a review). Then, the automatic view of sequential effects could account for the temporal orienting effects, thus questioning its endogenous nature (Los & Van den Heuvel, 2001).

Correa et al. (2004) found that both automatic sequential effects and endogenous cue validity effects co-occurred in a temporal orienting procedure, but they did not interact. When the SOA of the previous trial was included as a factor (SOA_{n-1}), the results revealed significant validity effects regardless the SOA_{n-1} duration (i.e., the SOA_{n-1} x cue validity interaction was far from significance, $F<1$). Although the conclusions were based in a null effect, the results could suggest that attention can be endogenously directed to a point in time according to the temporal expectancy induced by predictive cues, independently of any effect produced by the previous trial.

The present work further addressed the two mentioned issues concerning the flexible/endogenous functioning of the attentional orienting in time. First, in order to test the flexible nature of temporal orienting we investigated whether validity effects could be observed, not only at a short interval, but also at a long interval. Thus, a more systematic catch-trial manipulation was accomplished by using a broader range of catch-trial proportions than in our previous study (Correa et al., 2004), allowing a finer exploration of the reorienting and dispreparation processes. Then, we expected to observe a significant interaction between catch-trial percentage, SOA and cue validity, such that validity effects at the long SOA were only observed in the groups with catch trials.

Second, in order to test the endogenous nature of temporal orienting, the potential contribution of 'automatic' sequential effects was isolated by manipulating the duration of the preceding interval (see Note 2). If temporal orienting were not merely due to automatic sequential effects, but to endogenous predictive cues, we should observe a main effect of cue validity and no interaction between SOA_{n-1} and cue validity.

Furthermore, the type of task is another factor common to both temporal orienting and traditional studies on preparation. Previous research has found that temporal orienting effects are larger in less demanding tasks (i.e., simple-RT detection) compared to choice-RT discrimination tasks (Correa et al., 2004; see also Griffin et al., 2001). The size of temporal orienting effects also depends on temporal expectancy manipulation (i.e., within-blocks / between-blocks, Correa et al., 2004). These results have been attributed to the controlled nature of the processes involved in endogenous temporal orienting (see Discussion for a detailed explanation). Then, we expected to replicate such effects by observing significant task x cue validity, and expectancy manipulation x cue validity interactions.

In sum, the cue validity, catch-trial percentage, SOA duration of the previous trial, task and expectancy manipulation factors were manipulated within the same procedure to have a comprehensive understanding of the temporal orienting mechanism.

EXPERIMENT 1.4

Method

Participants

One hundred and twenty-eight students of psychology took part in the experiment for course credit. All participants gave informed consent prior to their inclusion in the study, which was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. There were 16 groups composed of 8 participants each, given by the factorial combination of the three between participants variables: catch-trial percentage (0%, 12.5%, 25% and 50% catch trials), task (detection vs. discrimination) and expectancy manipulation (within-blocks vs. between-blocks)[7].

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[7] Data from four groups of the discrimination task (within-blocks and between-blocks groups by the 0% and 25% catch trial groups) were already reported in a previous article (Correa et al., 2004)

Apparatus and stimuli

The presentation of stimuli and data collection were controlled using MEL software (W. Schneider, 1988). The experiment was run on a PC connected to a 14-in. monitor. All the stimuli were presented at the centre of the screen. The fixation point consisted of a “+” symbol. The temporal cue was either a short bar (0.38º x 0.95º of visual angle at a viewing distance of 60 cm) or a long bar (0. 38º x 2.1º). The short bar indicated that the target would appear early (after 400 ms). The long bar indicated that the target would appear late (after 1400 ms). The target was either the letter ‘O’ or the letter ‘X’ (0.38º x 0.76º). The two target letters appeared with a probability of .50. In the detection task groups, the participants pressed the ‘B’ key when either an ‘O’ or an ‘X’ appeared. In the discrimination task groups, participants pressed the ‘Z’ key for one target and the ‘M’ key for the other target. The assignment of targets to response keys was counterbalanced across participants within each group.

Procedure

The participants sat approximately 60 cm from the screen. They were instructed to respond as quickly and accurately as possible, and to use the temporal cue to anticipate the moment of target onset. Auditory feedback (a 400-Hz tone of 100 ms) was provided on error trials. The sequence of events in a trial is depicted in Figure 2.1. The fixation point was displayed in black on a gray background for a random duration of 500-1500 ms. The temporal cue appeared for 50 ms. Next, the screen remained blank for a variable delay of 350, 850, or 1350 ms depending on the SOA for that trial. The target was displayed for 100 ms and was then replaced by a blank screen until the participant made a response. Then, the next trial began. When no response was made, the next trial began after a delay of 2000 ms.

The experiment consisted of one block of 64 practice trials and four blocks of 128 experimental trials. There was a 1-min interruption for rest at the end of each block. Half of the participants (i.e., the between-blocks group) were presented two experimental blocks with an expect-early cue and two blocks with an expect-late cue.

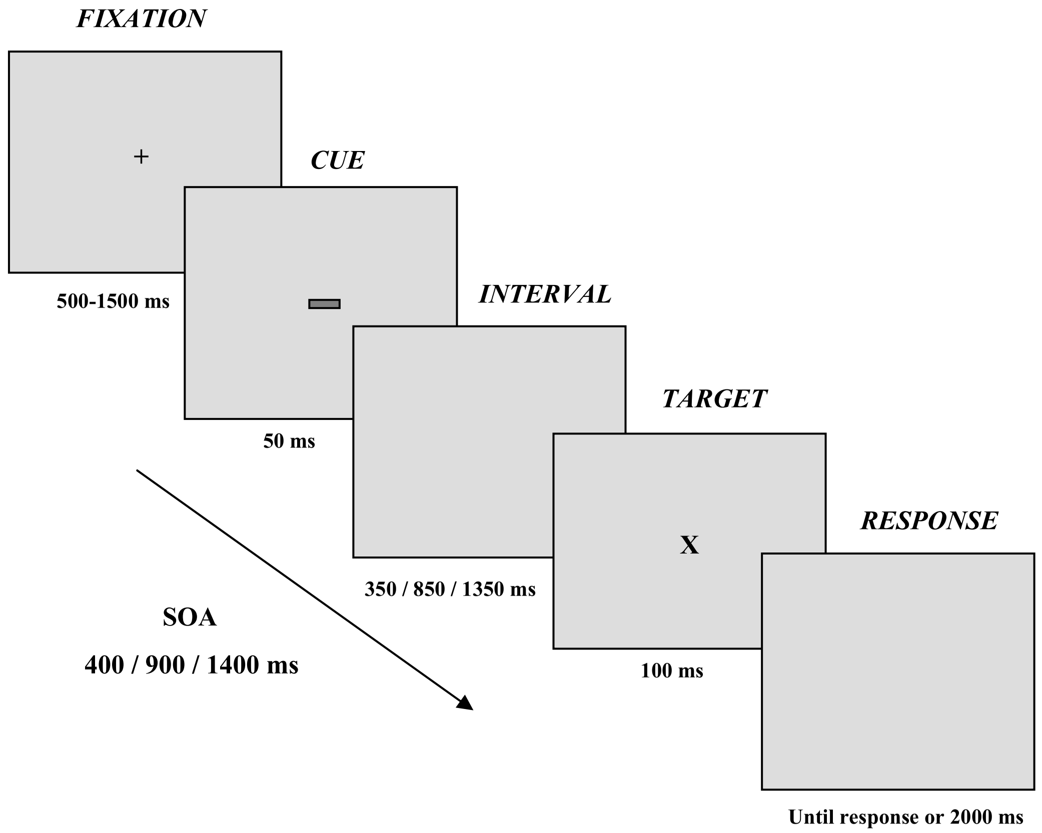

Figure 2.1. *Sequence of events in a trial.*

The order of presentation of these blocks was counterbalanced. In the within-blocks group, early cues and late cues were randomly intermixed among trials. Each experimental block consisted of 96 valid trials and 32 invalid trials, resulting in a validity proportion of .75. On half of the valid trials, the cue indicated that the target was likely to appear *early*, and the target appeared at the short SOA (i.e., 400 ms after cue onset). On the remaining half of the valid trials, the cue indicated that the target was likely to appear *late*, and the target appeared at the long SOA (i.e., 1400 ms after cue onset). The invalid trials were also equally distributed between SOAs. Thus, all the trials at the medium SOA (850 ms) were invalid[8]. The groups with

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[8] The medium SOA data were not included in the analyses due to insufficient observations in some experimental conditions (e.g., in the 50% catch trials group). The medium SOA has been previously used to make trend analyses in the RT function, in order to explore whether the attentional resources are

catch trials comprised a proportion of trials in which the target was not presented (i.e., 16, 32 and 64 trials for the 12.5%, 25% and 50% catch trials groups, respectively), holding constant the valid/invalid trial ratio to 3:1.

Results

Trials with correct responses faster than 100 ms (1.89%) or slower than 1000 ms (1.07%), incorrect discrimination responses (3.52%), and the first trial of each block were excluded from the RT analyses. Table 1 shows the mean RTs for each experimental condition. Mean RTs were submitted to a mixed factor analysis of variance (ANOVA) with SOA (short/long) and cue validity (valid/invalid) as within-subjects variables, and task (detection/discrimination), expectancy manipulation (between-blocks/within-blocks) and catch-trial percentage (0/12.5/25/50) as between-subjects variables.

The main effect of task was significant, $F(1,112)=143.69$; $p<.001$, revealing faster RTs for the detection task compared to the discrimination task. The increase of catch-trial percentage (also referred to as ‘catch’) progressively lengthened RTs, $F(3,112)=10.64$; $p<.001$, following a linear trend ($p<.001$) rather than a quadratic trend ($p=.14$). The main effect of SOA showed faster RTs at the short SOA compared to the long SOA, $F(1,112)=7.85$; $p<.01$. Importantly, a significant effect of cue validity showed that valid trials yielded faster RTs than invalid trials, $F(1,112)=233.88$; $p<.001$.

The interaction between task and cue validity was marginally significant, $F(1,112)=3.36$; $p=.07$, suggesting larger validity effects in the detection task (34 ms; $p<.001$) relative to the discrimination task (27 ms; $p<.001$). The interaction between expectancy manipulation and cue validity was significant, $F(1,112)=67.6$; $p<.001$, such that validity effects were larger in the between-blocks groups (46 ms; $p<.001$) compared to the within-blocks groups (14 ms; $p<.001$). The significant interaction between catch and SOA (see Figure 2.2),

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assigned to specific moments in time in a gradual manner. Hence, the medium SOA did not provide relevant information for the purposes of the present study.

$F(3,112)=33.14$; $p<.001$, revealed that in the condition without catch trials (0%), RTs at the long SOA were faster than at the short SOA ($p<.001$; i.e., the reorienting effect). In contrast, the conditions with catch trials (12.5%, 25% and 50%) showed that RTs at the long SOA increased with increments in catch-trial proportion (all *ps*<.02; i.e., the dispreparation effect).

Table 2.1. *Mean correct response times (in ms) for catch-trial percentage (%), task and expectancy manipulation as between-subjects variables, and for SOA and cue validity as within-subjects variables.*

CATCH-TRIAL %	**TASK**	**EXPECTANCY MANIPULATION**	**SHORT SOA**		**LONG SOA**	
			Valid	**Invalid**	**Valid**	**Invalid**
0%	**Detection**	**Within-blocks**	350	396	337	340
		Between-blocks	350	447	333	350
	Discrimination	**Within-blocks**	457	470	449	455
		Between-blocks	455	546	471	477
12.5%	**Detection**	**Within-blocks**	365	393	390	395
		Between-blocks	368	456	382	428
	Discrimination	**Within-blocks**	496	498	506	513
		Between-blocks	508	573	552	578
25%	**Detection**	**Within-blocks**	428	431	453	464
		Between-blocks	367	426	405	426
	Discrimination	**Within-blocks**	503	520	521	530
		Between-blocks	454	520	498	525
50%	**Detection**	**Within-blocks**	406	415	416	450
		Between-blocks	409	457	452	480
	Discrimination	**Within-blocks**	533	551	547	561
		Between-blocks	497	516	522	561

The interaction between SOA and cue validity, $F(1,112)=25.19$; $p<.001$, showed larger validity effects at the short SOA (42 ms, $p<.001$) than at the long SOA (18 ms, $p<.001$). Interestingly, this SOA x cue validity interaction was modulated by catch-trial percentage, $F(3,112)=6.91$; $p<.001$. Figure 2.2 depicts the effect of catch-trial percentage on RT as a function of SOA and cue validity. According to our predictions, the catch x SOA x cue validity interaction was further analysed by focusing on the validity effects at the long SOA within each catch-trial condition. The analyses revealed that the 0% catch-trial was the only condition that did not show validity effects at the long SOA ($p>.17$). In contrast, the 12.5%, 25% and 50% catch-trial conditions all showed significant validity effects at the long SOA (all $ps<.01$).

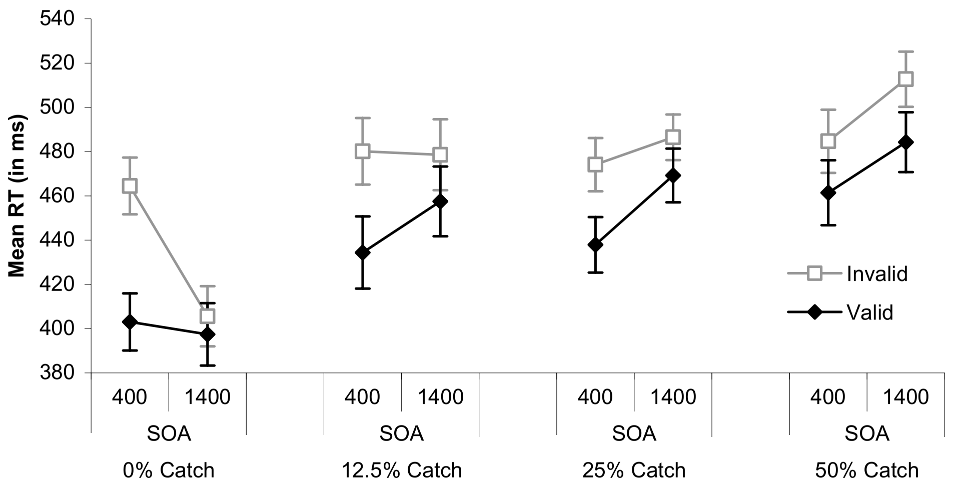

Figure 2.2. *Mean RTs as a function of catch-trial percentage, SOA and cue validity. The vertical bars represent the standard error of the mean.*

Also, we further compared the validity effects at the long SOA across catch-trial conditions and the effects were not significantly different between the three conditions with catch trials ($p=.4$). Importantly, however, the effects in the three conditions with catch trials were significantly different from to the condition without catch trials ($p<.04$). Moreover, the analyses of validity effects at the short SOA were significant in all the four catch-trials conditions (all $ps<.001$).

The interaction between task, catch and SOA, $F(3,112)=2.84$; $p<.05$, suggested that the reorienting effect, as indexed by the catch x SOA interaction (see above), was more pronounced in the detection task, $F(3,56)=20.35$; $p<.001$, than in the discrimination task, $F(3,56)=13.40$; $p<.001$.

Other significant three-way interactions (that were less relevant to the main point here) showed that the effect of blocking expectancy on validity effects, as revealed by the expectancy manipulation x cue validity interaction, depended on catch-trial percentage, $F(3,112)=2.75$; $p<.05$, such that the interaction was significant in the 0%, 12.5% and 25% catch-trial conditions (all $ps<.001$), but marginally significant in the 50% catch-trial condition ($p=.07$). Thus, the effect of blocking expectancy on validity effects seemed to be attenuated when catch trials were extremely frequent. This expectancy manipulation x cue validity effect also depended on the SOA, $F(1,112)=14.23$; $p<.001$, showing that the effect seemed more pronounced at the short SOA, $p<.01$, than at the long SOA, $p<.001$ (see Table 2.1 for further details).

The overall accuracy in the discrimination task was of 97.2%. A similar ANOVA to that preformed on RTs was performed on accuracy data. The only difference was that the detection task groups were not included, as they lacked incorrect discrimination responses. The main effect of SOA, $F(1,56)=6.38$; $p<.01$, was the only significant effect, revealing that discrimination responses were more accurate at the short SOA than at the long SOA.

Sequential effects analysis

The analysis of sequential effects consisted of a repeated-measures ANOVA with SOA_{n-1} (short/long/catch trial), SOA (short/long) and cue validity (valid/invalid) as variables. The between-subjects factors were not included in the analysis, in order to increase the amount of trials for each experimental condition and to simplify the design[9]. Then, the analysis focused on the effect of the previous SOA duration on temporal orienting. Data from the 0% catch-trial group were not included, given that this group lacked the SOA_{n-1} - catch trial condition.

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[9] The manipulation of the between-subjects factors (e.g., the task) did not reverse the cue validity effects, rather it modulated the size of the effect (see results above, and also Correa et al., 2004). Thus, the analysis by combining the groups did not qualitatively change the main results.

The main effect of SOA_{n-1} was significant, $F(2,154)=27.25$; $p<.001$, yielding the fastest RTs when the previous SOA was short and the slowest RTs when the previous trial was a catch trial. Replicating the analysis above, the main effects of both SOA and cue validity, and the SOA x cue validity interaction were significant, $F(1,77)=23.31$; $p<.001$, $F(1,77)=68.57$; $p<.001$ and $F(1,77)=4.87$; $p<.05$, respectively.

The interaction between SOA_{n-1} and SOA revealed sequential effects, $F(2,154)=17.24$; $p<.001$ (see Figure 2.3). At the short current SOA, RTs were faster when the SOA_{n-1} was short either compared to the long SOA_{n-1} ($p<.001$) or the catch-SOA_{n-1} ($p<.001$). In contrast, the effect reversed at the long current SOA, such that RTs were faster when the SOA_{n-1} was long either compared to the short SOA_{n-1} ($p<.05$) or the catch-SOA_{n-1} ($p<.001$).

More importantly for present purposes was that the SOA_{n-1} x cue validity and SOA_{n-1} x SOA x cue validity interactions were far from significance ($F=.17$ and $F=.58$). As can be seen in Figure 2.3, validity effects were significant independently of the previous SOA.

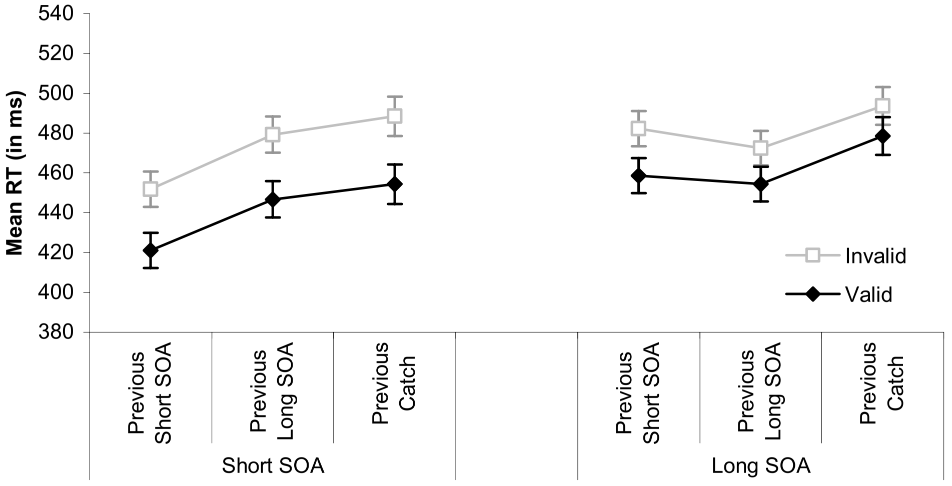

Figure 2.3. *Mean RTs as a function of the SOA of the previous trial, the current SOA and cue validity. The vertical bars represent the standard error of the mean.*

Discussion

The basic finding of a robust effect of *cue validity* suggests that participants can enhance RT performance by attending to the relevant moment indicated by the temporal cue. However, in most of the temporal orienting research, this effect had not been consistently observed to co-occur for intervals of several durations, which questioned the flexible character of temporal orienting. The lack of validity effects at long intervals has been attributed to a reorienting process (Coull & Nobre, 1998). This process is engaged when participants realize that the target did not appear at the early cued interval, so that they reorient their attention to a later interval. Then, participants are similarly prepared for a late target onset regardless the cue was early or late.

Despite the physiological evidence supporting the reorienting of attention (Coull, Frith, Büchel et al., 2000; Loveless & Sandford, 1974), this process had not been directly manipulated to study its influence on temporal orienting. Note that reorienting makes sense only when the certainty about target occurrence is high. In order to test this hypothesis, we manipulated the reorienting process by varying the probability of target occurrence. Our prediction was that the inclusion of catch trials would impair reorienting, in such a way that validity effects would then be observed at the long SOA. Previous experiments somehow supported this idea (e.g., Milliken et al., 2003), although without statistical significance (Correa et al., 2004).

In the experiment reported here, the systematic manipulation of *catch trials percentage* revealed a significant interaction between catch-trial percentage, cue validity and SOA, which further supported the reorienting hypothesis. The catch x SOA interaction showed that RTs increased at the long SOA with higher catch-trial proportions (see Figure 2.2). Importantly, just the groups with catch trials (12.5%, 25% and 50%) showed significant validity effects at the long SOA. In contrast, the 0% catch-trial condition showed faster RTs at the long SOA compared to the short SOA, presumably due to the reorienting process, and this was the only condition that did not show validity effects at the long SOA. Therefore, we propose that the target-occurrence uncertainty induced by catch trials produce a dispreparation effect that impairs reorienting, as deduced by the RT increments at the long SOA. According to the strategic view of studies on foreperiod, the state of preparation was weakened as the subjective probability of the expected target occurrence decreased at long foreperiods in a context of catch trials (Näätänen, 1972). In sum, the inclusion of catch trials afforded to observe temporal orienting effects at the long SOA, as well as at the short SOA, which further supports the flexibility of the attentional mechanism involved.

The marginal effect of *task* on temporal orienting was in line with previous research (Correa et al., 2004; Correa, Lupiáñez, & Tudela, in press), in which validity effects were smaller for discrimination than for detection tasks. This result was attributed to the fact that endogenous temporal orienting involves controlled processing (e.g., underlying processes of time perception, see Brown, 1985), and that the demands to maintain in working memory the task-set are higher for the discrimination task (i.e., an arbitrary mapping between stimuli and responses) than for the detection task. Thus, the increment in central resources demands engaged by the discrimination task could difficult the building up of temporal expectancy.

However, a robust interaction between task and cue validity is not easy to be observed, as temporal orienting effects are normally significant for both tasks (e.g., Correa et al., in press). Future research either including within-subjects manipulations of the task, or manipulating the working memory load within the same task might provide more consistent evidence to this hypothesis. In any case, the finding of significant effects in both tasks is interesting *per se*, as implies a general mechanism of attentional orienting that is not constrained to a particular task.

As previously reported, the effect of *blocking expectancy* increased the size of temporal orienting effects (Correa et al., 2004). This result is also consistent with an explanation based on the demands of attentional resources. In between-blocks groups, the continuous building of temporal expectancy for each new trial was unnecessary, given that it remained constant across a block of trials. In contrast, the variations of temporal expectancy in the within-blocks manipulation increased the attentional demands, leading to hindered temporal orienting effects. Converging evidence can be found in other studies that combined demanding discrimination tasks either with a between-blocks manipulation (Correa, Lupiáñez, Madrid, & Tudela, submitted) or a between-subjects manipulation (Milliken et al., 2003) and reported unusually large validity effects.

The manipulation of the *SOA_{n-1} duration* was critical to disentangle endogenous temporal orienting (elicited by predictive cues) from automatic sequential effects (produced by the SOA_{n-1} duration). The results showed the typical pattern of sequential effects, as revealed by the interaction between SOA_{n-1} and SOA, and the typical pattern of endogenous temporal orienting, as revealed by the main effect of cue validity (see Figure 2.3). Crucially, the SOA_{n-1} x cue validity and the SOA_{n-1} x SOA x cue validity interactions were far from significance ($Fs<1$), suggesting that sequential effects and temporal orienting trigger independent processes. As can be seen in Figure 2.3, RTs were faster for valid versus invalid cues, and this validity effect was observed either when the previous trial was a short SOA, a long SOA or a catch trial. This result replicated previous research, in which the SOA_{n-1} x cue validity interaction was also far from significance (Correa et al., 2004). Similarly, Zahn and Rosenthal (1966) reported main effects of both the previous foreperiod factor and the foreperiod probability factor, but no interaction between them. Taken together, the results suggest that predictive cues can be used to intentionally build temporal expectancy and to modulate the temporal course of preparation to achieve a matching with the expected relevant moment, regardless the automatic contribution of sequential effects to preparation.

As a general conclusion, the present work has provided an essential link between the research on temporal orienting and the traditional research on foreperiod and preparation. Several factors that showed to modulate the preparation process in RT experiments, and other factors that were found to influence temporal orienting effects in previous research (Correa et al., 2004; Correa et al., in press; Griffin et al., 2001; Milliken et al., 2003), were included within the same temporal-orienting procedure in order to obtain a more complete picture of the temporal orienting phenomenon.

The reviewed studies and the results reported here suggest that a predictive temporal cue is not the only source of information that people use to build expectancy, that is, to anticipate the critical moment of the onset of a relevant event. Rather, people are sensitive to several contingencies, more o less explicit, which are inherent to the context of a temporal orienting experiment. For instance, some of the factors involved concern the time certainty regarding target onset in designs with constant foreperiods (Bertelson, 1967; Klemmer, 1956); the information provided by the flow of time itself (Elithorn & Lawrence, 1955); the temporal information provided by the duration of the time interval of the previous trial, according to the strategic view (Drazin, 1961; Karlin, 1959; Niemi & Näätänen, 1981) or the exogenous influence of sequential effects, according to the automatic view (Los & Van den Heuvel, 2001); and the probability of stimulus occurrence (Drazin, 1961; Näätänen, 1972).

Additional factors, such as the task demands and the way by which temporal expectancy was manipulated in the experimental blocks modulated the process of preparation, mainly determining the size of temporal orienting effects. We propose that these two factors determine the amount of central resources available to control the endogenous process of preparation. Thus, in a highly demanding context, the ability to gain attentional benefits by attending to a particular point in time seems hindered. It could be that not only the processes of building and maintaining temporal expectancy in working memory became impaired (Correa et al., 2004), but also the time estimation processes necessary for temporal orienting could suffer from higher inaccuracy in highly demanding conditions (Brown, 1985).

To summarize, we conclude that the attentional mechanism by which people can anticipate and control their preparation for a critical moment depends on several factors that determine its functioning. The crucial strategic factor we have found is the predictive value of a temporal cue. That is, the effectiveness of the cue to endogenously induce confident temporal expectancies about the future occurrence of stimuli, allows the strategic development of states of optimal preparation synchronised to the most probable moment of occurrence of the stimuli. As suggested by the results, the use of predictive temporal cues is sufficient *per se* to yield attentional facilitation in behavioural performance.

The probability of stimulus occurrence is, however, also a determining factor of the temporal orienting mechanism. The results, showing that the catch-trial proportion modulated endogenous temporal orienting, suggest that people consider this probabilistic information to strategically develop the preparation most appropriate to the specific situation. For instance, when participants have the confident prediction that the stimulus will occur, sooner or later, the relevance of being prepared is sufficiently high to engage a reorienting process in case the initial early expectancy was disconfirmed. In contrast, when participants notice that the stimulus do not always occur (i.e., in a context of catch trials), their overall level of preparation decreases with lower *a priori* probabilities of stimulus occurrence. Furthermore, the dynamic process of preparation triggered in a specific trial decreases as the time without stimulus arrival increases (i.e., the dispreparation process), according to the fact that the conditional probability of occurrence decreases with time in the catch-trial conditions. Thus, the systematic manipulation of the catch-trial proportion has uncovered some neglected aspects in temporal orienting research regarding the functioning of the reorienting and dispreparation processes.

The last important factor investigated in the present research is the contribution of sequential effects to temporal orienting. The sequential effects produced by the duration of the preceding interval also influence the dynamic process of preparation in a current trial. However, such effects can be dissociated from the strategic preparation based on predictive temporal cues, which suggests the independence of these two processes involved in preparation. In fact, some authors consider the preparation triggered by sequential effects as unspecific, that is, an exogenous process driven by the stimulus (Los & Van den Heuvel, 2001).

The distinction between exogenous and endogenous attention is classical from the very origin of research on attention (James, 1890). More recently, studies on spatial orienting of attention have isolated specific features for both exogenous and endogenous mechanisms to commit attention to particular locations in space (e.g., Müller & Rabbitt, 1989). Analogously, it makes sense to assume exogenous and endogenous ways to commit attention to particular instants in time (see Coull, Frith, Büchel et al., 2000 for a different approach). This assumption accounts well for the present findings, such that sequential effects trigger exogenous preparation whereas predictive temporal cues trigger endogenous preparation. Then, a logical corollary that can be deduced is that factors that impair endogenous preparation should not necessarily affect exogenous preparation. Indeed, a further analysis revealed that the task and blocking temporal expectancy factors, which modulated endogenous preparation, had no effect on exogenous preparation produced by sequential effects (p=.16 and F<1, respectively). Thus, the demands on central processing impaired endogenous temporal orienting effects rather than exogenous sequential effects.

Certainly, there are other ways to induce exogenous temporal preparation, such as the induction of visual rhythms by presenting objects moving at a constant pace (Correa & Nobre, submitted; Doherty et al., in press) or the induction of auditory rhythms by presenting sounds at regular frequencies (Jones et al., 2002). A challenging research issue for the future could be to specify the characteristics of exogenous and endogenous temporal preparation and to compare them to those of exogenous and endogenous spatial attention.

Concerning the neural basis of the temporal orienting mechanism, neuroimaging studies have revealed a frontoparietal network of areas lateralised to the left hemisphere, including the inferior parietal and premotor cortices (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998). Moreover, event-related potential studies have found a negative electrophysiological component which is related to the intention of being prepared for an impending stimulus, that is, the contingent negative variation (CNV, Walter, Cooper, Aldridge, McCallum, & Winter, 1964). Interestingly, recent electrophysiological research shows that the temporal course of the CNV component can be flexibly modulated according to the temporal expectancies induced by predictive cues (Correa et al., submitted; Griffin et al., 2002; Miniussi et al., 1999), so that the point of maximal preparation (as indexed by the CNV) is time-locked to the expected stimulus onset. This result provides a clear link between this electrophysiological component and the preparation process concerned here. Once identified the key brain correlates of preparation, it would be interesting to explore whether different neural mechanisms underlie the dissociation we have established between exogenous and endogenous preparation.

To conclude, the present work has dissociated exogenous and endogenous factors involved in temporal orienting. The manipulation of such factors has revealed relevant attributes of this attentional mechanism, such as the flexible, strategic and controlled nature of the temporal orienting processes. Moreover, this work has specified suitable experimental conditions to observe robust temporal orienting effects in future research. Finally, the finding of several sources of temporal predictability has implications for RT experiments, especially for those in which the time interval between two stimuli is manipulated.

Series II: Does temporal attention modulate psychophysical indexes of perceptual processing?

Chapter 3. Attentional preparation based on temporal expectancy modulates processing at a perceptual-level.

Ángel Correa, Juan Lupiáñez and Pío Tudela

Universidad de Granada

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Abstract

Research based on simple RT tasks and neuroimaging emphasize that attentional preparation based on temporal expectancy modulates processing at motor levels. A novel approach was taken to study whether temporal orienting of attention can also modulate perceptual processing. A temporal cueing paradigm was used together with a Rapid Serial Visual Presentation procedure, in order to maximize the processing demands of perceptual analysis. Signal Detection Theory was applied to examine whether temporal orienting affects processes related to perceptual sensitivity or to response criterion (indexed by d' and beta measures, respectively). If temporal orienting implied perceptual preparation, we would expect to observe an increase in perceptual sensitivity (d') when the target appeared at expected rather than unexpected time intervals. Indeed, our behavioural results opened the possibility that focusing attention on time intervals not only enhances motor processing, as shown by previous research, but might also improve perceptual processing.

The environment continuously provides spatial and temporal information, which can be used to generate expectancies about when and where a relevant event will occur. Thus, expectancy helps us to develop a state of preparation in advance of the occurrence of stimuli, so that attention can be focused on the specific locations and moments at which stimuli are expected to occur. In this way, intelligent animals have some ability to predict the future, that is, to anticipate where and when an event will occur.

Attentional preparation based on expectancy generally implies two processes. First, sensory receptors and attention can be oriented to the expected place and moment, which improves stimulus perception. This improvement consists of an increase of the speed and/or accuracy of perceiving such stimuli. Moreover, preparation allows the anticipation of reactions to stimuli, in order to trigger a response as soon as they occur.

Concerning spatial attention, studies that used Posner’s Costs and Benefits paradigm (Posner et al., 1980) have shown that spatial expectancy influences processing. This attentional modulation can be deduced from faster and/or more accurate responses, and from amplification of visual evoked potentials, for targets appearing at expected locations (see Mangun, 1995, for a review). Hence, such results are often interpreted in terms of a perceptual preparation based on spatial expectancy.

Concerning temporal attention, it has also been found that RTs are faster when there is a match between the temporal expectancy for a target (early/late) and the time interval (short/long) at which the target actually appears, compared to RTs when they mismatch (see Nobre, 2001. for a review). This so-called ‘temporal orienting effect’ (Correa et al., 2004) is reliably found in detection tasks that used a temporal cueing paradigm.

At present, however, it still remains unclear whether temporal orienting effects are produced by perceptual preparation, motor preparation or both. Indeed, behavioural data based on classic RT experiments do not address this question appropriately, as perceptual and motor preparation have the same effect, that is, to decrease RT. On the other hand, studies that used physiological measures with detection tasks support the motor account of preparation (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998; Griffin et al., 2002; Miniussi et al., 1999).

However, it could be argued that the cerebral activation patterns observed in temporal orienting studies might be partially due to the specific demands of the task used. Thus, motor areas may be involved mainly in detection tasks, whereas perceptual areas may be more involved in other tasks, such as discrimination. Discrimination tasks demand a more detailed perceptual analysis than detection tasks, as processing of idiosyncratic features of the target is required. In contrast, detection tasks only demand a speeded response as soon as the target onset is detected regardless of its visual features.

Thus, some of us have conducted several RT experiments in which a discrimination task was used instead of a detection task (Correa et al., 2004; Milliken et al., 2003). However, the finding that temporal expectancy facilitated stimulus discrimination is insufficient to support that temporal orienting produces perceptual preparation, since it could be argued that facilitation in discrimination tasks is produced by motor preparation of the two possible responses (Nobre, 2001).

In order to overcome this problem we designed the present behavioural experiment, in which a good perceptual analysis of the target was essential to accomplish the task. We were interested in conditions that make the perception of the target difficult, in which accuracy is more important than the speed of the participant's responses, in order to discard motor preparation influences (see also Nobre, 2001). It is assumed that, if stimulus perception were improved by temporal expectancy in these difficult perceptual conditions without time pressure, this would suggest that temporal attention enhances perceptual processing.

How could these conditions of difficult perception be achieved? One possibility is to mask the target, so that its percept cannot be completely built by the visual system. Consequently, a Rapid Serial Visual Presentation (RSVP) procedure was used. This procedure consists of a very fast succession of stimuli presented at the same location of the screen. Given that stimuli occur very fast, they mask each other and the perception of the target becomes quite difficult.

However, it makes sense to expect that it is possible to override some masking effects if attention is focused on the target (Enns & Di Lollo, 1997). Specifically, this strategy is encouraged through cueing the likely time of occurrence. Given that the RSVP does not allow attention to be directed to each item individually, a temporal cue would improve performance by indicating the best temporal window in which to search for the target.

If temporal orienting exclusively implied motor preparation, we would not expect to observe temporal orienting effects in accuracy measures, as preparation for a speeded response is not relevant for this task. However, if temporal orienting implies perceptual preparation, we would expect to observe temporal orienting effects in accuracy measures, as preparation for an enhanced perception of the target is essential for this task.

Signal Detection Theory (SDT) was applied to analyze data. SDT provides two orthogonal indices that determine the observer's dichotomic decisions about a perceptual event under conditions of high uncertainty. The *d'* index is related to perceptual sensitivity, whereas the *Beta* index is related to response criterion (Green & Swets, 1966). High values of d' mean high perceptual sensitivity. High values of beta mean a strict criterion, whereas low values of beta mean a lax criterion. Then, the following predictions are based on the assumption that d' is a reliable index of perceptual sensitivity.

If temporal orienting enhances perceptual processing, we should expect perceptual sensitivity (d') to be affected by temporal expectancies, in particular, higher d's for targets appearing at validly rather than at invalidly cued time intervals.

Furthermore, an extra manipulation was incorporated. One group of participants were to identify the letter "X" in the RSVP stream (single-target task), whereas participants in the other group were to identify either an "X" or an "O" (double-target task). Previous research carried out in our laboratory (Correa et al., 2004) has shown that when temporal expectancy is manipulated on a trial-by-trial basis, as in present experiment, temporal orienting effects were larger in simple-RT (detection) than in choice-RT (discrimination) tasks. Such differences were attributed to the difficulty of generating a temporal expectancy, while maintaining in working memory the more complex task-set for the discrimination task (i.e., an arbitrary mapping between stimuli and responses). Thereby, we have proposed that the online generation of temporal expectancy requires controlled processing, which can be impaired as other demands on central resources increases.

In the present experiment, we further tested this hypothesis by manipulating the task-set demands, while holding constant the sensory input for both tasks. Assuming that the identification task was less demanding for a single target than for double targets, given that only one vs. two perceptual templates had to be maintained in Working Memory, we expected to observe larger temporal orienting effects in the former task.

Method

Participants

120 students of Psychology from the University of Granada participated voluntarily. They were divided in two groups (Experiment 3.1) and four groups (Experiment 3.2) of 20 participants each[10]. Participants were randomly assigned to the groups, and performed the task in a room equipped with 15 computers.

Apparatus and stimuli

MEL software (W. Schneider, 1988) controlled the experiment. All stimuli appeared in the centre of a 15-inch monitor. They were a temporal cue, a set of distractors and a target. The temporal cue was a red rectangle, 4mm in height (0.38º of visual angle). Its width was either 10mm or 22mm (0.95º and 2.1º). The distractors were a set of 24 letters of a standard keyboard, excluding the targets. The target was the letter 'X' for the single-target group, and either the letter 'O' or the letter 'X' for the double-target group. The distractors and target were 24x24 pixels (0.95º x 0.95º) in size. In the single-target group, participants pressed one key ("Z" or "M") if the target ("X") was presented, and the other if the target was absent. In the double-

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[10] The four groups of Experiment 3.2 were collapsed in two: single-target and double-target task. Originally, the X-target frequency was manipulated to explore changes in response criterion, as follows: two groups of .50 in Experiment 3.1, and two groups of .25 and .75, respectively, in Experiment 3.2. However, the detailed results are not reported here, as this manipulation was a secondary aim of the study and no clear results were obtained.

target group, participants pressed one of the same two keys depending on whether the ‘X’ target or the ‘O’ target was presented. The assignments were counterbalanced across participants.

Procedure

Participants sat approximately 60cm in front of the screen. They were informed that the temporal cue would help them to predict when the target would appear, and encouraged to respond as accurately as possible. However, they were not asked to make speeded responses.

The temporal cue appeared for 750 ms, and was followed by a fast stream of 43 letters (see Figure 3.1).

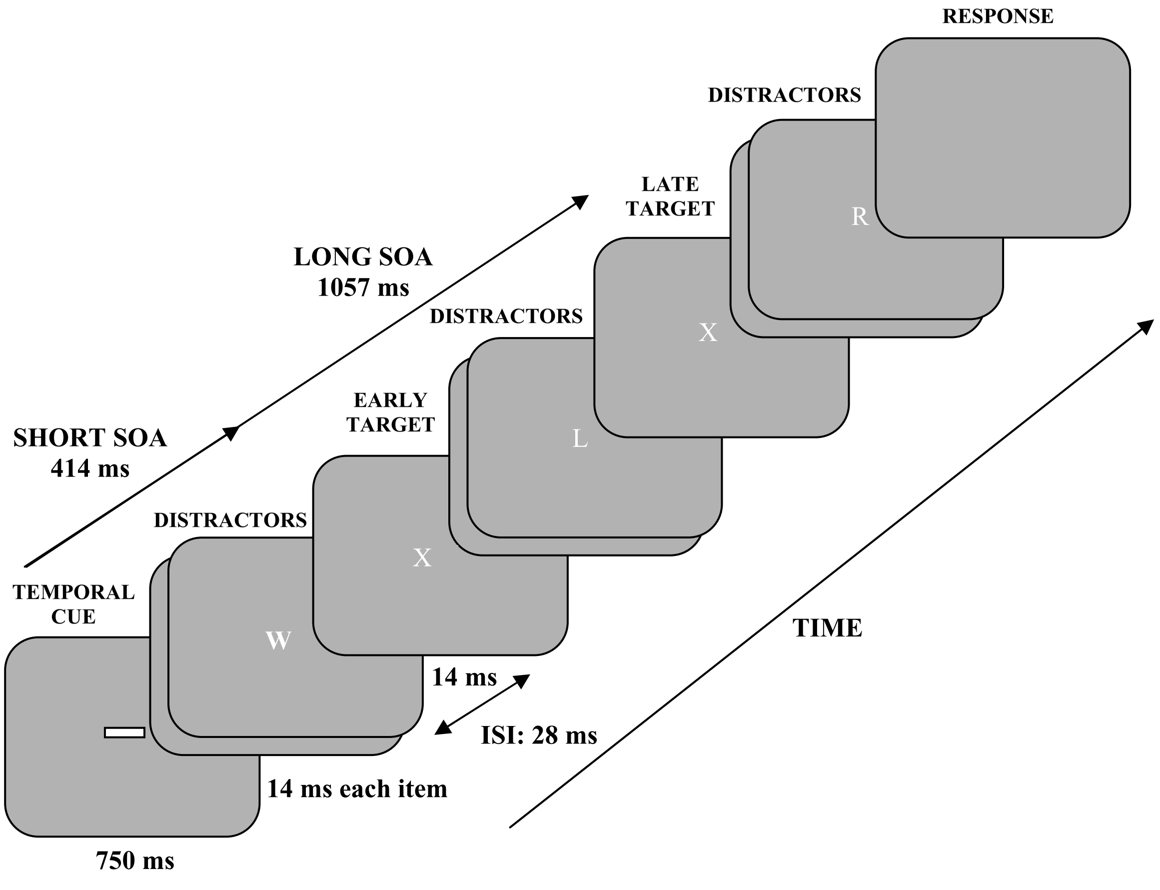

Figure 3.1. *Sequence of events on a trial.*

The items were presented for 14 ms each and there was an interstimuli interval (ISI) of 28 ms between them. In the first 9 positions of the stream only distractors were presented. The target could appear, only once, either in position 10 or 34, depending on SOA. Afterwards, 9 extra distractors were presented. Distractors were randomly selected from the set of 24. Given that there was no time pressure, participants responded after the stream had disappeared. The next trial started after response.

There were six blocks of 60 trials (the first one considered as practice) with a rest between them. Each set of 30 target trials consisted of 20 valid trials and 10 invalid trials (validity proportion of .66). The cue indicated that the target was likely to appear early on one half of trials, and late on the remaining half. With early cues, the target appeared 414 ms after cue onset (position 10; Short SOA) on 2/3 of the trials (valid trials) and 1057 ms after cue onset (position 34; Long SOA) on 1/3 of the trials (invalid trials). With late cues, instead, the target appeared 1057 ms after cue onset on 2/3 of the trials and 414 ms after cue onset on 1/3 of the trials.

Importantly, the same procedure and sensory stimulation were used for the single-target and double-target groups. The only difference was that the single-target group was given instruction to identify the X-target (they were not informed about the “O”, which appeared any time the “X” was not presented), whereas the double-target group was instructed to identify the presence of either the X-target or the O-target.

Design

Experiments 3.1 and 3.2 had a 2(Task: single-target/double-target) X 2(Cue Validity: valid/invalid) X 2(SOA: 414/1057 ms) mixed factor design. Task was manipulated between-participants. Cue Validity and SOA were manipulated within-participants and randomly intermixed within-blocks. Indices of perceptual sensitivity (d’) and response criterion (beta) were the dependent variables. For computing d’ and beta similarly for the single-target and double-target groups, the target was defined as “X” for the two groups. Thus, a “Yes” (or “X”) response to an “X” present trial was considered as a hit, whereas a “Yes” (or “X”) response to an “X” absent trial (i.e., “O” present) was considered as a false alarm.

EXPERIMENT 3.1

Results

Mean d’s, betas, hit rates and false alarm rates for each experimental condition of Experiments 3.1 and 3.2 are presented in Table 3.1.

Table 3.1. *Mean d’s, betas, hit rates and false alarm rates for each experimental condition in Experiments 3.1 and 3.2 (hits and false alarms do not match to d’ and beta in this table, as these are means computed over participants).*

			SOA							
			SHORT (414 ms)				LONG (1057 ms)			
	TASK	CUE	D’	Beta	Hits	False alarm	d’	Beta	Hits	False alarm
EXPERIMENT 3.1	SINGLE TARGET	EARLY	0,63	1,24	0,53	0,31	0,44	1,16	0,51	0,35
		LATE	0,52	1,16	0,47	0,29	0,82	1,38	0,57	0,28
	DOUBLE TARGET	EARLY	0,44	0,97	0,59	0,43	0,22	1,06	0,56	0,48
		LATE	0,25	0,93	0,56	0,47	0,42	0,89	0,61	0,45
EXPERIMENT 3.2	SINGLE TARGET	EARLY	0,91	1,51	0,58	0,28	0,58	2,41	0,44	0,28
		LATE	0,45	2,05	0,37	0,25	1,05	2,04	0,56	0,22
	DOUBLE TARGET	EARLY	0,50	0,98	0,63	0,44	0,44	1,02	0,61	0,46
		LATE	0,31	1,34	0,60	0,51	0,62	0,92	0,65	0,45

Mean d’s and betas were submitted to separated mixed factor ANOVAs with Cue Validity and SOA as within-participants variables, and Task as between-participants variable (this same analysis was used in Experiment 3.2).

D’ analysis. The main effect of Task [F(1,38)=11.61; p<.002] showed that d’s were higher in the single-target task than in the double-target task. More interestingly, there was a main effect of Cue Validity [F(1,38)=7.33; p<.01], such that d’s were higher for validly than for invalidly cued targets. Moreover, as can be seen in Figure 3.2, this validity effect did not depend on a specific SOA, since the interaction between Cue Validity and SOA was far from significance (p>.27).

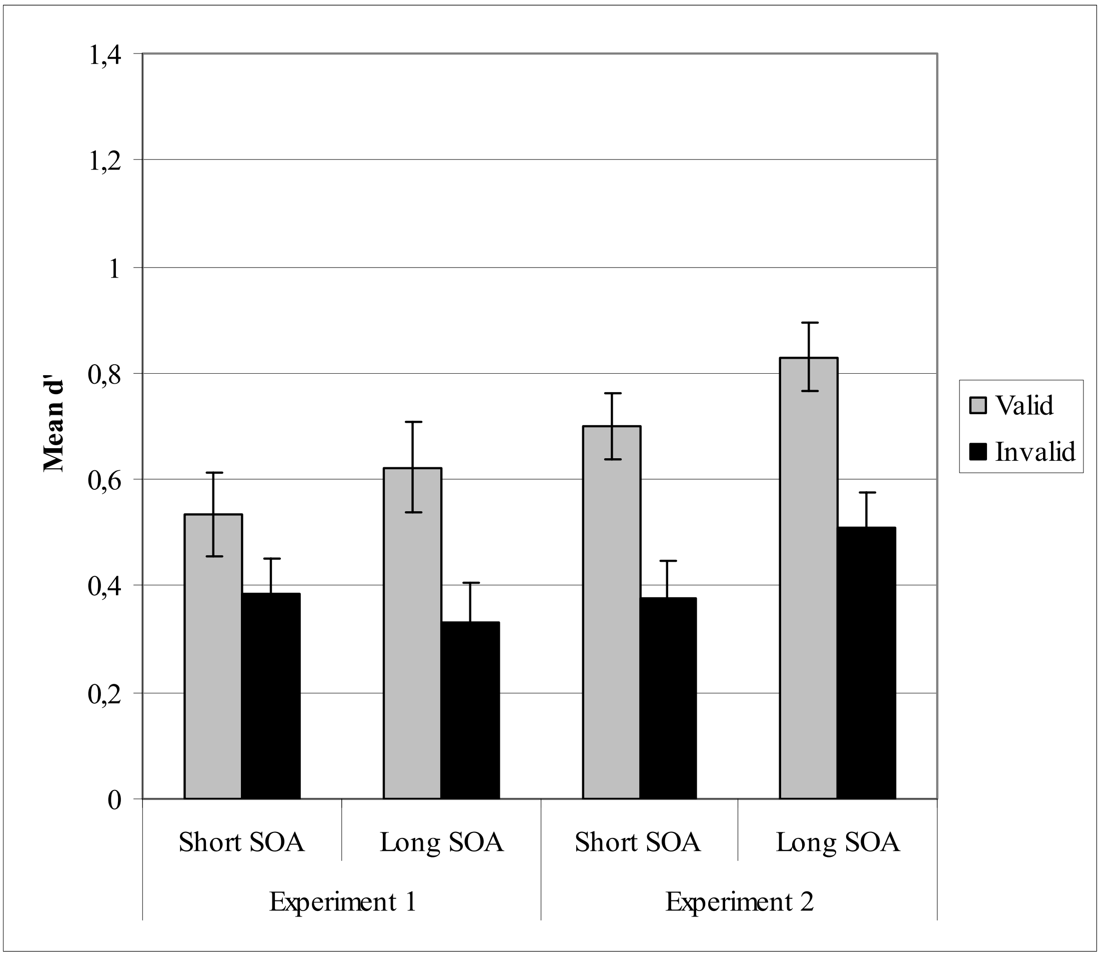

Figure 3.2. *Mean d’s of Experiments 3.1 and 3.2, as a function of Cue Validity and SOA. Note the validity effects for both short and long SOAs.*

Beta analysis. The main effect of Task [F(1,38)=10.85; p<.002] revealed that betas were higher in the single-target task than in the double-target task. This effect was modulated by Cue Validity [F(1,38)=5.61; p<.02], such that the higher betas in the single-target task were observed for valid cues. Such an effect could also reflect a modulation of temporal attention on late processing stages (Miniussi et al., 1999), such as decision processes. Nevertheless, the main effect of Cue Validity was far from significance (F<1).

EXPERIMENT 3.2

The primary aim of Experiment 3.2 was to replicate the most important finding of Experiment 3.1, that is, an increase of perceptual sensitivity presumably produced by the temporal orienting of attention. Moreover, we further explored the predicted interaction between Task and Cue Validity, which was not observed in Experiment 3.1. Also, we focused on the unexpected main effect of Task on d’, as we did not have any predictions concerning the observed decrement in performance produced by the knowledge of the alternative category (i.e., the O-target).

Results

D’ analysis. The main effects of Task and SOA were significant [F(1,78)=13.98; p<.001 and F(1,78)=5.38; p<.03, respectively], such that d’s were higher in the single-target task than in the double-target task, and d’s were higher at the long SOA than at the short SOA. The task effect replicated results of Experiment 3.1, that is, the fact of having more information about the potential targets produced a decrease in performance. The SOA effect might be due to perceptual preparation processes not being completed by the time the target appeared at the shorter SOA.

Crucially, as found in Experiment 3.1, there was a main effect of Cue Validity [$F(1,78)=21.10$; $p<.001$]. As shown in Figure 3.2, significant validity effects were observed at both the short SOA [$F(1,78)=12.80$; $p<.001$] and the long SOA [$F(1,78)=13.56$; $p<.001$].

This effect tended to be modulated by Task [$F(1,78)=3.83$; $p<.054$]. As predicted, the temporal orienting effect tended to be larger in the single-target task than in the double-target task.

Beta analysis. The only significant effect was the main effect of Task [$F(1,78)=9.65$; $p<.003$], which revealed that betas were higher in the single-target task than in the double-target task. This might be a consequence of different ways of responding to uncertainty about the target occurrence. Uncertainty would trigger more “No” responses in the single-target task, whereas the “Yes” and “No” (i.e., X and O) responses would be equal in the double-target task. Then, the X-responses would be more frequent in the latter task, thus producing lower betas.

Thus, in contrast to d’, beta was independent of the effect of Cue Validity in both experiments (except for the single-target group, Experiment 3.1). Therefore, the manipulation of Cue Validity mainly produced changes in perceptual sensitivity, but not in response criterion.

The effect of task on temporal orienting when the levels of performance are equated.

It can be argued that the differential validity effects observed in the single and the double-target groups could be simply due to differences in performance levels between the two tasks, rather than to differences in task-set demands. According to this, we would expect similar validity effects for both tasks if performance levels are equated. In order to investigate this baseline confound, Experiment 3.2 was reanalysed including Performance as a factor, so that we could explore its influence on validity effects and compare both tasks more reliably, once they had comparable levels of performance. Thus, each group of participants was divided in two subgroups, high vs. low performance, by use of a median-split procedure on the participants’ average d’ across the four within-participants conditions. Mean d’s were then submitted to a mixed factor ANOVA with Cue Validity and SOA as within-participants variables, and Performance (high/low) and Task (single-target/double-target) as between-participants variables.

The analyses revealed main significant effects of Performance, Task, SOA and Cue Validity [$F(1,76)=81.48$; $p<.001$, $F(1,76)=25.16$; $p<.001$, $F(1,76)=5.11$; $p<.03$, $F(1,76)=20.72$; $p<.001$, respectively]. It could not be otherwise, the low performance group had a lower d’ (0.38), than the high performance group (0.85). The other main effects were as explained above.

Importantly, once the noise due to the between participants differences was reduced in this analysis (by including performance as a factor), the interaction between Task and Cue Validity was now significant [$F(1,76)=4.06$; $p<.05$], showing larger validity effects for the single-target task than for the double-target task, as we predicted according to previous findings in our laboratory (Correa et al., 2004). And more relevant, this interaction was not modulated by Performance ($F<1$). As can be seen in Figure 3.3, the larger effects for the single-target task relative to the double target task are still present for both low and high performance groups. No other interactions were significant (all $p>.05$).

This result suggests that the task effects on temporal orienting cannot be explained just in terms of differences in global performance. Although it is possible that dividing participants ad-hoc could introduce other confounding selection effects, it is clear (see Figure 3.3) that the validity effect is greater for the Single Target Task (Low Performance group; mean d’=0.46) than for the Double Target Task (High Performance group; mean d’=0.67), despite the former having a worse overall performance.

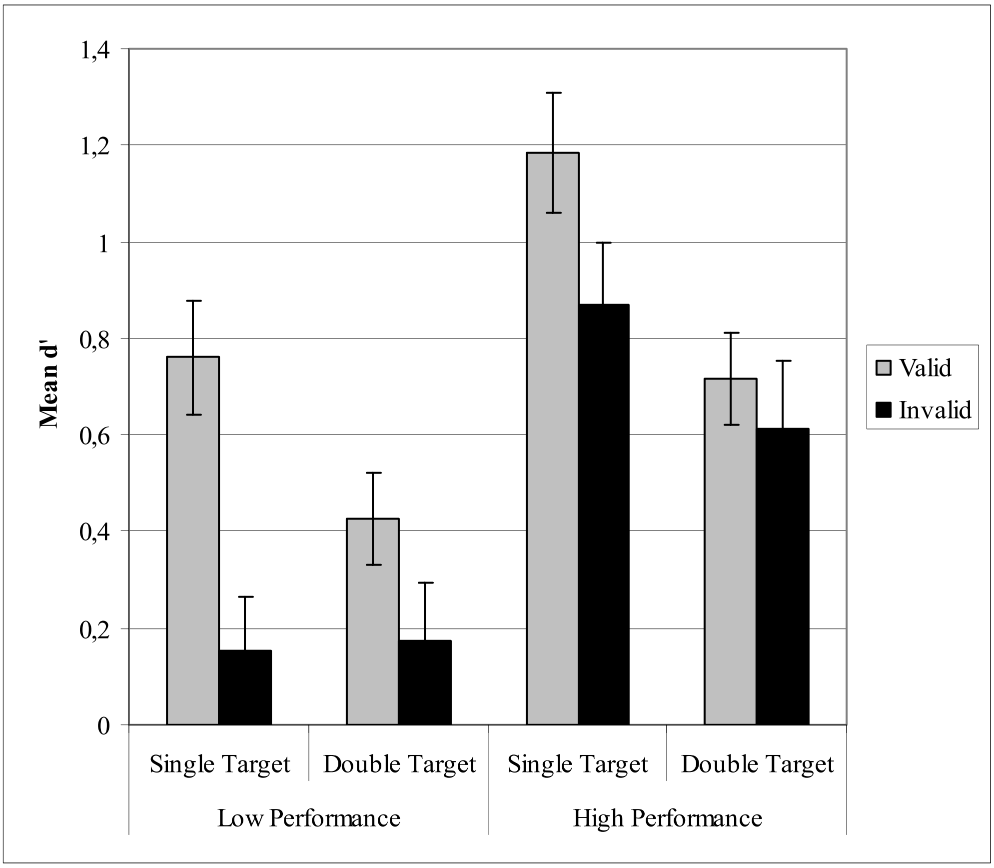

Figure 3.3. *Mean d's of Experiment 3.2, as a function of Cue Validity, Task, and Performance, low performance (left panel) versus high performance (right panel). Note that the validity effects in the single-target task are larger than in the double-target task.*

General Discussion

The present research provides new findings concerning the traditional debate about the specific influences of attention over processing. Such influences are better known in the space domain than in the time domain. Thus, it could be interesting to elucidate whether attentional preparation based on temporal expectancy modulates processing at perceptual level or motor level. Neuroimaging research is one approach to address this issue. However, the methodology used in the experiments reported here, represents a novel approach based on behavioural measures, which has also provided useful information.

The following are the major results concerning our main measure (d’). First, our central hypothesis has been consistently supported by robust cue validity effects observed in d’, in Experiments 3.1 and 3.2, so that valid temporal cues produced increments in participants’ perceptual sensitivity.

In relation to the effect of Task, it was found in both experiments that performance in the single-target task was better than in the double-target task. This finding could be surprising, considering that both tasks were identical in perceptual and motor terms. However, in the double-target group, more information was provided to find the target as compared to the single-target group, so that the former knew that the target could be either an 'X' or an 'O' whereas the latter could only search for the 'X' target. At first, one might expect that, the more information we have about what is being searched for, the higher the likelihood of finding it. However, this apparent paradox is easily explained from the memory search findings (Sternberg, 1966), as the search set size is higher for the double-target than for the single-target group.

In addition, such a feature that made harder the double-target task was also reflected in the interaction between Task and Cue Validity. We assume that the double-target task was more demanding than the single-target task, and so the generation of temporal expectancy was partly hindered by the former task. The present findings appear to be consistent with the conclusion drawn from previous research (Correa et al., 2004). In this sense, we suggest that online generation of temporal expectancy involves controlled processing (e.g., time estimation processes underlying temporal orienting). Hence, the ability to dynamically focus attention to time with success largely depends on other simultaneous cognitive demands.

In summary, temporal orienting effects have been consistently observed only in the measure related to perceptual sensitivity, which suggests that temporal attention can enhance early perceptual processing. However, there exists the possibility that our accuracy effects are produced by postperceptual factors, instead. For example, an increase in sensitivity might be due to participants’ encoding strategies of sampling more evidence (or preferentially rehearse information) from the cued vs. the uncued time interval. It is also possible then, that sensory processes are equivalent at both cued and uncued intervals, whereas the attended information could have an earlier and privileged access to late decision processes (Hawkins et al., 1990).

Nevertheless, there is also important evidence suggesting that such effects can be reasonably related to perceptual processing. In particular, several visual attention studies link variations in d’ to both modulations of sensory-evoked processing in extrastriate visual cortex as measured by ERPs (Luck et al., 1994) and modulations of early visual cortex activity (V1, V2 and V3) as measured by event-related fMRI (Ress, Backus, & Heeger, 2000). Furthermore, the paradigm used by Luck et al. was designed to prevent some of the confounds mentioned above.

Therefore, the findings obtained with this novel approach would challenge the notion that temporal orienting implies exclusively motor processes rather than perceptual preparation, as reported by physiological studies (Griffin et al., 2002; Miniussi et al., 1999; but see Griffin et al., 2002, Experiment 3.1 for some evidence supporting perceptual enhancement). Previous studies have shown that directing attention to time intervals enhanced the speeded responses that are habitually demanded in simple RT tasks. Presumably, such results mainly reflect the contribution of temporal orienting processes to motor preparation. Furthermore, we have found that focusing attention on a time interval could also enhance processes presumably related to perceptual sensitivity, which are essential to accomplish the task used in this experiment. This finding is in line with a recent study that reported attentional modulations of sensory neurons from area V4 of the visual cortex in monkeys, as a consequence of an anticipation of the timing of relevant events (Ghose & Maunsell, 2002). It makes sense, then, to expect that temporal attention, analogously to spatial attention, can flexibly enhance processing at different stages, according to the most relevant demands of the task at hand.

Chapter 4. Selective temporal attention enhances the temporal resolution of visual perception: Evidence from a temporal order judgment task.

Ángel Correa[1,2], Daniel Sanabria[2], Charles Spence[2], Pío Tudela[1], & Juan Lupiáñez[1]

1. Universidad de Granada. España

2. University of Oxford. United Kingdom

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Abstract

The present work addresses the temporal orienting of attention, a topic of growing interest, and provides the first empirical evidence for temporal attention enhancement in the temporal resolution of perception. We followed a novel approach that consisted of combining a temporal-cuing paradigm with a temporal order judgment (TOJ) task, to investigate whether the temporal resolution of pairs of visual stimuli could be improved by endogenously attending to the relevant moment in time. Participants were cued to expect the stimuli either after a short (400 ms) or long (1400 ms) cue-target interval. The results showed a significant improvement in TOJ performance (lower just noticeable differences) for attended compared to unattended stimuli (41 vs. 46 ms, respectively), suggesting that endogenous temporal attention enhances the temporal resolution of perceptual processing. The results are discussed in terms of theories about the effects of attention on both spatial resolution and temporal resolution of visual perception.

The ability to prioritize the processing of relevant stimulus attributes for the goals of intelligent organisms (i.e., selective attention) is fundamental for adaptive behaviour. Space provides one of the key attributes that has been the focus of research from the very first studies of visual selective attention (e.g., Posner, 1978), given the importance of the spatial information in vision. Studies of spatial attention have demonstrated benefits on reaction time (RT) and accuracy in the processing of stimuli appearing at cued locations (e.g., Posner et al., 1980; Spence & Driver, 2004). These results raise two related research questions, which form the focus of the present study. The first concerns the locus at which selective attention modulates stimulus processing. Of particular interest here is whether the enhancement of early perceptual or just late motor processes underlies the observed behavioural benefits. If so, a second aim is to specify those characteristics of visual stimulus processing that can be improved, that is, can the speed or the quality of visual processes be increased by selective attention?

Physiological research has reported amplifications of neural activity elicited by visual stimuli appearing at attended versus unattended locations, respectively for those event-related potentials (ERPs) related to the early stages of sensory information processing over occipital areas (e.g., P1/N1 components, see Mangun, 1995, for a review), as well as for metabolic activity in extrastriate cortex (Heinze et al., 1994). This suggests that spatial attention enhances early visual processes.

The temporal dimension is as important as the spatial dimension for representing the dynamic structure of the external world (e.g., Fraisse, 1963). However, until recently, selective attention research had not explored the ability to intentionally commit attention to specific points in time. Nobre and her colleagues (e.g., Coull & Nobre, 1998) studied the voluntary (or endogenous) orienting of attention to a particular point in time using a temporal analogue of Posner's spatial cuing procedure (Posner, 1978). Symbolic cues indicated the probable temporal interval at which the target was most likely to appear (either *early* or *late* in time after the start of the trial). As typically observed in spatial cuing studies, participants responded more rapidly to targets appearing at the expected time (i.e., on valid trials) as compared to unexpected time intervals (invalid trials). In contrast to spatial cuing studies, physiological data on the effects of temporal attention revealed selective activations in left premotor cortex (e.g., Coull & Nobre, 1998) and modulations of late electrophysiological components (Miniussi et al., 1999), suggesting a late postperceptual locus for temporal attention effects rather than a genuine perceptual enhancement. An alternative explanation considers that the detection task they used may have been insensitive to perceptual modulations, as simple-RT detection tasks exclusively demand speeded motor responses, so that the observed activations over motor areas might simply reflect task demands, instead of temporal attention effects (Correa et al., 2004).

In the present study, we take a novel approach to explore whether selective attention to time can actually enhance the temporal aspects of visual perceptual processing. We combined a temporal cuing procedure with a psychophysical task in which participants had to make temporal order judgments (TOJs) regarding which of two visual stimuli appeared first. The stimulus onset asynchrony (SOA) between the two stimuli was manipulated using the method of constant stimuli and the resulting psychophysical functions used to compute the just noticeable difference measure (JND, in milliseconds), which provides an index of the temporal resolution or acuity of temporal perception. Small JNDs indicate high temporal resolution, as observers are able to discriminate the onset of two events separated by few milliseconds. The use of a TOJ task is especially suitable to our two main goals. First, it provides an appropriate index of perceptual processing, since TOJ tasks normally involve accurate unspeeded responses (Klein et al., 1998). Moreover, the TOJ task provides a direct index of temporal resolution.

The attentional effects on visual temporal resolution have already been studied using a spatial orienting procedure, revealing discrepant results regarding a modulation of JNDs (see Shore & Spence, 2005, for a review). However, the effects of temporal attention on temporal resolution remain to be explored. Hence, the present experiment was designed to study whether temporal attention can modulate perceptual processing by improving the temporal resolution of visual processing. If attending to a particular moment in time really does improve visual temporal resolution then we should observe smaller JNDs for pairs of stimuli presented at an expected as opposed to an unexpected moment in time.

EXPERIMENT 4.1

Method

Participants

Forty-six participants from the University of Oxford took part in the experiment in return either for course credit or a £5 gift voucher. Eight of the participants were excluded from subsequent data analyses due to their poor temporal resolution (their JNDs fell outside the range of SOAs tested in the study). All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli

The E-prime software package was used to control the experiment (W. Schneider, Eschman, & Zuccolotto, 2002). A 15-inch monitor was placed in front of a black background. The fixation point consisted of a centrally-presented white cross (0.25° x 0.25° visual angle). The temporal cue consisted of the words “early” or “late”, subtending 3.1° and 2.4° horizontally, respectively. One orange target LED (1° in diameter) was attached to either side of the monitor (16° from fixation). White noise was presented continuously throughout the experiment at 70 dB(A) by means of two loudspeakers placed in front of the participant, who also wore headphones to attenuate this noise. An infrared camera was used to monitor participants’ eye movements. The ‘Z’ and ‘M’ keys on the keyboard were used to indicate that the left or right LED flashed first, respectively.

Procedure

The participants sat resting their chin in a chinrest placed 57 cm from the monitor, in a darkened soundproof booth. They were instructed to use the temporal cue to predict when the target would appear and thus to focus their attention at the appropriate temporal interval, and were encouraged to respond as accurately as possible with no time pressure.

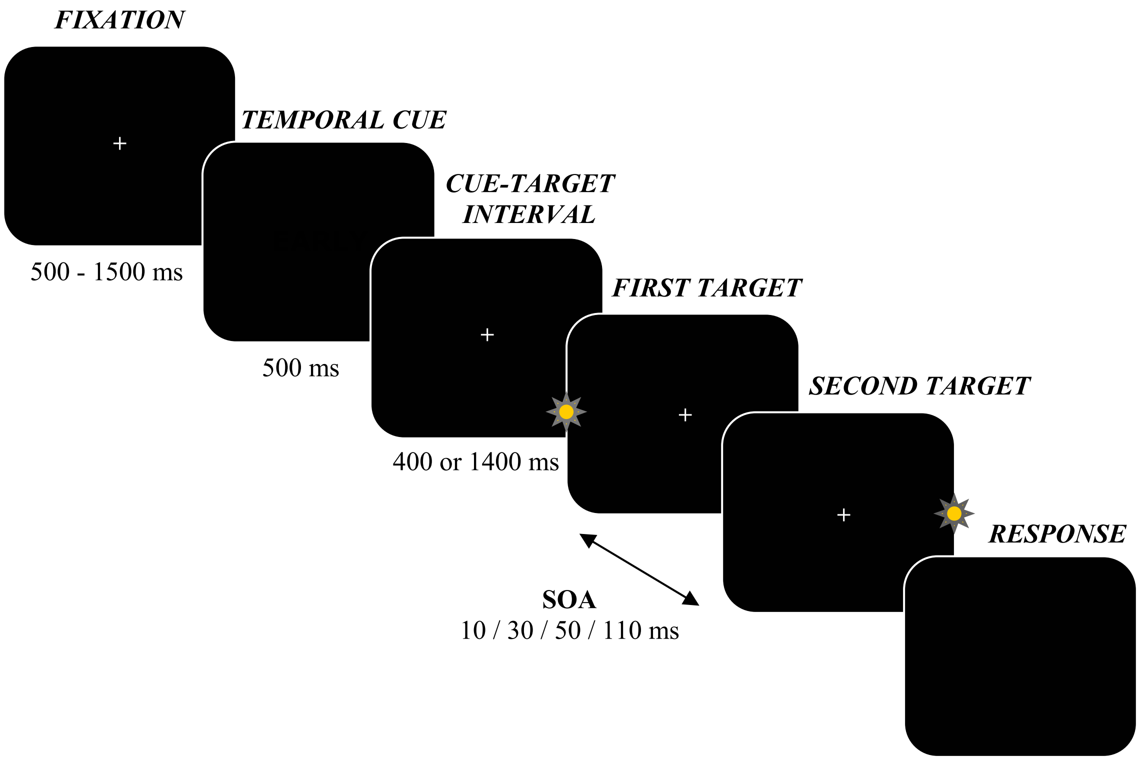

Figure 4.1. *The sequence of events in a typical trial.*

The fixation point appeared for a random duration of 500-1500 ms (see Figure 4.1). Next, the temporal cue was presented for 500 ms followed by the fixation point for a further 400 or 1400 ms, depending on the cue-target interval. One of the target LEDs was illuminated, and after a variable SOA of 10, 30, 50 or 110 ms, the other target LED was also illuminated on the opposite side. The two LEDs remained illuminated until the participants made a response. The side of the first target and the SOA factors were counterbalanced and randomly intermixed across trials.

At the start of the experiment, the participants completed one block of 8 practice trials for each temporal cue (early/late). The cue was 100% valid in these practice blocks. Next, four ‘early’ blocks and four ‘late’ blocks were presented in alternating runs (i.e., early-late-early-late, etc.). The temporal cue to be presented in the first block was counterbalanced across participants[11]. Each block of experimental trials comprised of 48 valid, 16 invalid, and 12 trials in which the target LEDs were not presented. On valid trials, the cue was 'early' (or late) and the first target appeared after 400 (or 1400) ms. On invalid trials, the cue was 'early' (or late) and the first target appeared after 1400 (or 400) ms.

Results and Discussion

Given that temporal orienting effects are typically reliable only at the short cue-target interval (see Nobre, 2001, for a review), only the data from the short interval were analyzed and reported here[12]. The accuracy data (percentages of errors) were submitted to a repeated-measures analysis of variance (ANOVA) with the factors of Cue Validity (valid/invalid) and SOA (-110/-50/-30/-10/+10/+30/+50/+110 ms; negative SOAs indicate that the left target was presented first, whereas positive SOAs indicate that right target was presented first).

The overall accuracy was of 76%. As expected, the main effect of SOA was significant, $F(7,259)=47.34$; $p<.001$, showing that the accuracy of participants' TOJ performance deteriorated as the targets were brought close together in time. More importantly for present purposes, the participants responded more accurately for pairs of targets appearing at the valid interval rather than at the invalid interval, leading to a main effect of cue validity, $F(1,37)=9.95$; $p<.01$. This finding reveals that endogenously directing attention to a particular point in time can improve performance in a temporal discrimination task in which efficient visual processing is demanded, suggesting a perceptual locus for such attentional effects.

The mean probability of 'right target first' responses is plotted as a function of SOA and cue validity in Figure 4.2. Visual inspection of the data suggests that JNDs were smaller in the valid as compared to the invalid condition. In order to compute the JND, the data from each

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[11] The cue served mainly to signal the onset of the temporal interval, as temporal expectancy was fixed during each block of trials. This procedure aimed to maximise attentional effects, as they are larger when temporal expectancy is manipulated between-blocks rather than within-blocks (Correa et al., 2004).

[12] The absence of effects at the long interval in previous research has been attributed to a reorienting of attention from short to long intervals when the target invalidly appears later than expected (Nobre, 2001). This strategy seems effective and makes sense, as the probability of the target arrival increases with time, such that it becomes maximal at the long interval. As expected, the analysis at the long SOA revealed no effects of cue validity either on accuracy or JND measures (*ps*>.05).

participant were transformed to Z scores, and the Z scores distribution was fitted to linear regressions (Finney, 1964) for both valid and invalid conditions (see Figure 4.2). JNDs were computed for each participant using the slopes of such linear trends. Two-tailed paired comparisons t-tests were performed on the JND data. Crucially, the JND was significantly smaller in the valid condition (41 ms) than in the invalid condition (46 ms), $t(1,37)=2.2$; $p<.05$. This result supported our main hypothesis that focusing attention on a specific point in time improves the temporal resolution of visual perception at that time relative to other relatively less attended times.

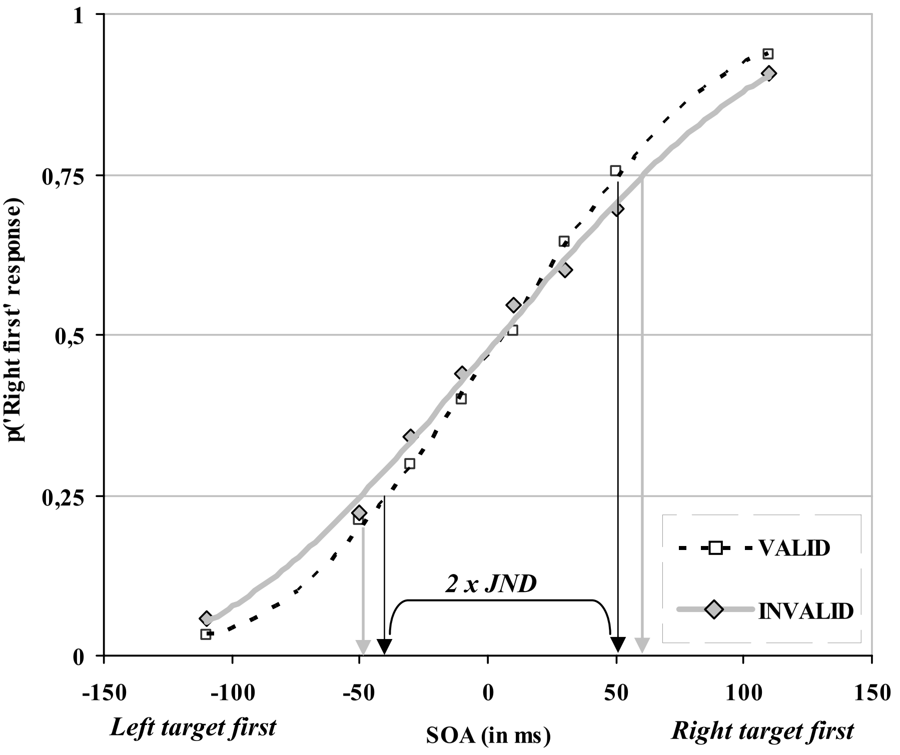

Figure 4.2. *The mean proportion of 'right target first' responses as a function of SOA and cue validity (data averaged across participants). The interval of uncertainty (2 x JND) is shown for valid and invalid conditions.*

General discussion

In the present study, we combined a temporal cuing procedure with a TOJ task in order to determine whether endogenously orienting attention to a particular point in time can enhance the temporal aspects of perceptual processing. Our results, revealing more accurate TOJs at the expected than at the unexpected time interval, supported such enhancement. This finding is in line with previous studies that reported temporal attention enhancements in d', an index of perceptual sensitivity (Correa et al., in press) and on P1, an ERP component linked to early visual electrophysiological activity (Correa et al., submitted), which contrasts with the conventional view that temporal attention exclusively modulates late motor processing (Coull & Nobre, 1998).

More crucially, the finding of smaller JNDs for attended than for unattended pairs of stimuli shows for the first time that limitations in the temporal resolution of visual perception may be attenuated by attending to the moment in time when the two events will occur. However, the combination of spatial cuing and temporal resolution tasks have not led to definitive results yet, on which explanations of the observed temporal attention effects could be based.

For instance, Yeshurun and Levy (2003) successively presented two flashes at the same location and determined the smallest asynchrony at which they were perceived as constituting two separate events. The authors observed that exogenous spatial attention impaired temporal resolution in this gap detection task. Considering that spatial attention increases spatial resolution (Yeshurun & Carrasco, 1999) but decreases temporal resolution, Yeshurun and Levy suggested that there might be a potential trade-off between spatial resolution and temporal resolution, with both processes triggering competitive cerebral mechanisms. However, an alternative explanation of these findings is that the onset of the exogenous cue in their study may have masked, not the object information of the subsequent targets, but the temporal information regarding targets onset (see also K. A. Schneider & Bavelier, 2003, for a similar explanation). Thus, the exogenous cue facilitated performance at the attended location in a high spatial resolution task (see Experiment 2). In contrast, this same cue interfered with the temporal resolution for detecting a temporal gap (Experiments 1 and 3), by adding irrelevant distracting information regarding cue onset to relevant information regarding the temporal onset of the two targets.

Other studies, by contrast, have reported no evidence to suggest a modulation of temporal resolution by spatial attention, as indexed by the JND in a TOJ task (e.g., Shore, Spence, & Klein, 2001). This discrepancy may reflect the different processes involved in temporal gap detection and TOJ tasks (K. A. Schneider & Bavelier, 2003). Another explanation emphasizes the fact that providing spatial information does not necessarily influence performance when temporal processing, rather than spatial processing, is involved. Importantly, in the present experiment, both TOJ and temporal cuing procedures engaged time as the relevant dimension. Thus, we assumed that providing temporal information signalling (instead of masking) the target onset could enhance performance in temporal resolution tasks, such as TOJs. Indeed, the present results suggested such attentional enhancement.

The mechanism by which temporal attention improves temporal resolution remains uncertain. Allik and Pulver (1994) have suggested that people may base their TOJ responses on a temporal filter which acts upon the neural response profiles to segregate stimulus onsets. In the same way as spatial attention enhances spatial resolution by narrowing the size of spatial filters (e.g., Yeshurun & Carrasco, 1999), temporal attention may enhance temporal resolution by modulating the temporal filter properties to optimise its functioning. A complementary explanation in line with the dynamic attending models (e.g., Large & Jones, 1999), is that the attentional oscillations could be speeded up at the attended time interval, thus increasing the '*refresh rate*' of processing, which would be necessary to detect novel stimulus onsets. Further research will hopefully help to elucidate the neural mechanisms by which temporal attention increases the temporal resolution in vision.

Series III: Does temporal attention modulate electrophysiological indexes of early perceptual processing of visual stimuli?

Chapter 5. Temporal attention enhances early visual processing: A review and new evidence from event-related potentials.

Ángel Correa, Juan Lupiáñez, Eduardo Madrid and Pío Tudela

Universidad de Granada

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Abstract

Two fundamental cognitive functions, selective attention and processing of time, have been simultaneously explored in recent studies of temporal orienting of attention. A temporal-orienting procedure may consist of a temporal analogue to the Posner's paradigm, such that symbolic cues indicate the most probable moment for target arrival. Behavioural measures suggest that performance is improved for events appearing at expected versus unexpected moments. However, there is no agreement on the locus of stimulus processing at which temporal attention operates. Thus, it remains unclear whether early perceptual or just late motor processes can be modulated. This article reviews current ERP research on temporal orienting, with an emphasis on factors that might determine the modulation of temporal orienting at early stages of processing. We conclude that: First, late components (N2 and P300) are consistently modulated by temporal orienting, which suggests attentional preparation of decision and/or motor processes. Second, early components (e.g. N1) seem to be modulated only when the task is highly demanding in perceptual processing. Hence, we conducted an ERP experiment which aimed to observe a modulation of early visual processing by using a perceptually demanding task, such as letter discrimination. The most relevant and novel finding was that targets appearing at attended moments elicited a larger P1 component than unattended targets. Moreover, temporal attention modulated the amplitude and latency of N2 and P300 components. This suggests that temporal orienting of attention not only modulates late motor processing, but also early visual processing when perceptually demanding tasks are used.

Keywords: time processing, ERP, P1, Posner's task, temporal orienting, endogenous attention

Timing is an essential function for intelligent organisms to coherently represent and to act upon the changing elements that structure our dynamic world. Some examples in which perceptual input is organized into temporal patterns are perception of motion, music or speech. Other activities illustrate the involvement of timing to organize motor output (Rosenbaum & Collyer, 1998), such as performing complex skills as sports, driving or speech production, as well as more basic actions such as reaching objects.

Another function that was presumably crucial in the past to successfully adapt ourselves to the environment is selective attention. Selective attention refers to the plastic ability to prioritize processing of certain stimulus features relevant to the individual's goals, in order to produce efficient behaviour. Since the seminal work by Posner and colleagues (Posner et al., 1978), many attentional-orienting studies have explored the effects of cueing in advance information concerning target features, such as its location, speed, colour, shape, identity, semantic meaning and so on (e.g., Corbetta et al., 1990). They have reported benefits on reaction time (RT) and/or accuracy in a variety of tasks when the target matches the cued feature (valid trials), compared to when such matching does not occur (invalid trials). A simple explanation is that cues allow an extra processing of the relevant target feature during the delay between cue and target (i.e., stimulus onset asynchrony or SOA). This extra processing may consist of a deployment of attentional resources to specific brain areas that code the relevant feature, thus enhancing the speed or the quality of the processes involved in the task.

Relatively recent studies based on physiological measures have discovered a network of brain areas recruited in focusing visual attention to spatial locations (Corbetta & Shulman, 2002). In addition, neuroscientists are interested in exploring how this attentional-orienting mechanism modulates stimulus processing. Thus, an important issue of research is to track the locus of attentional effects underlying behavioural benefits. Research on spatial attention have shown that attending to targets presented at one location leads to increments in both early electrophysiological activity over occipital sites (see Luck, Woodman, & Vogel, 2000; Mangun, 1995, for reviews) and regional cerebral blood flow in extrastriate cortex contralateral to the attended location (Heinze et al., 1994). These data suggest that attention enhances early perceptual processing of targets appearing at cued locations. Moreover, spatial attention has been shown to increase late electrophysiological activity related to decision and motor processes (Mangun, 1995). Taken together, these results indicate that spatial attention improves performance by producing a preparation of both early perceptual and late motor processing related to target stimuli.

Although space has been the predominant dimension in visual attention research, Nobre and colleagues gave an impetus to the study of orienting attention to time. Thus, two fundamental cognitive functions, selective attention and processing of time, were simultaneously explored. They have shown that the moment of target onset could also be a relevant feature, to which attention can be intentionally committed (Coull & Nobre, 1998; see also Kingstone, 1992). The traditional procedure used by the Posner's group to study spatial orienting of attention (Posner et al., 1978) was modified as follows. Instead of spatial cues, Coull and Nobre presented symbolic temporal cues to indicate that the target would appear either early (after a short interval of 400 ms) or late (after a long interval of 1600 ms). Then, the SOA was manipulated in order that the target actually appeared at the validly cued time interval in 80% of trials. The target appeared at the uncued interval in the remaining 20% of trials. Participants were asked to detect the target onset (a cross) as fast and accurate as possible. Behavioural data revealed validity effects restricted to the short SOA, such that RTs were faster for the early cue-short SOA condition compared to the late cue-short SOA condition. This result has been abundantly replicated (e.g. Naccache, Blandin, & Dehaene, 2002; see Nobre, 2001, for a review), and also extended to the long SOA in our laboratory (Correa et al., 2004, see Discussion for details).

Concerning the locus of attentional modulation, neuroimaging research have revealed selective activations in left premotor cortex produced by temporal attention as compared to spatial attention (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998). This finding suggests a prevalence of motor over perceptual preparation processes in temporal attention. However, this result has been observed when detection tasks that demand a speeded motor response are used. Therefore, it might be the case that the observed modulation of motor processes is not related to temporal orienting per se, but to the use of a simple detection task.

On the other hand, observing temporal orienting effects on RT in discrimination tasks opened the possibility of a perceptual preparation (Correa et al., 2004; Griffin et al., 2001; Milliken et al., 2003). Thus, attention may facilitate perceptual processes involved in analysing object features, which are essential to accomplish discrimination tasks. However, the motor account cannot be ruled out, since such results could be merely due to a facilitation of later postperceptual processes, such as decision or motor response execution, which are also demanded in choice-RT discrimination tasks (Nobre, 2001).

More convincing evidence comes from a psychophysical study that showed selective increments in perceptual sensitivity (as indexed by d’) with no changes in response criterion (as indexed by beta), produced by the temporal orienting of attention (Correa et al., in press). Motor explanations were weakened in this case, as the task minimised motor requirements by demanding unspeeded responses, whereas perceptual demands were optimised by asking for accuracy in responding, and principally by using a rapid serial visual presentation procedure in which perception of the target became quite difficult. In spite of the fact that research have correlated d’ to perceptual processing in visual cortex (Luck et al., 1994; Ress et al., 2000), one might argue that d’ is not a pure index of perceptual processing which can be influenced by postperceptual factors (see, for example, Correa et al., in press).

In sum, although behavioural findings are suggestive, they are unsatisfactory to confidently claim that temporal attention enhances early perceptual processing. More compelling evidence would be provided if we use a more direct measure of processing. Considering the high temporal resolution of the event-related potential (ERP) methodology, this technique is especially appropriate to explore on-line the dynamic modulations of temporal attention on processing (Doherty et al., in press).

Hence, the aim of the present work is twofold. We first present a review of the current ERP research on temporal orienting, with special attention being paid to the differential characteristics between experimental procedures that might determine the finding of modulations at early stages of processing. Then, we report an ERP experiment which included key aspects in its design to observe such modulations, according to the conclusions of the review.

ERP research on temporal orienting of attention: A review.

The ERP research on temporal attention is summarized in Table 1. To our knowledge, the first ERP experiment that studied temporal orienting was carried out by Miniussi and colleagues (Miniussi et al., 1999). The task was very similar to that used by Coull and Nobre (1998), that is, symbolic central cues indicated when the target would appear, with a probability of .80. The target to be detected was an abrupt onset of a cross symbol. Event-related potentials evoked by valid vs. invalid targets were compared at the short SOA. One important aspect was that all stimuli were presented foveally.

The major result was a modulation of the P300 latency, such that it peaked earlier for valid targets. This result is not usually reported in spatial attention research, so it seems characteristic of temporal attention. The authors suggested that temporal information may be used to synchronize and/or prepare motor processes, or sharpen processes linked to decisions or responses (p. 1516). The P300 amplitude was larger for valid targets, though the effect was significant only with additional analyses over midline and posterior areas. The N2 component was not considered a priori in the analysis. However, it showed to be influenced by temporal attention, such that invalid targets elicited a larger N2 over occipital sites. Miniussi et al. related this unexpected effect to the N2 component typically found in go/nogo tasks, so it was linked to a response inhibition process. However, the N2 in go/nogo experiments shows a scalp distribution which is more anterior than the observed for the temporal attention manipulation. Then, the authors proposed that the N2 effect could rather index the result of breaches in the expected stimulus associations that guide responses (Nobre, Coull, Frith, & Mesulam, 1999).

As a general conclusion, given that attentional modulations were found in late but not in early ERP components, they naturally interpreted that temporal attention seemed not to involve a perceptual preparation. Rather, temporal attention enhanced potentials related to motor

Table 1. The manuscripts are organised by rows. Each column includes information about the 'task', 'conditions' (those included in the ERP analysis, which showed significant behavioural effects). 'Exp' refers to the experiment number in the manuscript. Then, the 'ERP component' and the temporal window ('T.Window') used in the analysis are specified. Finally, the table shows the results on 'amplitude' and 'latency' measures and their 'interpretation', as proposed by the authors.

MANUSCRIPT	TASK	CONDITIONS	EXP.	ERP COMPONENT	T. WINDOW	AMPLITUDE	LATENCY	INTERPRETATION
Miniussi, Wilding, Coull, & Nobre (1999)	- Temporal cueing - Onset detection - 80% validity	Valid vs. Invalid at short SOA	1	P1	60 - 140	-	-	Temporal attention seems not to involve perceptual preparation
				N1	100 - 200	-	-	
				N2 (occipital)	200 - 300	↑ Invalid	-	Breaches in expected stimulus associations
				P300	250 - 500	↑ Valid (over midline and posterior areas)	↓ Valid	Temporal attention synchronizes & prepares motor processes (decisions/responses)
Griffin, Miniussi, & Nobre (2002)	-Temporal cueing - Feature detection - Peripheral targets (Exp. 1: bilateral; Exp. 2 unilateral) - 75% validity	Attended vs. Unattended non-target arrays at short SOA	1	P1	80 - 120	-	-	Unlike spatial attention
				N1 (bilateral)	120 - 200	↑ Attended	-	Perceptual preparation by temporal attention
				N2 (occipital)	240 - 320	↑ Attended	-	Unclear
				P300	250 - 500	↑ Attended	↓ Unattended	Decision processes & preparation for responses
			2	P1	80 - 120	-	-	-
				N1	120 - 200	-	-	-
				N2	250 - 300	↑ Unattended (p=.058)	-	- Related to go/nogo tasks (response inhibition) - or to temporal deviant stimuli
				P300	250 - 500	-	↓ Attended	Motor preparation
Lange, Rösler, & Röder (2003)	- Auditory stimuli - Temporal cueing (between-blocks) - Oddball (intensity) - 50% validity	Attended vs. Unattended standards at both SOAs	1	N1 (frontal)	100 - 140	↑ Attended	-	Modulation of early perceptual processing (gating process)
				N2 (target vs. standard)	225 - 275	↑ Target	-	Response to infrequent stimuli, novelty detection
				P300	300 - 370	↑ Attended	-	Amount of information delivered
Correa, Lupiáñez, & Tudela (submitted)	-Temporal cueing (between-blocks) - Discrimination - 75% validity	Valid vs. Invalid at short SOA	1	P1	130 - 170	↑ Valid	-	Enhancement of early visual processing
				N1	250 - 290	-	-	-
				N2	360 - 400	↑ Invalid	↓ Valid	Conflict detection
				P300	500 - 540	↑ Invalid	↓ Valid	Synchronization & preparation of decisions/responses
Doherty & Nobre (in press)	- Motion cueing - Feature detection (50% go/nogo) - Peripheral target	Temporal vs. Neutral expectancy	1	P1	110 - 130	-	-	Lack of retinotopic representation of time
				P1c (frontal-central)	100 - 120	↑ Temporal	-	- Early modulation -lingering anticipatory pre-target components (CNV)
				N1 (central-occipital)	170 - 190	↓ Temporal	-	Visual or post-visual processing (time perception)
				N2 (central-parietal)	220 - 330	↑ Neutral	-	Temporal uncertainty
				P300	500 - 600	-	↓ Temporal	Enhancement of late decision & motor processes
Correa & Nobre (in preparation)	- Motion cueing - Feature detection (80% go/nogo) - Peripheral target - 50% validity	Valid (50%) vs. Early-Invalid (25%)	1	P1	80 - 120	-	-	No perceptual demands in this task
				N1	160 - 220	↑ Valid (right hemisphere)	-	-
				N2	230 - 270	↑ Invalid	↓ Valid	Temporal uncertainty or conflict detection
				P300	350 - 450	↑ Valid	↓ Valid (p=.06)	Synchronization & preparation of decisions/responses

processing. However, the authors did not draw strong conclusions from that null effect and recognize a potential lack of sensitivity in their task. Importantly, it might be that attention was not needed in their task to further optimise visual processing, as all the stimuli were presented at an area already optimised (i.e., the fovea). Moreover, the abrupt onset of the target did not imply a considerable perceptual demand to accomplish the detection task.

Hence, two subsequent experiments were conducted to test these issues (Griffin et al., 2002). The main changes were the use of peripheral targets and a ‘feature detection’ task. This task was also a simple-RT task, but unlike onset detection, the feature detection task involved a finer perceptual analysis because the target was defined by more complex visual features. The target was a pattern of concentric squares with one of its inner squares missing. Event-related potentials evoked by attended (i.e., attend short SOA) versus unattended (i.e., attend long SOA) standard non-target arrays were compared at the short SOA, to avoid additional effects produced by targets.

Importantly, Experiment 1 showed an increased N1 in the attended condition over bilateral occipital electrodes. Experiment 2, however, did not replicate this early effect. One difference was the use of unilateral targets in Experiment 2, instead of the bilateral targets presented in Experiment 1. This finding was interpreted as a modulation of early visual processing by temporal attention. However, the diffuse (non-lateralised) enhancement, and the lack of effects on P1, led them to argue that the modulation had a different nature to the typical observed for spatial attention.

Concerning late components, Experiment 2 replicated with more success the previous study (Miniussi et al., 1999), such as the N2 enhancement at the unattended condition, and the earlier P300 peak at the attended condition. A novel interpretation was provided for the N2 effect, which was produced by stimuli appearing at unexpected moments (i.e., temporal deviant stimuli, Loveless, 1986).

To conclude, a modulation of early processing by temporal attention was observed in Experiment 1, in which a feature detection task and bilateral peripheral targets were used. This finding led us to assume that a high requirement of perceptual processing could be a key factor in order to observe such modulation.

A different approach was taken to investigate temporal orienting in the following study (Lange et al., 2003). The authors explored temporal attention in the auditory modality. The use of auditory stimuli could increase the sensitivity of the task to measure early modulations, as the auditory modality is superior to the visual one in temporal processing efficiency (e.g. Repp & Penel, 2002). Lange et al. adapted the paradigm introduced by Hillyard and coworkers (Hillyard, Hink, Schwent, & Picton, 1973) to the temporal domain. Two consecutive auditory stimuli delimited both the short and the long SOA. The second stimulus was the target in 20% of trials and the standard in the 80% remaining. The target was defined by a louder sound intensity. Participants were to respond to infrequent deviant stimuli (target). As in Griffin et al.'s study (Griffin et al., 2002), standard stimuli served as the event to which potentials were linked. A novel feature of this experiment was that temporal expectancy was manipulated between blocks, instead of trial-by-trial. Thus, participants attended to the short or to the long interval in alternating blocks. Unlike endogenous cueing procedures, there was a cue validity of .50, i.e., the same proportion for attended and unattended standard stimuli.

The most important result was that the typical auditory evoked potential, the frontal N1, showed to be larger for attended standard relative to unattended standard stimuli. This was also true for the P300 component. ERPs to deviant-targets versus standard-non targets were also compared, and a larger N2 for deviant-targets was found. The authors interpreted the auditory N1 effect as evidence supporting that temporal attention improves early perceptual processing in a similar way to spatial attention. On the basis on the superiority of audition over vision in temporal processing, they speculated that temporal attention could affect earlier levels of stimulus processing in the auditory modality.

In addition, as will be explained below, the way by which expectancy was manipulated could have been decisive in observing such early effects. In this study, perceptual demands were not maximised, although this could have been unnecessary given that the task gained sensitivity through using auditory stimuli and a blocked manipulation of temporal expectancy.

The last set of studies (Correa & Nobre, in preparation; Doherty et al., in press) largely differed from previous studies in the cueing procedure. In the latter, expectancy was induced by presenting symbolic explicit cues. In the former, expectancy was induced implicitly by showing a dynamic stimulus that followed predictable patterns of movement. The task consisted of a 'ball' that moved across the screen, in discrete steps from left to right before disappearing under an occluding band placed at the right hand-side of the screen. Once the ball reappeared, participants were to press a key when they detected a small dot in its centre (i.e., the target). They withheld response when the target was not present. The target appeared in 50% of trials (Doherty et al., in press), or in 80% of trials (Correa & Nobre, in preparation).

The pace of movement was manipulated to induce neutral expectancy (a random/unpredictable pace) or temporal expectancy (a regular/predictable pace), which allowed participants to predict the moment of the ball's reappearance. The temporal expectancy condition included a single expectancy, such that the speed of movement was the same for all trials (i.e., 550 ms per step). Behavioural results replicated studies that used the traditional Posner's paradigm, that is, RTs were faster in the temporal expectancy condition. Moreover, Doherty and Nobre found a modulation of an early positive component preceding P1 over central and frontal electrodes (referred to as 'P1c')[13]. Indeed, such a result could indicate early attentional enhancement, or alternatively, might be just due to lingering anticipatory pre-target components.

On the other hand, temporal attention attenuated N1 and N2 amplitudes. The attenuation of N1 had not been reported so far, and was assumed to reflect visual processing (i.e., a sort of perceptual modulation), or even post-visual processing (e.g., time perception). Finally, the modulation of P300 latency reported in previous studies was replicated with this paradigm.

The subsequent study aimed to extend such results to a broader range of temporal expectancies, by including a variety of predictable speeds of movement (Correa & Nobre, in preparation). Another difference was that the attentional manipulation was not based on patterns

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[13] I worked on a previous version of this manuscript, so that the results regarding this study will be updated.

of movement before the occlusion. Instead, both the attention and non-attention conditions were equated in perceptual input, but they differed in the time for which the ball was occluded. Thus, the temporal expectancy condition was divided into valid, early-invalid (earlier than expected targets) and late-invalid trials, depending on whether the ball virtually ‘moved’ during the occlusion at the same speed, faster or slower than before the occlusion, respectively. As occurred with other temporal-orienting paradigms, analyses focused on the early-valid versus early-invalid comparison (i.e., the short SOA). They revealed an earlier and smaller N2 component in valid relative to early-invalid trials. The latency modulation of N2 by temporal attention had not been observed previously. N2 was additionally considered as reflecting conflict detection (van Veen & Carter, 2002, see Discussion for details). The P300, replicating previous research, was significantly larger, and tended to appear earlier ($p<.06$) in the valid condition.

Broadly, this new procedure to study temporal orienting replicated the main behavioural and ERP findings obtained with the traditional Posner’s task (e.g., Miniussi et al., 1999), which suggests that both procedures could be engaging analogous cognitive processes. However, this novel approach seems more naturalistic and simulates more accurately our dynamic real world.

Concerning our main question, the Doherty and Nobre’s study provided additional evidence to the modulation of early processing as reflected by P1c and N1 components, though it was not evident over the occipital area. Given the low visibility of the target, the task can be considered as even more perceptually demanding than the feature detection task described above. Thereby, the presence of the target was not a salient feature, since it was peripherally presented, and had a small size and low colour contrast. In fact, participants frequently reported high uncertainty on whether they saw the target. In contrast, when the target was undoubtedly visible in the following experiment (Correa & Nobre, in preparation), the early effects vanished. This circumstance further emphasizes the necessity of high perceptual demands to obtain such early effects.

Conclusions

In summary, the following conclusions can be drawn from the present review. First, late components, such as N2 and P300, are consistently modulated by the temporal orienting of attention. The latency modulation (particularly of the P300) seems to be an idiosyncratic feature of temporal attention, and fits well with the function of synchronizing processes with the expected moment of occurrence of relevant events. Therefore, the reviewed studies provide converging support to the motor account. As mentioned earlier, there is a tight link between temporal and motor processing (Rosenbaum & Collyer, 1998).

On the other hand, the modulation of early perceptual processing by temporal attention is not a well-known phenomenon to date. Thus, several studies have failed to find the effect, whereas some others have succeeded to find it. Furthermore, when the attentional effect is observed, it is not consistently reflected in a particular modulation of ERPs, so that sometimes consisted of a P1 enhancement, N1 enhancement, or N1 attenuation, etcetera.

Although such a discrepancy might be due to methodological differences between experimental procedures, it could be due to more theoretical reasons such as the different nature of the way temporal and spatial attention modulates processing (Nobre, 2001). This could be a consequence of the differential nature of representations of space and time in the brain. Whereas space is accurately represented in retinotopic maps within the visual system, time implies a rather different way of representation, which might include the cerebellum and basal ganglia and cortical structures located in frontal-parietal areas (see Ivry & Spencer, 2004, for a review). Being that true, we might expect that temporal attention experiments scarcely show influences at perceptual levels of visual processing, as it actually happens. The findings in the auditory modality also supported this assumption, as audition does involve an accurate perceptual representation of time, which could be directly influenced by attention at early stages of processing.

Despite the discrepancy in procedures, one can find a common aspect in studies that have reported perceptual modulations. Specifically, high demands in perceptual processing appeared to be a key factor. Hence, we propose that temporal attention not only modulates late motor processing, but also early visual processing when perceptually demanding tasks are used.

EXPERIMENT 5.1

According to the conclusions drawn from the review, the present study aimed to find a modulation of visual processing by using a perceptually demanding task. The task consisted of letter discrimination (between ‘X’ and ‘O’), which demands more perceptual processing than detection tasks, as a more detailed analysis of the visual features is required. There was an inconvenient, however, since the use of choice-RT discrimination tasks produces smaller temporal-orienting effects than simple-RT detection tasks when temporal expectancy is manipulated on a trial-by-trial basis (Griffin et al., 2001). Nevertheless, other behavioural studies have reported robust temporal-orienting effects in discrimination tasks when temporal expectancy was blocked (Milliken et al., 2003).

In a subsequent study, we directly compared detection and discrimination tasks, and further examined the effects of blocking expectancy in the discrimination task (Correa et al., 2004). The results revealed larger effects for the detection task relative to the discrimination task. The analysis of the discrimination task revealed that the size of attentional effects was larger when temporal expectancy was manipulated between blocks, rather than within-blocks. We proposed that the on-line generation of temporal expectancy involves controlled processing (e.g., underlying time estimation processes), which could be impaired by demanding tasks. Thus, the effects were reduced in choice-RT compared to simple-RT detection tasks because the former task demanded more central resources to maintain in working memory a more complex and arbitrary stimulus-response association (see also Correa et al., in press, for further evidence). Moreover, this explanation accounted for the effect of blocking expectancy in discrimination tasks. Demands to generate temporal expectancy were reduced when expectancy did not change during a block of trials (i.e., between blocks manipulation), thus producing larger effects than when expectancy was manipulated within-blocks.

Consequently, the present experiment combined a shape discrimination task with the manipulation of temporal expectancy between blocks. Given that such features increased the sensitivity of our procedure, we expected to observe an early modulation of ERP components linked to visual processing, such as P1 and N1, produced by temporal attention. According to previous research, a modulation of late components (N2 and P300) was also expected.

Methods

Participants

Nineteen students from the University of Granada took part in the experiment as volunteers in exchange for course credits. All participants gave informed consent prior to their inclusion in the study. They reported normal or corrected to normal vision. Data from seven participants were rejected due to unsatisfactory recordings. Data from the same twelve participants were accepted for both behavioural and ERP analyses (age range: 18-26 years, mean age: 21; 10 women, 2 men). All participants were right-handed.

Apparatus and stimuli

E-prime software (W. Schneider et al., 2002) controlled the experiment. The experiment was run on a PC connected to a 17 inch monitor. This computer was connected to a Macintosh computer, which recorded continuous EEG (materials used for the EEG recording will be described below).

All stimuli appeared in the centre of the screen. On each trial, a fixation point (“+” symbol; font: Arial 24), a temporal cue and a target were presented. The cue was the word ‘EARLY or ‘LATE’, coloured in black (Tahoma 16, in italics. In Spanish: ‘PRONTO or ‘TARDE’, subtending 0.67º of visual angle in height, and 3.91º and 3.25º in width, respectively). The target was either the letter ‘O’ or the letter ‘X’, 8 mm in height by 8 mm in width (Arial 24. 0.76º). The two target letters appeared with a probability of .50. Participants pressed with their left index the left key of a button box for one target, and pressed the right key (with their right index) for the other target. The assignment of targets to response keys was counterbalanced across participants.

Procedure

Participants were seated at approximately 60 cm in front of the monitor. Instructions concerning the task were displayed on the screen. Participants were explicitly informed that the temporal cue would help them to predict when the target would appear. Auditory feedback (a 2000 Hz tone of 50 ms) and visual feedback (the word “incorrect” coloured in red for 500 ms) was provided on error trials. Participants were encouraged to respond as quickly and accurately as possible, and to avoid eye blinks and movements during stimulus presentation. The sequence of events on a trial is displayed in Figure 5.1.

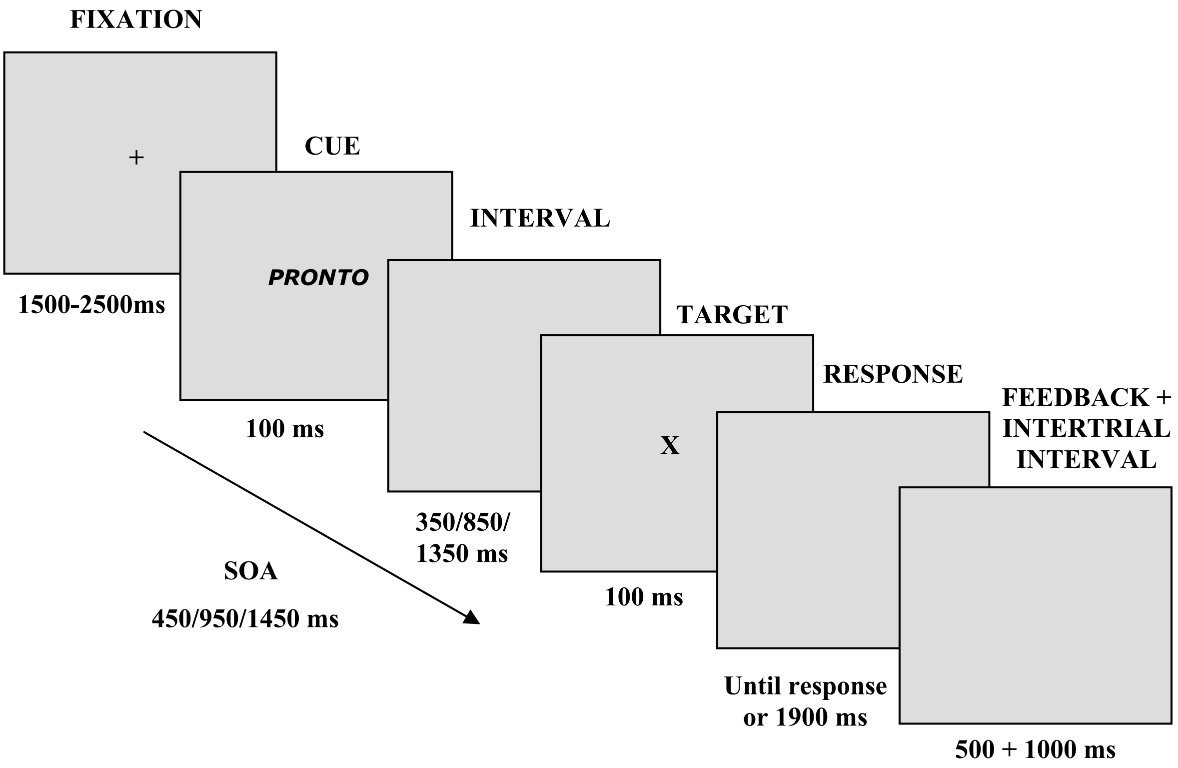

Figure 5.1. *Sequence of events on a trial.*

The fixation point was displayed in black on a white background for a random interval ranging between 1500 and 2500 ms. The temporal cue then appeared for 100 ms. After that, the screen remained blank for a variable delay of 350, 850 or 1350 ms, depending on the SOA for that trial. The target was displayed for 100 ms and was then replaced by a blank screen in waiting for the discrimination response, for a maximum delay of 1900 ms. Following the response (or the 1900 ms delay), the screen either remained blank on correct trials or displayed the feedback message on incorrect trials (i.e., anticipations, incorrect discriminations or response on catch trials) for 500 ms. There was an intertrial interval of 1000 ms in which eye blinks were less disrupting.

The whole session lasted about 100 minutes. Each session included one block of 20 practice trials and six blocks of 128 experimental trials. On half of the experimental blocks, the cue indicated that the target was likely to appear “early”. On the remaining blocks, the cue indicated that the target was likely to appear “late”. Blocks of early expectancy and late expectancy were successively alternated, and the order of delivery was counterbalanced across participants.

There were short breaks in the middle and at the end of each block, and a longer break in the middle of the experiment. Each experimental block consisted of 112 trials with target and 16 trials without target, thus producing a catch trial proportion of .125. The 112 target trials consisted of 84 validly cued trials and 28 invalidly cued trials, yielding a validity proportion of .75. Valid trials included the two following conditions: Early cue-450 ms SOA and late cue-1450 ms SOA. Invalid trials were equally distributed between the two uncued SOAs for both early and late cues. All the trials at the medium SOA were invalid. Once the participants finished the task, they were shown their own EEG and were informed about the purposes of the study.

EEG recording

The EEG recording was performed in an electrically shielded room, using a 128-channel Geodesic Sensor Net of Ag/AgCl electrodes (Tucker, Liotti, Potts, Russell, & Posner, 1994). The distribution along the scalp is depicted in Figure 5.2.

The head-coverage included sensors lateral to and below both eyes to monitor horizontal and vertical eye movements (electrooculogram, EOG electrodes). Impedances for each channel were measured and kept below 50 KΩ before testing, as recommended for the Electrical Geodesics high-input impedance amplifiers. All electrodes were referenced to the Cz electrode during the recording and were algebraically re-referenced off-line to calculate the average reference. The EEG was amplified with a band pass of 0.1-100 Hz (elliptic filter) and digitized at a sampling rate of 250 Hz.

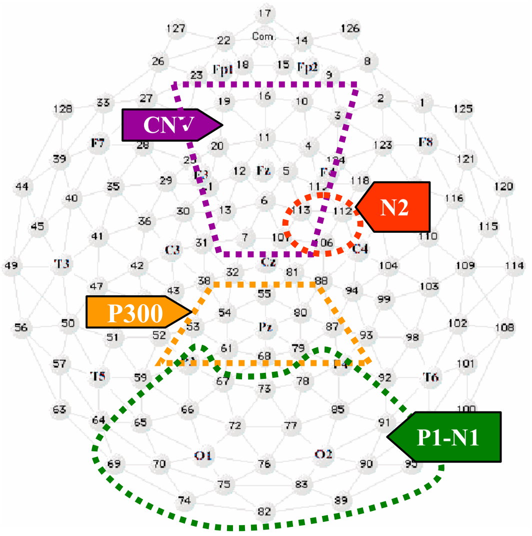

Figure 5.2. *Sketch of the electrodes distribution around the scalp as viewed from above (the top of the figure represents the frontal area). The electrodes selected for analyses are specified for each component (P1/N1, N2, P300 and CNV). Additional sites according to the 10-20 International system are shown for further reference.*

ERP analysis

The continuous EEG was 30 Hz low-pass filtered offline, and then segmented in epochs of [-200, 800] ms and [-200, 600] ms relative to the cue onset and the target onset, respectively. A 200 ms segment previous to the cue presentation was used to calculate the baseline. A strict baseline correction was performed for the target, [-40, 40] ms, in order to minimise unspecific preparatory effects prior to target presentation (e.g., Griffin et al., 2002). Additionally, a long epoch of [-100, 2300] ms with a [-100, 0] ms baseline was created for visual inspection, to have a general impression of all the events occurring on a trial.

The epochs were submitted to software algorithms for identification of artefacts. Trials with eye blinks or saccades (i.e., deflections larger than ±50µV in EOG electrodes), and trials that did not meet the behavioural performance criteria were rejected. Data from participants with less than 25 artefact-free trials per condition were discarded.

The epochs were then averaged separately for cues and targets according to the experimental conditions. ERP waves elicited by temporal cues were separated into early-expectancy and late-expectancy conditions. ERPs evoked by targets were separated into valid and invalid trials. Given that analyses focused on the short SOA (see Discussion), the valid condition included trials in which the cue was ‘early’ and the target appeared at the short SOA, whereas the invalid condition included trials in which the cue was ‘late’ and the target appeared at the short SOA.

Identifiable ERP components (P1, N1, N2, CNV and P300) were analysed at electrode locations and temporal windows where they were most evident. The selected electrodes are shown in Figure 5.2. The temporal windows were [139-179], [247-287] and [435-475] ms for P1, N1 and CNV components of the cue analysis. In the target analysis, the temporal windows were [127-167], [247-287], [359-399] and [499-539] ms for the respective P1, N1, N2 and P300 components. The mean amplitude and latency of the largest peak were analysed by repeated-measures ANOVAs for each component. The experimental condition (i.e., early vs. late for the cue analysis, and valid vs. invalid for the target analysis) and hemisphere (left, midline and right) were included as factors. The value for each hemisphere was calculated by averaging all the electrodes included in that hemisphere.

Results

Behavioural results

Data from the 12 participants who contributed to ERP results were used for behavioural analyses. Trials with correct responses faster than 200 ms or slower than 1000 ms, anticipations (i.e., responses before target presentation), misses, responses in catch trials and incorrect responses were excluded from the RT analysis. Less than 5% of the trials were rejected.

Mean RTs were submitted to a repeated-measures ANOVA with expectancy (early/late) and SOA (450/950/1450 ms) as factors. Crucially, the interaction between expectancy and SOA was significant, $F(2, 22)=37.5$, $p<.001$. As can be seen in Figure 5.3, valid trials were significantly faster than invalid trials at both the short SOA, $F(1,11)= 44.73$, $p<.001$ and the long SOA, $F(1,11)= 11.75$, $p<.01$. However, validity effects seemed to be larger at the short SOA (50 ms) than at the long SOA (36 ms).

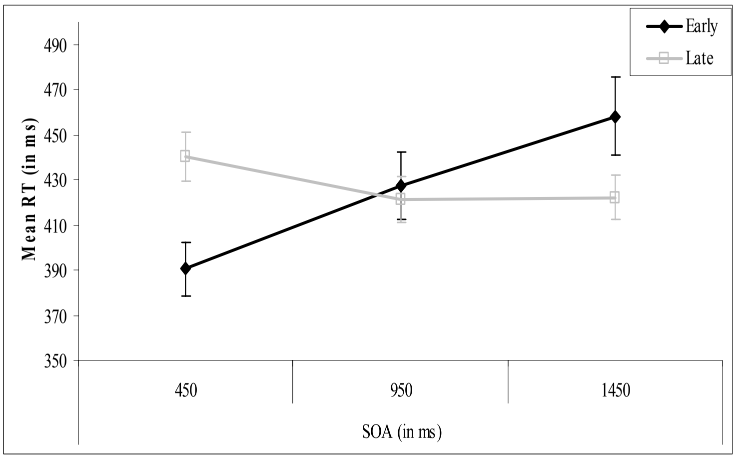

Figure 5.3. *Mean RTs as a function of temporal expectancy (early or late) and SOA. Note that at the short SOA the early expectancy condition is valid (late expectancy is invalid), whereas at the long SOA the late expectancy is valid (early expectancy is invalid).*

Further analyses revealed that both early and late expectancies followed a linear trend, $F(1,11)= 44.99$, $p<.001$, $F(1,11)= 19.01$, $p<.001$, respectively. The quadratic trend was far from significance for the early expectancy, $F<1$ and was marginally significant for the late expectancy ($p<.07$).

The global accuracy in the discrimination task was of 96% correct. The analysis of correct responses percentage was in line with RT results, although it did not reveal significant effects.

Electrophysiological results

Data from 7 participants were rejected from analyses due to excessive artefacts during the recording.

ERPs evoked by temporal cues

Figure 5.4 (Panel A) represents ERP waveforms, evoked by valid-early and valid-late cues, recorded at occipital and central electrodes. The occipital electrode (lower panel A) showed the typical response to visual stimulation. In particular, the P1/N1 component was produced by both early and late cues, by targets appearing at the short SOA when the cue was (valid) early, and by targets appearing at the long SOA when the cue was (valid) late.

The central electrode (upper panel A) showed a positive deflection peaking at around 260 ms. Then, a negative deflection appeared with an earlier onset and a shorter duration for the early cue compared to the late cue. Moreover, this negativity was larger for early vs. late cues during an interval that included the early-target onset (i.e., 450 ms after cue onset). In contrast, the negativity appeared larger for late vs. early cues during an interval that included the late-target onset (i.e., 1450 ms after cue onset). In other words, this negative potential seemed to be time-locked to the expected target onset, which suggests a link to the contingent negative variation (CNV) component (Walter et al., 1964). Afterwards, positive waves related to the P300 component were observed in response to respective early and late targets.

These visual impressions were statistically tested by a 2 (expectancy: early/late) x 3 (hemisphere: left/midline/right) repeated-measures ANOVA, using shorter epochs for analysis [-200, 800] ms. Since such epochs were longer than the shortest SOA (450 ms), trials with targets appearing at the short SOA (regardless its validity) were rejected to exclude activity related to targets.

The P1 component was larger for the early expectancy compared to the late expectancy, $F(1,11)=11.67$, $p<.01$ (see Figure 5.4). As shown in Figure 5.4, the CNV was more negative for the early expectancy at the short temporal window [435-475] ms, $F(1,11)=9.69$, $p<.01$. Thus, the state of increased preparation matched the expected target onset.

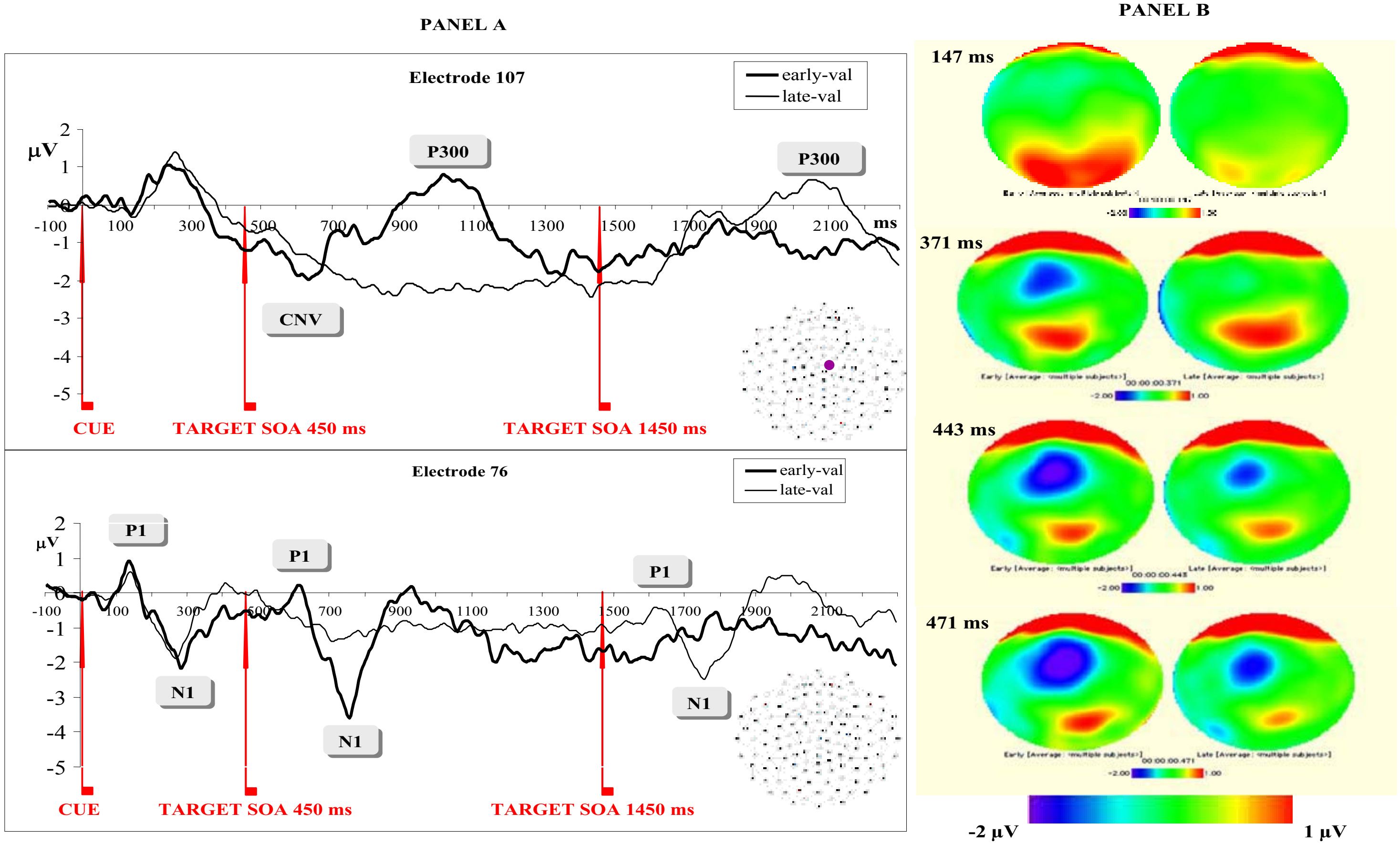

Figure 5.4. *Panel A, on the left, shows the ERP waveforms (positive is plotted upward) evoked by valid-early (thick line) and valid-late cues (thin line), recorded at central electrodes (the electrode 107, adjacent to Cz, is shown in the left upper panel) and occipital electrodes (the electrode 76, between O1 and O2 is shown on the left lower panel). The onset of relevant stimuli, cue and targets, are indicated. Panel B, on the right, shows the topographical distribution of the ERPs for early and late cues (see heads on the left and right hand-side in Panel B, respectively) at 147, 371, 443 and 471 ms after cue onset, as viewed from above.*

The topographical distribution of the ERPs elicited by early and late cues is also depicted in Figure 5.4 (see Panel B at the left head and the right head, respectively). The mentioned P1 effect was evident at around 147 ms over occipital sites. The CNV started earlier (see panels of 371 ms) and was more negative for the subsequent intervals (443 ms, 471 ms) for the early expectancy over frontal-central sites. At the same time, it is important to note a higher positive anticipatory activity for the early-expectancy wave compared to the late-expectancy. Remarkably, this activity distributed over posterior electrodes, and matched the time of the expected target appearance (see 443 ms, 471 ms).

ERPs evoked by targets

The visual components evoked by targets appearing at the short SOA, recorded at occipital sites, are shown in Figure 5.5 for valid and invalid trials (i.e., early expectancy-short SOA and late expectancy-short SOA, respectively). Mean amplitude and latency measures were submitted to a 2 (validity: valid/invalid) x 3 (hemisphere: left/midline/right) repeated-measures ANOVA.

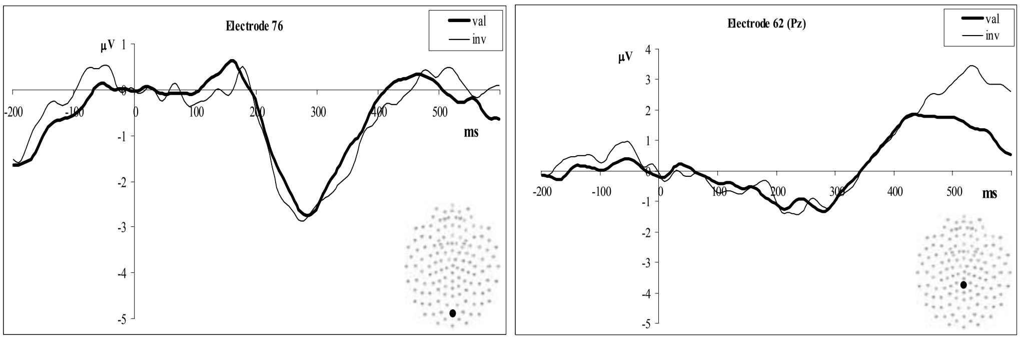

Figure 5.5. *The left panel shows the visual components (P1/N1) evoked by targets appearing at the short SOA recorded at occipital sites for valid trials (thick line) and invalid trials (thin line), i.e., for early expectancy-short SOA and late expectancy-short SOA conditions, respectively.* *The right panel shows the P300 component evoked by the target recorded at central-parietal sites for valid and invalid trials (the Cz electrode is shown.*

The most relevant result was that targets appearing at the cued time interval yielded a larger P1 amplitude than targets appearing earlier than expected, $F(1,11)=5.64$, $p<.04$.

The characteristic N2 waveform was clearly observed only at three frontal electrodes, so that the ANOVA only included validity as a single factor. N2 was also modulated by temporal attention, such that its peak was attenuated, $F(1,11)=8.62$, $p<.02$ and appeared earlier, $F(1,11)=11.18$, $p<.01$ in valid trials (367 ms) compared to invalid trials (376 ms).

The P300 component evoked by the target recorded at central-parietal sites is also depicted in Figure 5.5 for valid and invalid trials (see lower panel). Separate 2 (validity: valid/invalid) x 3 (hemisphere: left/midline/right) repeated-measures ANOVAs were conducted for the amplitude and latency of the P300 component. The P300 amplitude was larger in invalid trials, $F(1,11)=7.4$, $p<.02$ and its peak appeared earlier in valid trials (510 ms) than in invalid trials (520 ms), $F(1,11)=8.85$, $p<.02$ for the selected time window.

Discussion

Behavioural data revealed faster RTs for expected vs. unexpected targets at both the short and the long SOA, which suggests that attentional resources can be flexibly deployed to different points in time. However, most temporal orienting studies have observed validity effects exclusively at the short SOA (e.g. Coull & Nobre, 1998). It is assumed that a reorienting process from short to long intervals is engaged when an invalid target appears later than expected, so that the predicted cost in RT for invalid targets is not observed at the long SOA. We have shown that the reorienting process can be controlled by manipulating the participant's certainty about the target occurrence (Correa et al., 2004). Specifically, validity effects at the long SOA were only observed in the groups that included catch trials (i.e., a proportion of .25). We interpreted that catch trials increased the uncertainty of target occurrence, such that the reorienting process was impaired. The present data replicated previous findings, revealing significant attentional effects at the long SOA with a catch trial proportion of .125. However, validity effects at the long SOA seemed to be smaller compared to the short SOA, which might suggest that the reorienting process was not completely prevented by the presence of catch trials. Additional observations in our laboratory (unpublished data) pointed that the dispreparation induced by catch trials decreases gradually with lower catch trial proportions. Thus, invalid trials may not be equivalent for the short and the long SOA conditions (see Coull, Frith, Büchel et al., 2000, for neuroimaging evidence), so that the early expectancy-long SOA was not a pure condition of non attention in our experiment, albeit catch trials were included. Consequently, the ERP analyses focused on the short SOA.

Concerning electrophysiological data, the typical major findings of temporal orienting research (e.g. Griffin et al., 2002; Miniussi et al., 1999) have been replicated using a different system for ERP recording and analysis (see Figure 5.4). In particular, the negative deflection related to the CNV component developed earlier for early than for late expectancies. Moreover, the CNV was larger at the short SOA for the early expectancy, and appeared to be larger at the long SOA for the late expectancy condition, which suggests that temporal cues tuned the preparation process to the expected relevant moment. This preparation seemed already evident at processing stages prior to the CNV, since early cues showed a larger P1 component compared to late cues. To our knowledge, this result has not been previously reported in other attentional studies. The effect cannot be attributed to differential trial proportions, since both early and late blocks were balanced in that respect. It might be explained considering that our procedure gained sensitivity as expectancy was manipulated between blocks. Thus, the mental set developed during a homogeneous block of trials in which the expectancy does not change could be influencing processing, more strongly and at earlier stages, than when temporal expectancies have to be generated on line in trial-by-trial manipulations. Hence, the modulation of preparation induced by early cues could be observed as early as in P1. This result fits into behavioural experiments in the sense that the size of temporal-orienting effects in discrimination tasks is enhanced by a between blocks manipulation (Correa et al., 2004). In any case, further research would be necessary to elucidate this intriguing effect.

However, the most important result was found in the ERPs evoked by targets. Valid targets increased the P1 component compared to invalid targets over occipital sites. Effects of temporal attention on P1 had not been observed so far. Only Doherty and Nobre (in press) reported a modulation of an early positive component previous to P1 over central and frontal electrodes (‘P1c’). The sensitivity of our procedure to find the effect on P1 could have been optimised by the use of a shape discrimination task in which temporal expectancy was manipulated between blocks. As said above, temporal orienting effects in choice-RT discrimination tasks are larger when expectancy is manipulated between blocks rather than within-blocks (Correa et al., 2004). Therefore, expectancy was manipulated between blocks in this task, in order to obtain robust behavioural and physiological effects. In contrast with results of the ERPs evoked by cues, the effect of targets on P1 can indeed be attributed to differential trial proportions (i.e., 75% valid vs. 25% invalid), which suggests that visual attention was strategically focused on the relevant time interval.

Moreover, temporal attention modulated the N2 component. The increase of N2 by invalid targets replicated several studies (Correa & Nobre, in preparation; Griffin et al., 2002, Experiment 2; Miniussi et al., 1999). According to van Veen & Carter (2002), N2 may be considered as an index of general conflict detection. In our specific case, N2 could be reflecting processes involved in temporal expectancy disconfirmation. For example, N2 reflects a process of conflict detection between the expected and the actual temporal occurrence of the target, followed by a reconfiguration of the system to adapt behaviour to the unexpected situation. Thus, N2 increased when temporal expectancy had been disconfirmed by a sudden target onset on invalid trials. On the other hand, attention could prevent conflict detection and reconfiguration processes, so that an expected target would produce a smaller N2. Likewise, this saving of processing time by attention may be the source of the smaller N2 latency observed on valid trials. The effect on N2 latency had been only observed in a previous experiment (Correa & Nobre, in preparation).

Furthermore, the P300 was influenced by the temporal orienting of attention. First, the P300 amplitude was increased in response to invalid targets. This result is discrepant with studies that found no differences between valid and invalid targets (Doherty et al., in press; Griffin et al., 2002, Exp. 2; Miniussi et al., 1999), and other studies that found a larger P300 for valid targets (Correa & Nobre, in preparation; Griffin et al., 2002, Exp. 1; Lange et al., 2003).

Considering that infrequent invalid targets produce an effect of surprise, P300 could reflect a process of novelty detection (Duncan-Johnson & Donchin, 1977). This inconsistency concerning effects on P300 amplitude is also found in spatial attention studies (Martin-Loeches, Barceló, & Rubia, 1997). Further research would be required to isolate the experimental situations that determine the P300 component, and to better understand its psychological significance.

On the other hand, results of P300 latency are convergent in temporal orienting studies (see Table 1). The P300 peak appeared earlier for valid targets compared to invalid targets. It is considered that temporal attention enhances and synchronizes processes of decision and preparation for responses (Miniussi et al., 1999). In sum, it seems that one idiosyncratic feature of temporal attention is the ability to modulate the latency of cognitive processes in order to synchronize them to the behaviourally relevant moment.

General conclusions

The present experiment confirmed that focusing attention on a point in time improves behavioural performance, decreasing RTs in detection tasks (see Nobre, 2001) as well as in discrimination tasks (e.g., Correa et al., 2004). Moreover, electrophysiological results suggest that, underlying this improvement, there is an increase of preparatory activity which is time-locked to the expected target occurrence. Thus, the temporal course of the preparation process can be flexibly modulated according to the participant’s temporal expectancy induced by the cue. Previous studies have linked such a process to the CNV component (Loveless & Sandford, 1974; Miniussi et al., 1999; Walter et al., 1964).

In addition, the ERP methodology allowed us to explore the locus of such attentional effects. Electrophysiological studies that used detection of visual targets as task have mainly found that temporal attention influences late components (N2 and P300), which are mostly related to motor processing. Our results have replicated the modulation of N2 and P300, supporting thus the notion that temporal attention produces a motor preparation. However, the finding of behavioural benefits in the discrimination task raised the possibility of a perceptual preparation. Hence, attention could facilitate perceptual processes involved in discriminating object features. Alternatively, it could be argued that attention exclusively facilitated decision or motor response processes demanded in choice-RT discrimination tasks (Nobre, 2001).

Nevertheless, our physiological data provided further evidence to the perceptual hypothesis. First, we observed an increment of anticipatory activity over the parietal-occipital area just before the predicted moment of the target arrival (see Figure 5.4). Activity preceding stimuli presentation is generally balanced for cued and uncued conditions, in order to isolate effects of spatial attention on visual processing (see Näätänen, 1975). Although this logic makes sense in spatial attention research, it may not be similarly applicable to temporal attention. Thus, it could be assumed that the synchronization of this anticipatory activity to relevant moments is precisely the hallmark of temporal orienting, so that it should not be balanced for attended and unattended conditions. Presumably, the fact that this activity was observed over the occipital area could be indicative of perceptual enhancement.

Furthermore, the enhancement of a component traditionally linked to visual processing (P1) represents more compelling evidence of perceptual enhancement produced by temporal attention. Despite the strict correction of the pre-target activity for both conditions, attended targets still evoked a larger P1 component relative to unattended targets. This finding is in line with previous physiological studies of temporal orienting, which have found attentional enhancements at early stages of processing (Doherty et al., in press; Griffin et al., 2002, Exp. 1; Lange et al., 2003).

As we have seen in the review, common to all these studies is the demand of optimising perceptual processing to accomplish the task rather than the demand of just speeded responses. This leads to question whether spatial and temporal attention modulates visual stimulus processing in an analogous fashion. Whereas spatial attention can easily influence early and late stages of processing, it seems that temporal attention yields less evident effects on early processes. This difficulty could be due to the fact that the brain lacks a retinotopic map in visual areas to code temporal features analogous to the map involved in visuospatial coding. Thus, neural representations of specific locations can be directly amplified by spatial attention

(Mangun, 1995), whereas higher perceptual demands would be necessary to capture the effects of temporal attention. In contrast, coding of temporal features is mainly involved in auditory processing as well as in sequencing motor acts (see also Nobre & O'Reilly, 2004), so that when the auditory modality is involved (Lange et al., 2003) or motor processing is demanded (Miniussi et al., 1999), effects of temporal attention are clearly observed at early or late stages of processing, respectively. Accordingly, we suggest that spatial attention and temporal attention could engage a similar mechanism of processing modulation, which has a partially different manifestation depending on the nature of the representations and the processing demands being involved. To conclude, the present research supported the hypothesis drawn from the review, that is, temporal attention not only modulates late motor processing, but also early visual processing when perceptually demanding tasks are used. Further research, however, should elucidate the experimental conditions in which the early ERP components are modulated in a specific manner.

Series IV: Temporal attention in natural environments: Behavioural and electrophysiological studies on temporal orienting to dynamic stimuli.

Temporal attention in natural environments involving moving stimuli

Ángel Correa [1, 2] and Anna C. Nobre [1]

[1] University of Oxford. United Kingdom

[2] Universidad de Granada. Spain

Manuscript in preparation

Abstract

We explored whether attention can flexibly build temporal expectancies based on moving objects across a wide range of speeds. The attentional orienting task consisted of an object that moved across the screen from left to right before disappearing under an occluding band. Once the object reappeared, participants were to detect a black dot in its centre. Experiment 6.1 manipulated the pace of movement to induce temporal expectancy (regular/predictable pace) or neutral expectancy (random/unpredictable pace). Experiment 6.2 manipulated the time for which the object was occluded, thus dividing the temporal expectancy condition into valid, early-invalid (earlier than expected targets) and late-invalid trials. The neutral expectancy condition (Exp. 6.1) and late-invalid trials (Exp. 6.2) were not pure conditions of non attention, as they afforded temporal predictions according to probabilistic information inherent in the occlusion time (the hazard function). Experiment 6.3 explored, for the first time, the electrophysiological correlates underlying temporal attention based on moving objects across multiple speeds. The analyses focused on the valid versus early-invalid comparison, which showed a robust attentional effect on RTs. The ERP analysis revealed attentional modulations on the latency and amplitude of late components as N2 and P300. The latency modulation is considered as one idiosyncratic effect of temporal attention, and suggests preparation and synchronization processes tuned to the expected relevant moment. Hence, behavioral and physiological data replicated the main findings of traditional temporal orienting tasks by using a task that simulates more realistically our dynamic environment, in which temporal information is often implicitly provided. Moreover, the results suggest that humans can build on-line temporal expectancies tuned to a broad range of speeds of moving objects.

The attentional mechanism likely plays a key role in everyday situations, for example, when someone anticipates the upcoming location of a moving object, especially when it is temporary occluded by other objects in a visual scene. A recent study (Doherty et al., in press) has explored our ability to build spatial and temporal expectancies by attentive tracking to object movements (see Schubotz & von Cramon, 2001, for a different approach). The task developed by Doherty et al. consisted of a ball that moved across the screen from left to right before disappearing under an occluding band. Upon the ball's reappearance, subjects discriminated the presence of a black dot in its centre. Then, the way the ball moved before the occlusion served to induce temporal expectancy, spatial expectancy or no expectancy, which allowed participants to predict the moment or the location of the ball's reappearance. The behavioral results revealed that participants were faster when the stimulus movement before the occlusion followed a trajectory either spatially predictable (i.e., a straight line) or temporally predictable (i.e., a pace with constant speed), compared to when the pattern of movement could not be predicted (i.e., random trajectories or speeds).

Such attentional benefits are analogous to the observed in classical studies on both spatial orienting of attention (Posner, 1980) and temporal orienting of attention (see Nobre, 2001, for a review). Importantly, these studies have traditionally used static artificial displays. For example, the temporal orienting of attention has been investigated with a temporal analogue to the Posner's paradigm, such that explicit static cues (i.e., two cross symbols centrally presented for 100 ms) indicated the most probable moment for target onset (Coull & Nobre, 1998). The results showed that performance was improved as targets appeared at expected versus unexpected moments.

Thus, both the classical and Doherty et al.'s tasks have found faster reaction times (RTs) for stimulus appearing at predicted locations or moments, compared to unpredicted targets. To establish an analogy between the two procedures, the stimulus movement before the occlusion in the Doherty et al.'s task would act as the cue, which could be spatial, temporal or neutral depending on the pattern of movement involved. The information provided by the cue is used to build expectancy. Then, the expectancy works during the period of stimulus occlusion, in order to predict the location or the moment of its upcoming reappearance. This occlusion period would correspond to the time interval between cue and target, typically called "stimulus onset asynchrony" (SOA) in the Posner's procedure.

Hence, the two procedures might be engaging similar cognitive processes. Note, however, that traditional attentional-orienting procedures use static and explicit cues, whereas the Doherty et al.'s procedure use dynamic implicit cues, which seems more naturalistic and simulates more accurately our dynamic world. Then, a challenging issue of research is to assess the extent to which dynamic and static procedures involve the same processes of attentional orienting. This should provide more confident extrapolations and richer concepts about the real functioning of the attentional mechanism in natural environments.

Another aim of the Doherty et al. study was to compare differential and/or interactive effects on stimulus processing produced by spatial attention and temporal attention. However, the spatial and temporal conditions were not completely comparable. The spatial condition included a large range of spatial expectancies derived from potentially infinite straight trajectories, whereas the temporal condition only included a single temporal expectancy derived from movements with the same speed for all trials. Therefore, the flexibility of the attentional mechanism to build temporal expectancies based on moving objects remained to be investigated. In the same way as Coull and Nobre (1998) showed that attentional resources could be flexibly deployed to more than one fixed foreperiod (see Niemi & Näätänen, 1981, for a review of the foreperiod literature), the present work aimed to extend the Doherty et al.'s results to more than one single temporal expectancy. Moreover, the present work used the event-related potentials methodology (ERPs) to study on line the electrophysiological correlates of temporal attention based on moving objects.

EXPERIMENT 6.1

Experiment 6.1 explored the flexibility of temporal attention by inducing a wide range of expectancies related to a variety of stimulus speeds. Kinetic temporal attention was defined as 'the preparation based on temporal expectancy induced by an object that moves with predictable speed'. If kinetic temporal attention included such flexibility, the behavioral benefits observed for spatial expectancies as well as for a single temporal expectancy (Doherty et al., in press), should be replicated across a broad range of stimulus speeds.

Furthermore, the manipulation of the stimulus speed afforded to explore whether the process of temporal expectancy generation is facilitated or hindered at particular speeds. In other words, we examined which stimulus speeds were more suitable to build temporal expectancies, in order to observe the mentioned attentional effects.

Method

Participants

Fourteen participants (age range 20-34 years, 6 female) took part voluntarily in Experiment 6.1. Two of them were discarded due to accuracy near chance. The experimental methods were non-invasive and had ethical approval from the Department of Experimental Psychology (University of Oxford).

Apparatus and stimuli

The stimuli were presented on a monitor connected to a PC, which controlled the presentation of stimuli and data collection. An infrared eye tracker connected to another PC recorded eye movements. The display consisted of a dark green fixation point (diameter: 0.18º) placed at the centre of the screen, over a black background. A gray occluding band (width: 3.5º) was placed at an eccentricity of 11.4º - 14.9º from the centre. The moving stimulus was a yellow 'ball' (diameter: 0.7 º) that always appeared on the left-hand side of the screen and moved from left to right in 15 steps of size 1.3º , so that there were 9 steps before the occluder, 2 steps underneath it and 4 steps after the occluder. Only the first step after occlusion was selected for the possible appearance of the target. The target consisted of the same yellow ball with a black dot in its centre (diameter: 0.15º). Participants were to press the space bar if the black dot was present (go trials), or withheld response if the yellow ball appeared without the black dot (nogo trials). There was a go/nogo trial proportion of .80. RTs and accuracy were collected.

Procedure

Participants were comfortably seated in a dimly illuminated room at approximately 100 cm in front of the screen. Then, the task was explained and they were instructed to use the information inherent in the way the ball moved, if possible, to anticipate the moment of the ball reappearance after the occluder. Participants were also encouraged to respond as fast and accurately as possible, and to permanently keep their gaze on the central fixation point. Thus, they could track the ball movements only with their covert attention, which was necessary to discriminate the small black dot of the target. Participants felt additionally encouraged to hold their gaze as they knew that their eye movements would be monitored.

The sequence of events on a trial for the different conditions is depicted in Figure 6.1.

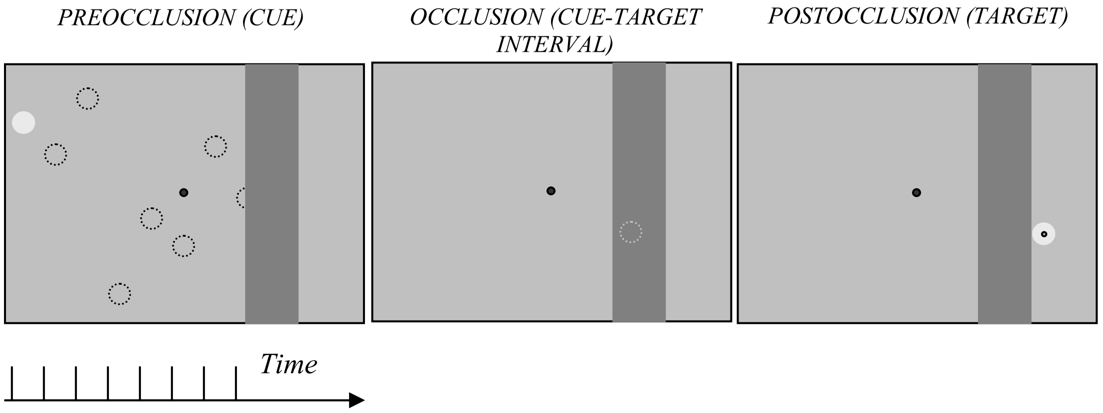

Figure 6.1. *Example of a trial in the temporal expectancy condition. In the pre-occlusion period, the ball moves from left to right at a constant pace. The vertical bars in the time arrow represent the duration of each step, showing the same height in the temporal expectancy condition. In the occlusion period, the ball disappears under the occluding band. In the post-occlusion period, the target appears at the right hand-side of the occluding band for 550 ms.*

The trial began when the ball appeared on the left-hand side of the screen and moved from left to right in all trials. The ball did not follow a predictable spatial trajectory, as it was randomly placed in a different vertical location on each step. When reaching the occluder, the ball disappeared underneath it for 2 steps. Then, the ball (or the target) reappeared on the right-hand side of the occluder for 550 ms in all conditions, showing a black dot in its centre in 80% of trials. After the reappearance step, the ball moved 3 additional steps until exiting the screen on the right-hand side to provide a continuous sensation of movement. The next trial began after a random intertrial interval that ranged from 700 to 1000 ms.

The ball moved with different types of paces, depending on the experimental condition. In the temporal expectancy condition, the ball held a constant pace (i.e., speed), so that it remained on the screen for the same amount of time on every step until a trial is finished. Note that there was a single speed for all trials in this condition (550 ms per step) in the Doherty et al. study. In contrast, the ball could move at a different speed on each trial (between 200 ms and 900 ms per step) in the present study. Thus, once the speed was randomly selected from this range at the beginning of a trial, the ball moved with the same speed till the end of that trial. This temporal regularity allowed participants to build temporal expectancies tuned to the ball speed, so that they could predict and focus their attention on the moment when the ball would exit the occluder. In the neutral (no expectancy) condition, the ball did not follow a regular speed, since each step within a trial lasted a different time interval, which randomly ranged between 200 ms and 900 ms. Therefore, the participants could not anticipate when the ball would reappear.

There were 2 blocks of 50 trials plus 2 practice blocks of 20 trials, with the same go/nogo trial proportion. Each experimental block consisted of 40 go trials and 10 nogo trials. The expectancy (temporal versus neutral) was manipulated between blocks, such that there was one block for each condition. Each experimental block was preceded by a practice block of the similar experimental condition. The order of presentation of the experimental blocks was counterbalanced. A short break was allowed between blocks. Considering that each trial lasted approximately 9 seconds on the average, the session took around 25 minutes to be completed.

Results and Discussion

Trials with correct responses faster than 100 ms or slower than 1000 ms, incorrect responses, as well as saccades, were excluded from the RT analysis. Mean RTs for correct responses were submitted to a repeated-measures ANOVA with expectancy (temporal / neutral) as a factor. In line with our prediction, RTs seemed faster for the temporal expectancy (432 ms) than for the neutral condition (445 ms), yet the effect did not reach significance ($p>.19$).

Accuracy data showed a high level of overall performance, which ranged between 75% and 100% of hits (89% on the average). The main effect of expectancy on hits percentage was far from significance ($F<1$).

Thus, the manipulation of expectancy did not seem to produce a clear effect on performance. One explanation might be that the attentional system is not as flexible as expected, so that the building of temporal expectancy is hindered when the moving stimulus involves a complex range of different speeds. In order to test this hypothesis, we further examined the effect of expectancy as a function of the average speed on a trial, to see whether some speeds were especially appropriate for the generation of temporal expectancy. Briefly, the analysis revealed an effect between the temporal and the neutral condition only at fast speeds. Surprisingly, this effect was not due to a larger benefit in the temporal condition, but to a larger cost in the neutral condition, when compared to RTs at slow speeds. That is, RTs in the temporal condition were independent of speed, whereas RTs in the neutral condition appeared to be enhanced as the speed decreased. This result suggests that temporal expectancies worked, at least, at fast speeds. What was happening at slow speeds, then?

Presumably, the neutral condition might also involve a kind of predictability, which masked the attentional effect due to a RT improvement at slow speeds. This explanation will become clearer if we relate the speed variable to the occlusion time. The time for which the stimulus is occluded becomes longer as the speed is slower. Consequently, participants could make predictions to overcome temporal uncertainty in the neutral condition on the basis on the hazard function, that is, ‘the longer the stimulus is occluded, the higher the probability of the stimulus to appear’.

Hence, this hypothesis was tested by including occlusion time as a factor. We expected to observe the largest attentional effect at short occlusion times. At long occlusion times, however, the effect would vanish, as the moment of the stimulus reappearance could be anticipated according to either predictable speeds in the temporal condition, or the information provided by the flow of time during the occlusion in the neutral condition. Occlusion time was divided ad hoc into three categories: short (400 – 866 ms), medium (866 – 1333 ms) and long (1333 ms – 1800 ms). Crucially, the 2 (expectancy: temporal / neutral) x 3 (occlusion time: short / medium / long) repeated-measures ANOVA revealed a significant interaction between expectancy and occlusion time, *F*(2,22)=3.97, *p*<.03. This interaction is depicted in Figure 6.2.

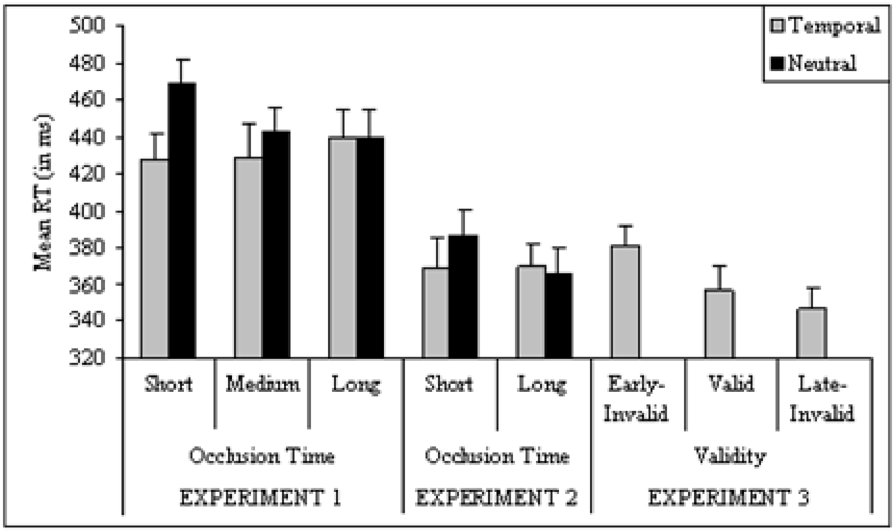

Figure 6.2. *Mean RTs as a function of expectancy (temporal and neutral) and occlusion time in Experiments 6.1 and 6.2. Mean RTs as a function of cue validity (early-invalid, valid and late-invalid) in Experiment 6.3.*

Further analyses showed a significant effect of expectancy, exclusively when occlusion time was short (*p*<.01). Moreover, RTs tended to decrease linearly with increments in occlusion time in the neutral condition (*p*<.07), but not in the temporal condition (*p*>.2). The quadratic trends were not significant in either case (all *ps*>.28).

These findings suggest that occlusion time is a key factor that determines the observation of attentional effects in this task. Possibly, the main effect of expectancy was more robust in Doherty et al.'s study due to the use of a single temporal expectancy, which strongly benefited performance independently of the occlusion time factor.

Additionally, the trend analyses may suggest that the neutral condition also allowed for attentional anticipations at long occlusion times. Such anticipations were afforded by the temporal predictability involved in the occlusion time of the stimulus. On the other hand, the finding that the temporal expectancy condition produced similar effects on RT at 3 different speeds, suggest that the attentional mechanism is sufficiently flexible to generate temporal expectancy across several speeds.

Given the relevance of occlusion time, this factor was directly manipulated in the following experiment to obtain more reliably evidence supporting our conclusions.

EXPERIMENT 6.2

The aim of Experiment 6.2 was to replicate the previous findings by manipulating occlusion time *a priori*. Interestingly, this manipulation opened the possibility to include valid and invalid trials. The cue validity manipulation is central in studies of attentional orienting (Posner, 1980). Then, we could further explore the attentional modulations in a more refined way by holding a regular pace of movements during the pre-occlusion, while varying the occlusion time to create valid and invalid trials. Thus, the temporal condition included valid trials in which the ball appeared at the expected moment according to the regular speed of the ball before the occlusion, invalid trials in which the ball appeared earlier than expected (early-invalid condition), and invalid trials in which the ball appeared later than expected (late-invalid condition). Despite the 'neutral' condition was not ideal to study temporal expectancy effects, it was included to compare Experiments 6.1 and 6.2.

According to previous studies of temporal orienting of attention (e.g., Coull & Nobre, 1998), we expected to observe a validity effect in the temporal expectancy condition, so that RTs were faster at valid trials than at invalid trials. Concerning the occlusion time factor, we expected to replicate interaction between expectancy and occlusion time (see Figure 6.2, Experiment 6.1), so that RTs in the temporal condition were faster than in the neutral condition only at short occlusion times. In the neutral condition, RTs were expected to decrease at long occlusion times.

Method

Participants

Twelve participants (aged 19-34, 4 female) took part voluntarily in Experiment 6.2.

Apparatus and stimuli

The following were the changes introduced in Experiment 6.2. E-prime software (W. Schneider et al., 2002) controlled the experiment. The background colour was changed from black to light gray, because many participants reported an uncomfortable confusion due to the target-dot and the background shared the same colour. Other minimal changes were that a dark gray occluding band (width = 2.55º) was placed at an eccentricity of 11.7º - 14.25º, the black dot of the target and the fixation point size were increased (diameter = 0.17º and 0.23º, respectively), and the step size was reduced to 1.24º.

Procedure

Everything was the same as in Experiment 6.1, except for the temporal condition, which was divided into valid, early-invalid and late-invalid trials by manipulating the expected occlusion time. In valid trials, the expected occlusion time was not modified, since occluded and non occluded steps kept the same duration. In early-invalid trials, the expected occlusion time was shortened, and the occluded steps lasted less than the non occluded steps. Then, the ball reappeared between 100 and 700 ms earlier than expected. In late-invalid trials, the expected occlusion time was lengthened, so that the ball reappeared between 100 and 700 ms later. Values from such a range were randomly selected and had, at least, a difference of 100 ms between the expected and the actual time of the ball reappearance, in order to make the invalid conditions more distinctive to the valid condition.

There were 4 blocks of 40 trials plus 2 practice blocks of 10 trials, with the same go/nogo trial proportion. Each experimental block consisted of 32 go trials and 8 nogo trials. Expectancy (temporal versus neutral) was manipulated between blocks, such that there was one set of two identical blocks for each condition. Each block set was preceded by a practice block of the similar experimental condition. The order of presentation of the block sets was counterbalanced across participants.

In the temporal condition, validity was manipulated trial-by-trial, so that each block included 20 valid trials and 20 invalid trials. The invalid condition included two groups (early-invalid and late-invalid) of practically similar number of trials, as occlusion time was randomly selected for each invalid trial. Obviously, there was no validity manipulation in the neutral condition.

Results

Trials with correct responses faster than 100 ms or slower than 1000 ms, incorrect responses, as well as saccades, were excluded from the RT analysis. Mean RTs were submitted to a repeated-measures ANOVA with validity (valid / early-invalid / late-invalid) as a factor. A significant effect of validity, $F(2,22)=13.63$, $p<.001$, showed faster RTs for valid trials (370 ms) compared to early-invalid trials (389 ms, $p<.02$). However, RTs for late-invalid (352 ms) were faster than for valid trials ($p<.01$).

The analysis based on the occlusion time consisted of a 2 (expectancy: temporal / neutral) x 2 (occlusion time: short / long) repeated-measures ANOVA. As in Experiment 6.1, the temporal condition only included valid trials. Occlusion time was divided into two categories: short (400 - 1100 ms) and long (1100 ms – 1800 ms), as the medium interval did not show relevant information in Experiment 6.1.

Results showed a similar pattern of findings to that of Experiment 6.1 (see Figure 6.2, Experiment 6.2). The interaction between expectancy and occlusion time was marginally significant, $F(1,11)=4.66$, $p<.054$. Interestingly, as found in Experiment 6.1, occlusion time was a decisive factor in the neutral condition, which yielded faster RTs at long versus short occlusion times (365 ms and 387 ms, respectively, $p<.01$). In contrast, RTs in the temporal condition were not affected by the occlusion time, $F<1$.

The analysis of accuracy revealed no significant effects.

Discussion

The most relevant finding in this experiment was the achievement of reliable attentional effects on RTs across a variety of temporal expectancies. Such expectancies were derived from a wide range of speeds of the moving stimulus. Specifically, task performance was improved when the target appeared at the expected time compared to when it appeared earlier than expected. In terms of the analogy proposed above, we propose that the time information inherent to the regular speed followed by the ball before the occlusion acted as an implicit cue. This cue induced a temporal expectancy according to that particular speed, despite not being predictable (.50). The occlusion period, analogously to the foreperiod or SOA, was the time interval for which participants used the expectancy to anticipate and to synchronize their point of optimum preparation to the predicted relevant moment. Consequently, the processing of the target was enhanced by temporal attention when it had appeared within the attentional focus. In contrast, the preparation process was not ready when the target had appeared earlier than expected.

Late-invalid trials were analysed separately from early-invalid trials, given that they did not constitute a homogeneous invalid condition. Research on temporal orienting of attention has typically reported significant validity effects restricted to the valid versus early-invalid comparison (Nobre, 2001). On the other hand, RTs are not generally faster on valid trials compared to late-invalid trials probably due to a reorienting process. Then, participants can reprepare themselves for a later moment once they realize the target did not occur at the initial expected time (Karlin, 1959). A previous study suggests that a high certainty on target occurrence is necessary to engage the reorienting process (Correa et al., 2004). As occurred with the neutral condition of Experiment 6.1, such certainty progressively increases with time, according to the conditional probabilities of the target occurrence (i.e., the hazard function).

However, when the certainty on target occurrence is compromised, for instance, by including trials in which the target is not presented (catch trials), the reorienting process is not engaged and RTs increase in late-invalid compared to valid trials.

As the present experiment did not include catch trials, the late-invalid condition was not adequate to study attentional effects (as occurred with the neutral condition in Exp. 6.1), given that attention was supposed to be present in both late-invalid and valid trials. In fact, RTs were unexpectedly lower for late-invalid than for valid trials. This discrepancy might be due to a low validity proportion in this experiment (.50) compared to other studies that reported no differences between late-invalid versus valid trials (.75 of valid trials). Nevertheless, despite this low cue validity, we still observed a robust attentional modulation when early-invalid and valid conditions were compared.

In relation to the occlusion time analysis, Experiment 6.2 was in line with the main results of Experiment 6.1. Thereby, the lack of attentional benefits for temporal vs. neutral trials was not due to a rigid mechanism unable to build a variety of temporal expectancies in the temporal condition. Rather, the occlusion time factor was modulating the effects, such that the neutral condition also involved temporal anticipation at long occlusion times. In the neutral condition, the time information about the stimulus reappearance was not extracted from the stimulus movement, but from the amount of time for which the stimulus was occluded, instead.

To summarize, Experiments 6.1 and 6.2 showed that the neutral and the late-invalid condition were not pure conditions of non attention, given that they involved temporal predictability. Instead, the comparison of valid versus early-invalid conditions seemed more appropriate. Promisingly, this novel task provides a naturalistic and dynamic procedure to study attentional orienting processes in the temporal dimension as well as in the spatial dimension.

EXPERIMENT 6.3

Once we had refined the task to trigger a robust attentional effect on behaviour, the following step was to explore for the first time the electrophysiological brain correlates of the temporal attention based on moving objects across a range of speeds.

Experiment 6.3 aimed to extend the physiological findings obtained with the previous version of the task (Doherty et al., in press). Thus, Experiment 6.3 further examined the flexibility of kinetic temporal attention by exploring whether attention based on multiple temporal expectancies modulated processing similarly to attention based on a single fixed expectancy. If so, then we should observe modulations on ERPs quite similar to the observed by Doherty et al.. That is, a modulation of potentials related to late processing, such as an attenuation of N2 and an earlier P300 peak produced by temporal attention when compared to the neutral condition. Moreover, we pretended to compare our results with the findings of the traditional temporal orienting task (Griffin et al., 2002; Miniussi et al., 1999).

Method

Participants

Twenty students (age range 18-32 years, 13 female) from the University of Oxford took part as paid volunteers in Experiment 6.3. Data from thirteen of them were accepted for both behavioral and ERP analyses.

Apparatus and Stimuli

Everything was identical to Experiment 6.2. Materials used for the EEG recording will be described below.

Procedure

As in Experiment 6.2, validity was manipulated trial-by-trial, so that each block included 20 valid trials and 20 invalid trials. Approximately half of the invalid trials were early-invalid, whereas the remaining half were late-invalid trials. However, according to the conclusions of Experiment 6.2, analyses focused exclusively on the comparison between valid and early-invalid trials, so that the early-invalid condition was referred to as ‘invalid’.

There were 8 blocks of 40 trials plus 1 practice block of 10 trials, with the same go/nogo trial proportion. Each experimental block consisted of 32 go trials and 8 nogo trials.

EEG recording

The EEG recording was performed in an electrically shielded room, using Ag/AgCl electrodes mounted on an elastic cap and distributed along 34 scalp sites according to the 10-20 International system (AEEGS, 1991). The montage included 6 midline sites (FZ, FCZ, CZ, CPZ, PZ and OZ) and 14 sites over each hemisphere (FP1/FP2, F7/F8, F3/F4, FT7/FT8, FC3/FC4, T7/T8, C3/C4, TP7/TP8, CP3/CP4, P7/P8, P3/P4, PO7/PO8, PO3/PO4 and O1/O2). Additional electrodes were used as ground and reference sites, and for recording the electrooculogram (EOG).

All electrodes were referenced to the right mastoid during the recording and were algebraically re-referenced off-line to calculate the average of the right and left mastoids. Horizontal and vertical eye movements were monitored by horizontal and vertical EOG bipolar recordings with electrodes placed around the eyes. Every subject’s eye movement was also controlled using the eye tracker. The EEG was amplified with a low-pass filter of 200 Hz and digitized at a sampling rate of 500 Hz.

ERP analysis

The continuous EEG was segmented offline in epochs of [-200, 822] ms, relative to target onset (i.e., the first reappearance step after the occlusion). A 200 ms epoch previous to target presentation was used to calculate the baseline. Epochs in which an eye blink or eye movement occurred were rejected on the basis on large deflections (± 50μV) in the HEOG or VEOG electrodes. Saccades were also detected with the eye tracker. A minimum criterion of 30 artefact-free trials per condition was set in order to have a confident signal/noise ratio.

The epochs were then averaged according to the experimental conditions, resulting in separate ERP waves elicited for targets appearing on valid trials and invalid (i.e., early-invalid) trials.

According to previous studies (e.g., Doherty et al., in press), identifiable ERP components (P1, N1, N2 and P300) were analysed at electrode locations and temporal windows where they were most evident. P1 and N1 were analysed at electrodes P7/P8, PO7/PO8, P7/P8 and O1/O2, using the mean amplitude from 120-160 ms and 160-200 ms, respectively. N2 was analysed at electrodes F3/Fz/F4 and FT7/FCz/FT8, between 230 and 270 ms. P300 was analysed at electrodes CPz and Pz, between 350 and 450 ms. The latency of the largest peak was also analysed for each component using the same electrodes and temporal windows.

Mean amplitude and latency values for valid and invalid conditions were submitted to repeated-measures ANOVAs for each component. The design will be specified below for each analysis.

Results

Behavioral results

Data from the same 13 participants were used for both behavioral and ERP analyses. Trials with correct responses faster than 100 ms or slower than 1000 ms, incorrect responses, as well as saccades, were excluded from the RT analysis. Mean RTs were then submitted to a repeated-measures ANOVA with validity (valid / invalid) as a factor. Crucially, according to our hypothesis, there was a significant validity effect of 24 ms, $F(1,12)=51.11$, $p<.001$, such that participants were faster on valid vs. invalid (i.e., early-invalid) trials (see Figure 6.2, Experiment 6.3). The analysis of correct responses percentage revealed no significant effects.

Electrophysiological results

Data from 7 participants were rejected from the analyses due to too many artefacts during the recording. The visual components evoked by the target recorded at occipital sites are shown in Figure 6.3 for valid and invalid trials (only the PO3/PO4 electrodes are shown).

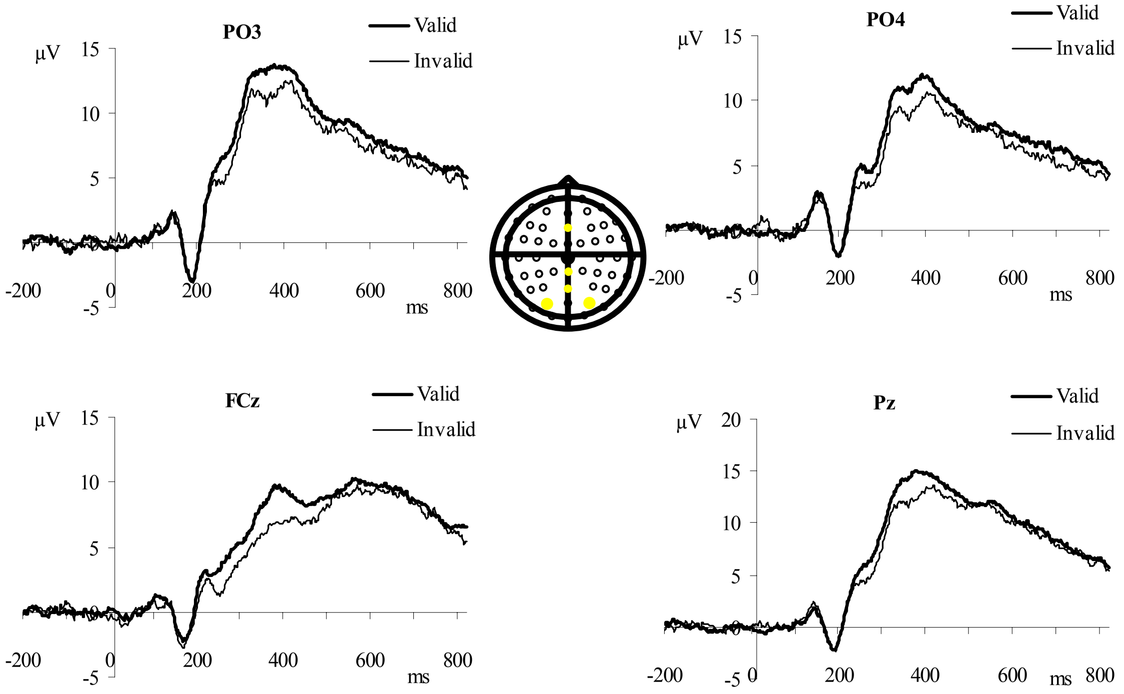

Figure 6.3. *Grand-averaged waveforms evoked by valid targets (thick line) and invalid (early-invalid) targets (thin line), recorded at occipital (PO3 and PO4 are shown), frontocentral (FCz is shown) and parietal sites (Pz). The electrode montage is shown at the centre, with the locations of electrode sites for the sample waveforms coloured in yellow. The polarity of the waveforms is plotted with positive values upward.*

The same 2 (validity: valid, invalid) x 4 (electrode position: P7/P8, PO7/PO8, O1/O2, PO3/PO4) x 2 (hemisphere: left, right) repeated-measures ANOVAs were separately conducted for amplitude and latency measures of P1 and N1 components.

The P1 peak tended to appear earlier over the left (142 ms) than over the right hemisphere (148 ms), $F(1,12)=4.40$, $p<.06$. Concerning P1 amplitude, the only significant effect was the interaction between validity and hemisphere, $F(1,12)=8.75$, $p<.01$, such that P1 seemed to be larger for valid than for invalid trials over the right hemisphere, but slightly larger for invalid trials over the left hemisphere (although both simple effects were far from significance, $Fs<1$).

The N1 had a larger amplitude and its peak appeared earlier over the hemisphere contralateral to target presentation, that is, the left hemisphere, $F(1,12)=6.03$, $p<.03$ and $F(1,12)=23.06$, $p<.001$, respectively. As occurred with P1 amplitude, the interaction between validity and hemisphere, $F(1,12)=7.38$, $p<.02$, showed a slightly larger N1 amplitude for valid trials over the right hemisphere whereas the effect was reversed over the left hemisphere (these validity effects were no significant in any hemisphere).

The N2 component evoked by the target recorded at frontocentral sites is also shown in Figure 6.3 for valid and invalid trials (only the FCz electrode is shown). A 2 (validity: valid, invalid) x 2 (electrode position: F3/Fz/F4, FT7/FCz/FT8) x 3 (hemisphere: left, midline, right) repeated-measures ANOVA was separately conducted for the amplitude and latency of N2.

Importantly, the predicted attentional effect was clear for the N2 component. Thus, targets appearing at expected times produced a smaller N2 amplitude, $F(1,12)=12.73$, $p<.01$, and an earlier N2 peak, $F(1,12)=4.80$, $p<.05$, than targets appearing earlier than expected. In contrast with P1-N1 results, the N2 peak was earlier over the right (ipsilateral) hemisphere than over the midline or the left hemisphere, $F(2,24)=3.46$, $p<.05$. The validity effect on N2 amplitude was modulated by electrode position, $F(1,12)=10.41$, $p<.01$, so that the effect was more pronounced (i.e., N2 was more attenuated by valid targets) over the most frontal electrodes (F3/Fz/F4). Also, the interaction between electrode position and hemisphere, $F(2,24)=8.13$, $p<.01$, indicated that N2 was larger over the most frontal electrodes over the left and right hemispheres, whereas the reverse was true for the electrodes placed over the midline.

The P300 component evoked by the target recorded at centroparietal sites is shown in Figure 6.3 for valid and invalid trials (only the Pz electrode is shown). Separate 2 (validity: valid, invalid) x 2 (electrode position: CPz, Pz) repeated-measures ANOVAs were conducted for the amplitude and latency of the P300 component. Interestingly, as occurred with N2, the

P300 was sensitive to the attentional manipulation. Thereby, the P300 was significantly larger, $F(1,12)=8.97$, $p<.01$, and tended to appear earlier, $F(1,12)=4.31$, $p<.06$, for valid than for invalid trials. The validity effect on P300 amplitude was more pronounced over the most anterior site (CPz), as indicated by the interaction between validity and electrode position, $F(1,12)=5.03$, $p<.04$.

Discussion

Behavioral results replicated the main finding of Experiment 6.2, that is, a robust attentional effect when valid and early-invalid conditions were compared. Furthermore, physiological data also reflected such attentional modulation. Thus, we found that late components related to motor processing (N2 and P300) were modulated by temporal attention, whereas early components related to perceptual processing (P1/N1) were unaffected. Therefore, the results obtained with this task did not support the idea that temporal attention produce an enhancement of perceptual processing, in contrast with the typical reports of spatial attention (Mangun, 1995). Previous studies on temporal orienting that used a simple-RT detection task neither show a perceptual modulation (Griffin et al., 2002, Exp. 2; Miniussi et al., 1999), suggesting that temporal attention mainly produces a motor preparation. This conclusion is also supported by neuroimaging research, showing brain activity alterations in left premotor cortex (Coull, Frith, Buchel, & Nobre, 2000; Coull & Nobre, 1998).

On the other hand, there is a recent ERP study (Lange et al., 2003), which reported a N1 modulation by temporal attention in a discrimination task of auditory stimuli. A modulation of N1 was also reported in a temporal orienting work that presented targets peripherally (Griffin et al., 2002, Exp. 1). Another ERP study found an enhancement of the P1 component by using a shape discrimination task (Correa et al., submitted). Moreover, a behavioral study revealed that temporal attention enhanced perceptual sensitivity (d’), which is a measure largely related to perceptual processing.(Correa et al., in press), Taken together, all these studies suggest that temporal attention not only modulates late but also perceptual processing.

Such a discrepancy could be explained considering that studies that reported a motor modulation used detection tasks, whereas studies that reported a perceptual modulation used discrimination tasks (see Correa et al., submitted, for a review). Detection tasks seem not to be very sensitive to perceptual modulations, given that they mainly demand a speeded motor response. On the other hand, discrimination tasks demand more perceptual processing, as well as detection tasks in which targets are presented peripherally (e.g., Griffin et al., 2002, Exp. 1).

Moreover, the use of auditory stimuli could have enhanced the sensitivity to measure temporal attention effects, as the auditory modality is superior to the visual in temporal processing efficiency (Grondin, Meilleur-Wells, Ouellette, & Macar, 1998). In the same line of argument, one complementary explanation to the differential effects observed for temporal and spatial attention could be that, spatial locations are accurately represented in retinotopic maps of the visual system, so that attention can selectively influence the set of neurons that coded a specific location. However, the influence of temporal attention on visual processing is not as obvious, since we lack an analogous map for temporal coding of visual features.

Concerning the results of late components, the attenuation of N2 by temporal attention was previously found using a temporal orienting task analogous to the Posner's (Miniussi et al., 1999). Invalid trials elicited a larger N2 than valid trials, but in more posterior sites than in the present study. Moreover, our results replicated the Doherty et al. study, in which a smaller N2 peak for the temporal compared to the neutral condition was found (Doherty et al., in press). N2 have been related to temporal uncertainty regarding target arrival in studies in which an increased N2 peak was observed in response to temporal deviant stimuli (Loveless, 1986). Thus, attention in the valid condition reduced temporal uncertainty, presumably indexed by N2.

A complementary explanation considers N2 as a general conflict detector (van Veen & Carter, 2002). We speculate that N2 could be reflecting processes involved in expectancy disconfirmation, that is, conflict detection and reconfiguration of the system to adapt behavior to the unexpected situation. In our particular case, N2 increased when the temporal expectancy had been disconfirmed by the sudden appearance of an early-target. Temporal attention, in contrast, may prevent conflict detection and reconfiguration processes, so that an expected target would elicit a smaller N2. Likewise, this saving of processing time might be also the source of the smaller N2 latency observed on valid trials. Strikingly, the modulation of N2 latency had not been observed in other temporal attention experiments.

Moreover, P300 was modulated by temporal attention. In particular, the P300 peak was larger and tended to appear earlier in the valid compared to the invalid condition. The modulation of P300 amplitude has been found in temporal orienting studies (Griffin et al., 2002; Miniussi et al., 1999), and could be considered as an index of functional decision processes and preparation for responses (Mangun, 1995).

However, one idiosyncratic feature of temporal attention is the latency modulation. Effects on P300 latency have been well documented in temporal orienting research (Doherty et al., in press; Griffin et al., 2002; Miniussi et al., 1999), and have been interpreted as that temporal information influences the synchronization of processes involved in the response. Hence, we suggest that the time course of preparation processes is dynamically tuned to the temporal expectancy induced by a given speed of movement. Thus, preparation processes were not synchronized and they were not ready when the target appeared earlier than expected, so that such processes reflected by P300 could suffer a delay compared to valid trials.

General discussion

A set of three experiments was conducted to explore whether the attentional mechanism is able to flexibly build temporal expectancies based on moving objects across a range of speeds. Results showed behavioral benefits in RTs and modulations of brain electrical activity produced by the dynamic deployment of attentional resources to an expected point in time, which are quite analogous to the findings observed in temporal orienting studies that used the Posner’s task adapted to the time domain (Griffin et al., 2002; Miniussi et al., 1999). Our data supported the flexibility of temporal attention to modulate the preparation process according to a variety of rhythmic patterns of movement, and to synchronize it to the expected relevant moment. Moreover, this novel task could be an interesting approach to the study of temporal orienting of attention, by simulating more realistically the natural conditions of our complex and dynamic environment than the classical Posner's task.

Experiments 6.1 and 6.2 refined the task to observe a robust attentional effect on behavior, in order to correlate it to physiological modulations. In particular, Experiment 6.1 found no attentional effects when temporal expectancy and neutral conditions were compared. Further analysis based on the speeds of the moving stimulus suggested that the neutral condition was not a pure condition of non attention, as it may involve temporal predictability. Thus, the period for which the moving stimulus was occluded (occlusion time) was a crucial factor that modulated the attentional effect, so that it was only observed at short occlusion times. According to the fact that 'the probability of the stimulus reappearance increases as the occlusion time becomes longer', we suggested that occlusion time provided useful information to overcome the temporal uncertainty induced by the neutral condition, producing thus faster RTs at long compared to short occlusion times.

Such hypothesis was tested in Experiment 6.2 by manipulating occlusion time directly. This manipulation allowed the inclusion of valid and invalid trials in the temporal expectancy condition, so that the task gained resolution to study the attentional effect by comparing *uncontaminated* conditions of attention and non attention, respectively. First, the results confirmed that occlusion time determined the expectancy effects (i.e., when temporal and neutral conditions were compared). More importantly, the validity manipulation showed a robust RT benefit for trials in which the stimulus reappeared at the expected moment compared to trials in which the stimulus appeared earlier than expected (early-invalid). Late-invalid trials, however, did not seem to be a pure condition of non attention, as a reorienting process from an early to a later point in time was presumably engaged when an early expectancy was disconfirmed.

Thus, Experiments 6.1 and 6.2 have identified two implicit sources of temporal expectancy. First, participants could extract temporal information from regular speeds of movement. However, when this information was not available in neutral trials, participants built temporal expectancies according to probabilistic information provided by the occlusion time, namely, the hazard function.

Finally, Experiment 6.3 focused on the valid vs. early-invalid comparison to investigate the electrophysiological correlates underlying kinetic temporal attention. Behavioral results replicated the reliable attentional benefit on RTs observed in Experiment 6.2. Physiological results revealed attentional modulations on the latency and the amplitude of late components as N2 and P300. Specifically, N2 amplitude was increased in the early-invalid condition. N2 enhancements have been linked to processes of temporal uncertainty (Loveless, 1986) and conflict detection (van Veen & Carter, 2002). Thus, the rupture of temporal expectancies in early-invalid trials, and possibly the additional processes engaged to solve such a conflict (e.g., the reconfiguration of the system), were reflected as increments in N2 amplitude. In contrast, temporal attention attenuated the N2 amplitude in valid trials.

Additionally, the P300 peak was increased in the valid condition. We propose that the P300 enhancement could be indexing a motor preparation for responding produced by temporal attention.

However, the most striking result was the modulation of ERPs latency. The latency of N2 and P300 peaks was reduced in valid trials, which suggests that temporal attention either speeded or saved processing time. Two related explanations might be proposed. First, some processes could be speeded in valid relative to invalid trials. Given that late processing is enhanced, decision and motor preparation processes involved in responding could be facilitated and synchronized to the expected relevant moment. Second, the time savings could be due to the fact that some processes engaged in the early-invalid condition were prevented by temporal attention in the valid condition, for example, conflict detection (i.e., temporal expectancy disconfirmation) or system reconfiguration processes.

These results together suggest that the attentional mechanism can flexibly build temporal expectancy based on different speeds, optimising behavioural performance and producing facilitation and synchronization of late processing probably related to decision and motor response processes.

DISCUSIÓN GENERAL

VII. Discusión general.

El objetivo fundamental que ha guiado la presente investigación se basa en la especificación de las consecuencias que el mecanismo atencional de orientación en el tiempo tiene sobre el procesamiento de estímulos. Concretamente, pretendíamos determinar si la atención temporal puede potenciar el procesamiento perceptual temprano, es decir, si las personas pueden mejorar su percepción visual atendiendo al instante temporal en el que se espera que ocurra un evento importante.

Para ello, previamente era necesario obtener un conocimiento más completo de los determinantes y atributos más relevantes del mecanismo de orientación temporal, relacionados con su naturaleza *endógena* y *flexible*, el carácter controlado de los procesos implicados, y con la posibilidad de que su funcionamiento sea *generalizable* o aplicable a una variedad de tareas.

Una vez conocidas sus características básicas y las condiciones que determinan la obtención de efectos robustos de orientación temporal, seguimos distintas estrategias para el diseño de los experimentos que compartían el objetivo común de estudiar si la atención temporal podía mejorar el procesamiento perceptual. Estas estrategias se basaron en el registro de medidas de TR, psicofísicas y de activación electrofisiológica cerebral, en las series experimentales I, II y III, respectivamente. Los experimentos de la serie IV pretendían conocer si este mecanismo era igualmente aplicable a tareas más próximas a contextos reales. Es decir, nos planteamos cómo sería el funcionamiento del mecanismo de orientación temporal en situaciones naturales donde los estímulos relevantes se mueven.

El procedimiento experimental general que hemos utilizado en la presente tesis consiste en una versión temporal del paradigma de costes y beneficios, desarrollado por el grupo de Posner para el estudio de la orientación espacial de la atención (Posner et al., 1978). Los participantes recibían información temporal explícita por medio de señales temporales predictivas. Éstas indicaban con alta probabilidad (.75) el momento de aparición del estímulo objetivo. El objetivo podía aparecer, bien pronto (después de un intervalo corto de 400 ms) o tarde (después de un intervalo largo de 1400 ms). En la Figura 7.1 se presenta un esquema resumen del procedimiento que se utilizó específicamente en cada una de las series experimentales.

El efecto de orientación temporal lo definimos como el beneficio atencional resultante de la diferencia entre el procesamiento de estímulos que aparecen en el momento esperado o atendido (condición válida) y el procesamiento de estímulos que aparecen en el momento inesperado o no atendido (condición inválida), tanto si empleamos medidas comportamentales como fisiológicas.

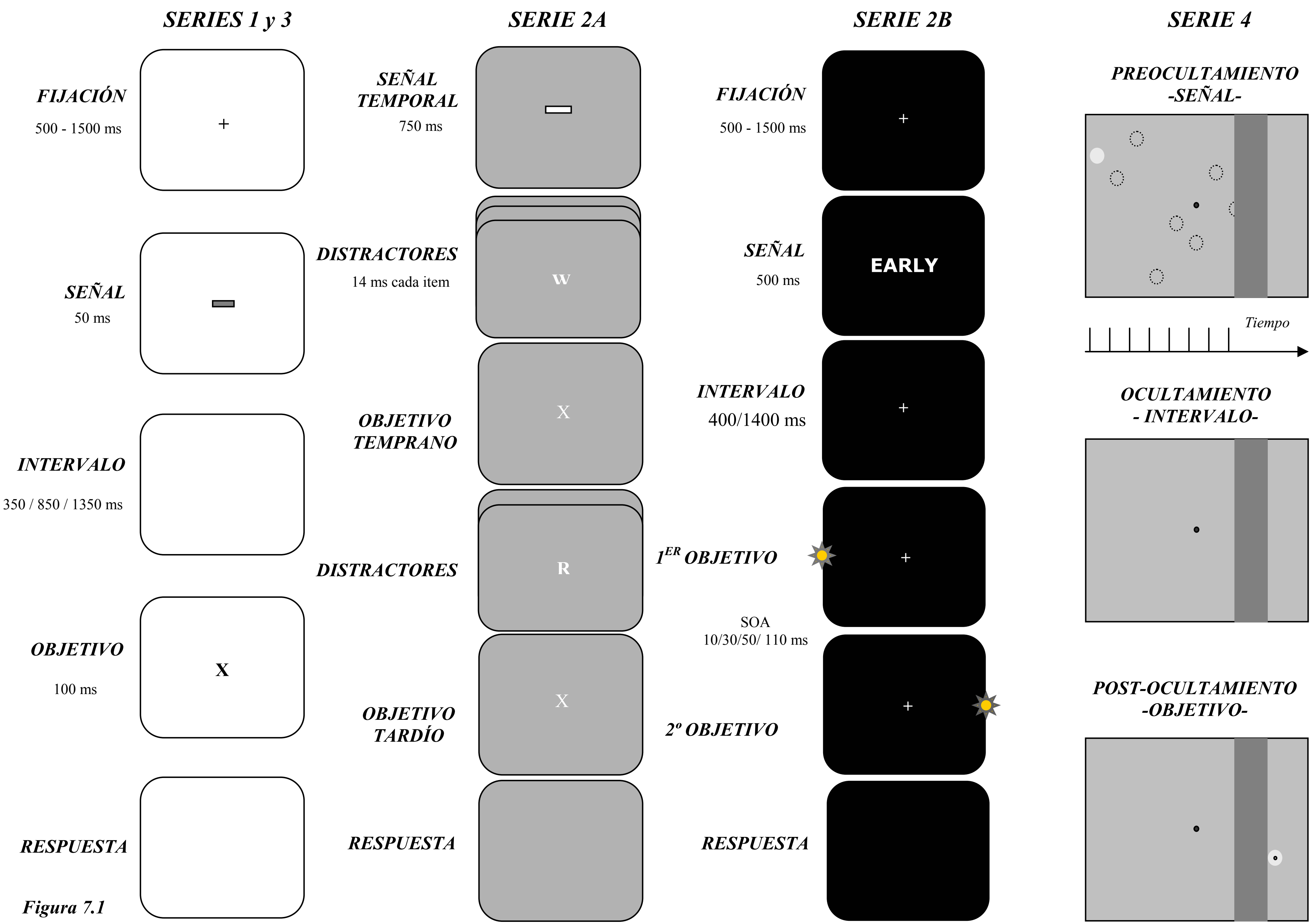
SERIES 1 y 3
FIJACIÓN
500 - 1500 ms
+
SEÑAL
50 ms
INTERVALO
350 / 850 / 1350 ms
OBJETIVO
100 ms
X
RESPUESTA
SERIE 2A
SEÑAL TEMPORAL
750 ms
DISTRACTORES
14 ms cada item
W
OBJETIVO TEMPRANO
X
DISTRACTORES
R
OBJETIVO TARDÍO
X
RESPUESTA
SERIE 2B
FIJACIÓN
500 - 1500 ms
+
SEÑAL
500 ms
EARLY
INTERVALO
400/1400 ms
+
1ER OBJETIVO
+
SOA
10/30/50/ 110 ms
2º OBJETIVO
+
RESPUESTA
SERIE 4
PREOCULTAMIENTO
-SEÑAL-
Tiempo
OCULTAMIENTO
- INTERVALO-
POST-OCULTAMIENTO
-OBJETIVO-

Figura 7.1

7.1. La naturaleza *endógena* del mecanismo de orientación temporal: Determinantes y atributos fundamentales

7.1.1. *Flexibilidad* para focalizar la atención a diversos intervalos de tiempo: Efecto de la incertidumbre producida por los catch trials

Nuestro punto de partida para profundizar en el estudio de la orientación temporal fue evaluar la *flexibilidad* para focalizar la atención a intervalos de tiempo de duraciones diversas, de modo que en los Capítulos I y II buscábamos la obtención generalizada de efectos de orientación temporal a varios intervalos de tiempo. Mientras que las primeras investigaciones concluyeron que el proceso de preparación seguía un curso temporal rígido y único (Woodrow, 1914), Coull y Nobre (1998) demostraron recientemente que éste podía modificarse flexiblemente en función de la expectativa temporal que inducía la presentación de señales predictivas. Sin embargo, en contra de tal flexibilidad estaba el hecho de que los efectos de orientación temporal suelen limitarse al más corto de los intervalos utilizados y rara vez se observan en el intervalo más largo (no obstante, véase Griffin et al., 2001; Milliken et al., 2003). Posiblemente, esto se deba a un proceso de reorientación, que consiste en el desarrollo de un nuevo estado de preparación hacia el intervalo largo, una vez que el objetivo no apareció en el intervalo corto esperado. La reorientación así compensa el nivel de preparación de la condición inválida (expectativa temprana-intervalo largo), dando lugar a TR similares a los de la condición válida (expectativa tardía-intervalo largo).

A pesar de que existe evidencia fisiológica a favor de la reorientación de la atención (v.g., Coull, Frith, Büchel et al., 2000; Loveless & Sandford, 1974), este proceso no se había manipulado directamente para conocer su influencia sobre la orientación temporal. Dado que la reorientación cobra pleno sentido cuando hay gran certeza sobre la ocurrencia del objetivo, intentamos manipular este proceso variando dicha probabilidad de ocurrencia. El Capítulo I reúne tres experimentos exploratorios en los que se incluyó una proporción de ensayos donde no se presentaba el objetivo, es decir, de '*catch trials'*. En el Capítulo II (Experimento 2.1), la manipulación del porcentaje de catch trials se realizó de forma más sistemática, lo que permitió un estudio más preciso del proceso de reorientación. Según nuestra hipótesis, la presencia de catch trials incrementaría la incertidumbre sobre la ocurrencia del objetivo, lo que minimizaría la reorientación, o dicho de otro modo, incrementaría la despreparación. En consecuencia, en los grupos con catch trials esperábamos observar efectos de validez significativos tanto en el intervalo corto como en el largo.

En la Figura 7.2 se presenta un resumen de los resultados más relevantes observados en cada una de las series experimentales.

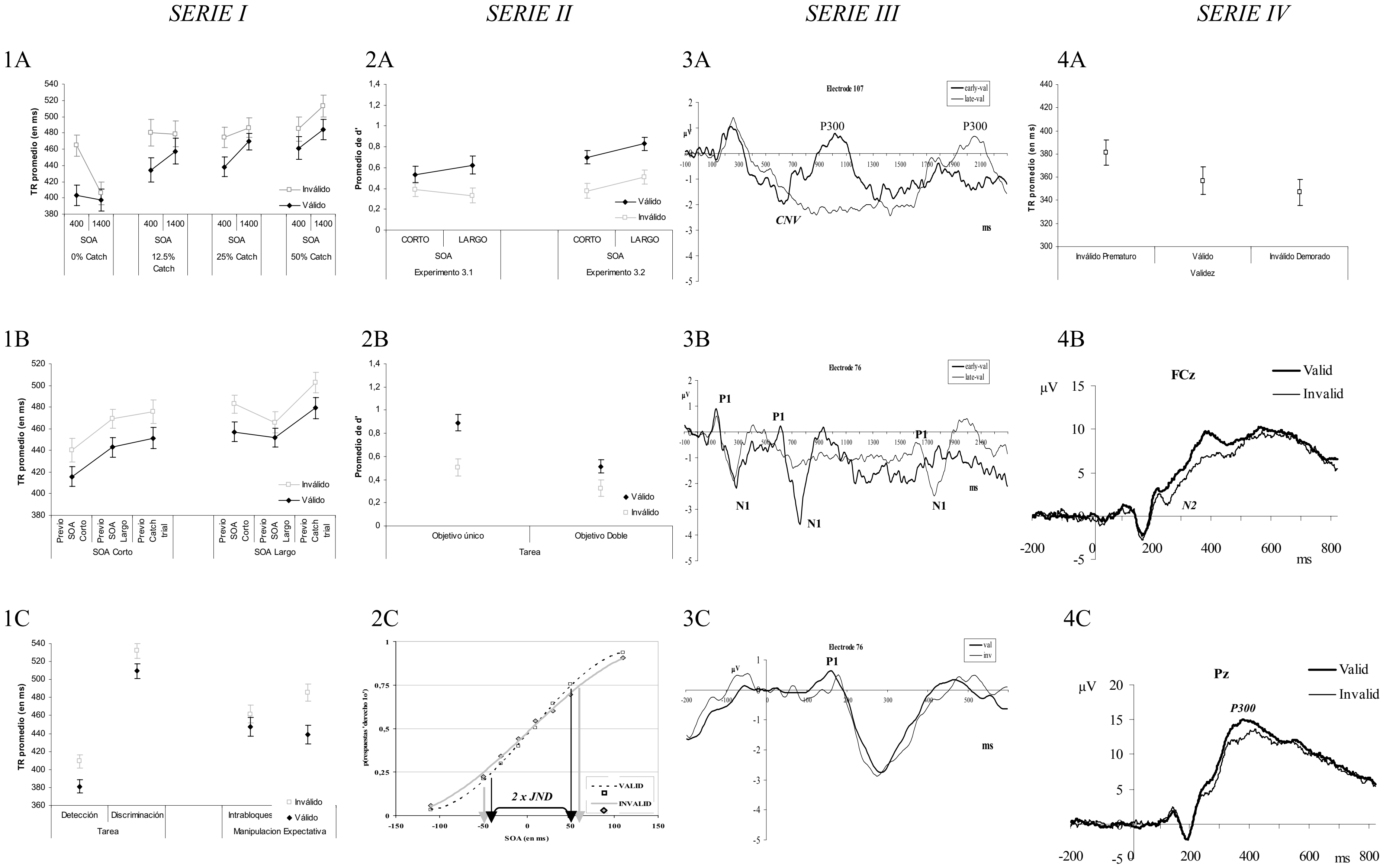
SERIE I
SERIE II
SERIE III
SERIE IV
1A
TR promedio (en ms)
Inválido
Válido
400
1400
SOA
0% Catch
12.5% Catch
25% Catch
50% Catch
2A
Promedio de d'
Válido
Inválido
CORTO
LARGO
SOA
Experimento 3.1
Experimento 3.2
3A
Electrode 107
early-val
late-val
μV
P300
P300
CNV
ms
4A
TR promedio (en ms)
Inválido Prematuro
Válido
Inválido Demorado
Validez
1B
TR promedio (en ms)
Inválido
Válido
Previo SOA Corto
Previo SOA Largo
Previo Catch trial
SOA Corto
SOA Largo
2B
Promedio de d'
Válido
Inválido
Objetivo único
Objetivo Doble
Tarea
3B
Electrode 76
early-val
late-val
μV
P1
P1
P1
N1
N1
N1
ms
4B
FCz
Valid
Invalid
μV
N2
ms
1C
TR promedio (en ms)
Inválido
Válido
Detección
Discriminación
Tarea
Intrabloques
Manipulacion Expectativa
2C
p(respuestas 'derecho 1o')
VALID
INVALID
2 x JND
SOA (en ms)
3C
Electrode 76
val
inv
μV
P1
ms
4C
Pz
Valid
Invalid
μV
P300
ms

Figura 7.2

Los resultados confirmaron sin lugar a dudas nuestra hipótesis, de manera que en la condición sin catch trials el efecto de reorientación anulaba los efectos de validez en el intervalo largo. Sin embargo, la mera presencia de un 12.5% de catch trials fue suficiente para observar efectos de orientación temporal en el intervalo largo (véase Figura 7.2, Gráfica 1A. Datos del Experimento 2.1). El incremento progresivo de la proporción de catch trials no se correspondió con mayores efectos de validez, lo que sugiere que la despreparación no es una cuestión de grado sino que más bien se ajusta a un proceso de todo o nada. En conclusión, la obtención conjunta de efectos de orientación temporal para intervalos de distinta duración, en los grupos con catch trials, ofrecía un apoyo más sólido a la flexibilidad del mecanismo de orientación.

7.1.2. *Intencionalidad*: El efecto estratégico de expectativa temporal inducido por señales predictivas es disociable del efecto automático secuencial inducido por el intervalo previo

Una revisión de los estudios clásicos sobre preparación atencional reveló factores que seguramente también estaban implicados en los estudios de orientación temporal. En efecto, la manipulación de intervalos de tiempo es un procedimiento común a ambos campos de estudio, que igualmente da lugar a patrones de resultados análogos. De este modo, factores implicados en los estudios de preparación, como los efectos automáticos secuenciales producidos por la duración del intervalo del ensayo anterior, podrían contribuir de manera decisiva a los efectos de orientación temporal. Sin embargo, en la investigación sobre orientación endógena temporal no se había tenido en cuenta su influencia potencial (v.g., Nobre, 2001), ya que únicamente se dirigía a estudiar el efecto endógeno de la validez de la señal. Así, los efectos de orientación temporal podrían ser explicados según una concepción automática de los efectos secuenciales, lo cual cuestionaría su carácter endógeno (Los & Van den Heuvel, 2001).

Para examinar su carácter *endógeno*, tratamos de disociar experimentalmente las contribuciones automáticas (exógenas) y estratégicas (endógenas) al efecto de orientación temporal. En la primera serie experimental (Capítulos I y II), manipulamos de forma conjunta la validez de la señal y la duración del intervalo previo. Si los efectos de orientación temporal se debían al uso de señales predictivas endógenas y no a un mero efecto secuencial, debiéramos observar un efecto principal de la validez de la señal que fuera independiente de la duración del intervalo previo.

En efecto, como se observa en la Gráfica 1B de la Figura 7.2 (datos globales de los 4 experimentos de la Serie I), los resultados muestran la contribución de efectos secuenciales automáticos (mayores TR cuando el intervalo corto actual es precedido por un intervalo largo en lugar de por un intervalo corto) y de efectos de validez estratégicos (menor TR en los ensayos válidos que en los inválidos). Lo importante de estos resultados es que muestran claramente que no había interacción entre ambos efectos, de manera que los efectos endógenos de orientación temporal producidos por la señal temporal no dependían de la duración del intervalo previo, lo cual demuestra el carácter estratégico de dicho mecanismo.

7.1.3. *Control* de los procesos de orientación temporal: Efectos de las demandas de tarea y del bloqueo de expectativa en el tamaño de los efectos atencionales

Para comprobar si la orientación temporal es un fenómeno generalizable a una diversidad de tareas, comparamos la ejecución de tareas de detección de TR-simple con la de tareas de discriminación de TR-de elección. Considerando la orientación atencional como un mecanismo universal con unas propiedades básicas generales que son independientes de las demandas específicas de tarea, esperábamos replicar con tareas de discriminación los efectos de orientación típicamente observados en la tarea de detección (Coull & Nobre, 1998). Esta tarea consistía en discriminar entre las letras ‘X’ y ‘O’.

Los resultados apoyaron la universalidad de dicho mecanismo, pues se obtuvieron efectos de orientación temporal con tareas de detección y de discriminación. Curiosamente, los efectos fueron de menor magnitud en la tarea de discriminación (véase Gráfica 1C, datos globales para la Serie I). Como explicación, encontramos que ambas tareas se diferenciaban en la cantidad de demandas de recursos centrales de procesamiento que implicaba el tipo de correspondencia entre estímulos y respuestas (E-R). Así, la tarea de discriminación era más demandante porque requería el mantenimiento en la Memoria de Trabajo de una correspondencia E-R arbitraria, y al mismo tiempo más compleja que la de la tarea de detección. Por otro lado, asumimos que la generación endógena de expectativas temporales también demandaba recursos atencionales, por ejemplo, debido a procesos subyacentes de estimación temporal que son de tipo controlado (Brown, 1985). Como consecuencia, la competencia entre ambas demandas resultó en menores efectos atencionales para la tarea de discriminación.

Los Experimentos 3.1 y 3.2 (Capítulo III) mostraron evidencia adicional en favor de la hipótesis de la interferencia entre las demandas de orientación temporal y de tarea (véase Gráfica 2B). Así, los efectos de validez fueron mayores para la tarea menos demandante (identificar un sólo objetivo) que para la tarea más demandante (identificar dos objetivos), considerando que la demanda en tareas de búsqueda visual (W. Schneider & Shiffrin, 1977) o tarea de búsqueda en memoria (Sternberg, 1966) incrementa con el número de objetivos.

La estrategia que seguimos para aumentar los efectos de orientación temporal en la tarea de discriminación consistió en reducir las demandas para desarrollar la preparación mediante la manipulación de la expectativa entre bloques en lugar de ensayo a ensayo (intrabloque). Así, los participantes no tenían que generar una expectativa ni una preparación nueva para cada ensayo, ya que cada bloque experimental estaba formado por ensayos homogéneos en los que la expectativa no cambiaba. Como se aprecia en la Gráfica 1C, los efectos de orientación temporal fueron considerablemente mayores cuando la expectativa se manipuló entre bloques, dado que en esta condición había más recursos disponibles para los procesos de preparación temporal.

En conclusión, la manipulación de las demandas en función del tipo de tarea y del modo en que se inducía la expectativa temporal aportó información útil sobre el carácter *controlado* frente *automático* de los procesos implicados en la orientación en el tiempo. Además, el conjunto de experimentos realizado hasta el momento especificaron las condiciones experimentales apropiadas para observar efectos de orientación temporal robustos en experimentos posteriores.

7.2. La atención temporal mejora el procesamiento perceptual temprano de estímulos visuales

Una vez que encontramos evidencia a favor de un mecanismo flexible e intencional de orientación temporal y que hallamos las condiciones apropiadas para su estudio, nuestro objetivo siguiente era determinar sobre qué etapas del procesamiento puede influir la atención temporal. En relación con la atención espacial, los estudios de potenciales evocados y de neuroimagen han revelado modulaciones del procesamiento tanto en niveles perceptuales tempranos como en motores tardíos (Heinze et al., 1994; Mangun, 1995).

A diferencia de la atención espacial, los estudios fisiológicos revelan que la atención temporal genera activaciones específicas en la corteza premotora del hemisferio izquierdo (Coull & Nobre, 1998), así como modulaciones de componentes electrofisiológicos tardíos asociados con procesos de decisión y de ejecución motora de respuestas (Miniussi et al., 1999). Estos resultados sugieren que los efectos de la atención temporal tienen lugar sobre niveles de procesamiento posteriores al perceptual. No obstante, pensamos que la tarea de detección que habitualmente se emplea en tales estudios no es sensible para captar efectos perceptuales, ya que las tareas de detección únicamente demandan respuestas motoras rápidas. De este modo, las activaciones observadas en áreas motoras podrían ser un mero resultado de las demandas de la tarea más que de los efectos de orientación temporal, de manera que no quedaba resuelta la cuestión de si los efectos de orientación temporal pueden producirse mediante una preparación perceptual o motora.

7.2.1. Evidencia basada en medidas de TR

La obtención de efectos atencionales con tareas de discriminación podría sugerir una mejora del procesamiento perceptual, dado que estas tareas demandan un análisis visual más detallado que las tareas de detección. En consecuencia, en la Serie I llevamos a cabo cuatro experimentos comportamentales con tareas de discriminación con el objeto de encontrar evidencia a favor de la preparación perceptual. Los resultados mostraron efectos de validez significativos (véase Gráfica 1C), lo cual sugería que la atención temporal implica una preparación perceptual consistente en la facilitación de procesos de análisis de rasgos visuales del estímulo objetivo.

Sin embargo, la evidencia basada en medidas de TR no era suficientemente sólida para descartar completamente la hipótesis de la preparación motora. Por ejemplo, Nobre (2001) ha sugerido que los efectos de orientación temporal en tareas de discriminación pueden deberse a la preparación motora de las dos respuestas que intervienen en esta tarea. Así, nuestros resultados podrían ser simplemente consecuencia de la facilitación de procesos post-perceptuales de decisión o ejecución de una respuesta motora. En este sentido, los datos comportamentales únicamente basados en experimentos clásicos de TR no abordan de forma apropiada nuestra cuestión principal, dado que las contribuciones perceptuales y motoras al TR no son fácilmente disociables.

7.2.2. Evidencia basada en medidas psicofísicas

La estrategia que seguimos para diseñar los experimentos de la Serie II consistía en la utilización de medidas psicofísicas para aislar procesos perceptuales y de tareas que optimicen el procesamiento perceptual y minimicen la contribución de procesos motores. Para ello, analizamos la precisión de respuestas ejecutadas sin presión temporal, en lugar del TR de respuestas rápidas.

En los Experimentos 3.1 y 3.2 incrementamos las demandas perceptuales de la tarea enmascarando el objetivo mediante el procedimiento de *presentación visual serial rápida* (PVSR), de manera que el objetivo y los distractores se presentaban tan rápidamente que se enmascaraban entre sí (véase Figura 7.1). No obstante, esperábamos que la señal temporal ayudara a evitar tal enmascaramiento porque indicaba el mejor momento para prestar máxima atención y buscar el objetivo, dado que no era posible prestar atención individualmente a cada uno de los ítems presentados (Enns & Di Lollo, 1997). Como variables psicofísicas utilizamos la sensibilidad perceptual (d') y el criterio de respuesta (beta). Según la teoría de detección de señales ambas medidas son independientes, de manera que el procesamiento perceptual reflejado por d' puede disociarse de otros procesos post-perceptuales relacionados con decisión y sesgo de respuesta, reflejados por el índice beta (Green & Swets, 1966). Nuestra predicción era que si la atención temporal facilitaba el procesamiento perceptual, entonces observaríamos un aumento en la sensibilidad perceptual para identificar los objetivos que aparecen en los intervalos temporales válidamente señalados.

Los datos apoyaron la idea de la preparación a nivel perceptual, pues se observaron efectos de orientación temporal significativos en d' pero no en beta (véase Gráfica 2A). No obstante, la solidez de nuestras conclusiones dependía de la capacidad de d' para aislar procesamiento perceptual puro. De este modo, podría argumentarse que el índice d' puede ser influido por factores post-perceptuales (v.g., estrategia de codificar y repasar más en memoria la información presentada en los intervalos de tiempo señalados, véase Hawkins et al., 1990). Esta posibilidad implica que aunque el hallazgo de efectos de orientación temporal en medidas de sensibilidad perceptual es sugerente, no puede considerarse como evidencia indiscutible de una preparación perceptual.

En el Experimento 4.1 buscamos evidencia adicional mediante la combinación de un procedimiento de señalización temporal con una tarea de *juicios de orden temporal* (JOT). En esta tarea, se presentan dos estímulos separados por un intervalo de tiempo (SOA) muy corto y el observador decide cuál de los dos se presentó primero (véase Figura 7.1). La manipulación del SOA da lugar a una función psicofísica que sirve para calcular el umbral diferencial, expresado en milisegundos. El umbral diferencial nos da una idea de la resolución temporal o agudeza de la percepción temporal. Es decir, valores bajos de umbral diferencial implican buena resolución temporal, indicando que el observador es capaz de discernir con exactitud el orden de comienzo de dos eventos prácticamente simultáneos, es decir, separados por escasos milisegundos.

Las tareas JOT también se utilizan para aislar procesamiento perceptual, ya que suelen demandar exactitud y no rapidez en las respuestas (Klein et al., 1998). Interesantemente, estas tareas además proporcionan un índice directo de la resolución temporal de procesos de percepción. Así, esperábamos que si la atención temporal mejoraba el procesamiento perceptual, lo haría mediante un incremento en la resolución temporal de la percepción visual. En efecto, los resultados revelaron que el umbral diferencial era menor para los ensayos válidos (41 ms) que para los inválidos (46 ms; véase Gráfica 2C).

En resumen, la metodología psicofísica que se ha seguido en esta serie experimental aporta un apoyo más sólido a la hipótesis perceptual que los experimentos de TR realizados en la Serie I. En cualquier caso, aún es posible objetar que la evidencia basada exclusivamente en datos comportamentales no es suficiente para inferir sin lugar a dudas que la atención temporal mejora el procesamiento perceptual temprano. El uso de medidas más directas de procesamiento cognitivo proporcionaría resultados aún más convincentes para los más escépticos. En este sentido, la técnica de potenciales evocados es especialmente adecuada para investigar a tiempo real las modulaciones dinámicas que la atención temporal pueda ejercer sobre la actividad electrofisiológica cerebral relacionada con el procesamiento de estímulos. De esta manera, la siguiente serie experimental se valió de esta ventaja de las técnicas electrofisiológicas.

7.2.3. Evidencia basada en medidas de activación electrofisiológica cerebral

Para continuar con nuestro objetivo principal, antes de realizar el Experimento 5.1 revisamos la investigación sobre orientación temporal realizada con potenciales evocados, poniendo especial énfasis en las características diferenciales entre procedimientos experimentales que pudieran determinar la obtención de modulaciones atencionales en etapas tempranas del procesamiento. Como conclusión, encontramos que los componentes asociados con procesos tardíos de decisión y ejecución de respuesta, como N2 y P300, son habitualmente influenciados por la orientación temporal de la atención, lo cual apoya la hipótesis de la preparación motora.

Por otro lado, la modulación del procesamiento perceptual producida por la atención temporal no es un hecho bien contrastado hasta la fecha: la mayoría de las investigaciones han fallado en encontrar efectos atencionales en componentes relacionados con procesamiento perceptual, y aquellas que sí los han encontrado no revelan un patrón consistente. Es decir, algunos estudios revelan incrementos en N1 producidos por objetivos atendidos frente a no atendidos (Griffin et al., 2002; Lange et al., 2003), mientras que otros revelan justo lo contrario: decrementos en N1 (Doherty et al., in press).

Estas discrepancias podrían deberse a diferencias metodológicas, aunque, crucialmente descubrimos un elemento común a los estudios que observaron modulaciones perceptuales. En concreto, un factor esencial parecía ser la existencia de una gran demanda en el procesamiento perceptual. Así, en el Experimento 5.1 utilizamos una tarea de discriminación de letras como la utilizada anteriormente. Recuérdese que esta tarea implica una mayor demanda de procesamiento perceptual que la tarea de detección, ya que requiere un análisis más detallado de los rasgos visuales. En consecuencia, esperábamos que con el uso de la tarea de discriminación la atención temporal no sólo potenciara el procesamiento motor tardío, sino también el procesamiento visual temprano.

El resultado más espectacular consistió en la obtención de efectos de orientación temporal en el componente P1 (véase Gráfica 3C), lo que reforzaba la idea de la preparación perceptual. Además, replicamos un resultado clásico como es la modulación en la latencia del P300, que parece ser una característica idiosincrásica de la atención temporal y que concuerda con la función de sincronizar determinados procesos con el momento esperado de ocurrencia de eventos relevantes.

7.3. Correlatos electrofisiológicos cerebrales de la preparación atencional basada en expectativas temporales

Aparte de estudiar las consecuencias que la presentación de estímulos atendidos y no atendidos tiene sobre el procesamiento, el Experimento 5.1 pretendía conocer los mecanismos cerebrales implicados en el proceso de preparación inducido por la presentación de señales temporales. La variación contingente negativa (CNV) era un buen candidato sobre el que dirigir los análisis, dado que es un componente electrofisiológico que ha sido relacionado con procesos intencionales de preparación para la llegada inminente de un estímulo, así como con procesos de estimación temporal (Macar & Besson, 1985).

Como se observa en la Gráfica 3A, la CNV muestra una perfecta sincronía con el momento anticipado de ocurrencia del estímulo. Cuando la señal temporal inducía una expectativa temprana, el desarrollo de la CNV comenzaba antes y su punto más álgido coincidía con el momento de aparición indicado por la señal, es decir, el intervalo corto (450 ms). En el caso de la expectativa tardía, la CNV seguía un curso temporal más lento pero que también se ajustaba rigurosamente al momento esperado, es decir, al intervalo largo (ver 1450 ms).

Este patrón de datos tan elegante establece una vinculación estrecha entre el proceso de preparación que se infiere a partir de efectos atencionales observados en el comportamiento y su manifestación en el cerebro a nivel electrofisiológico. Así, las expectativas que genera una señal temporal modifican el curso temporal de la preparación, tal y como refleja la CNV. Además, el nivel de preparación que se infiere a partir del patrón de datos de TR muestra una gran concordancia con el nivel de preparación que se refleja en la CNV.

7.4. La atención temporal en contextos naturales: Estudios comportamentales y electrofisiológicos sobre la orientación temporal hacia estímulos dinámicos

El estudio de la orientación temporal normalmente se ha realizado en contextos artificiales, en los que se presentan señales simbólicas explícitas, intervalos vacíos de tiempo entre la señal y el objetivo, y objetivos estáticos. No obstante, para atender a los estímulos tal y como ocurren en la estructura espaciotemporal del mundo real seguramente sean necesarios procesos de orientación temporal más dinámicos que los que demandan los contextos artificiales. Un ejemplo es la generación de expectativas temporales basadas en información implícita que subyace al modo en que se mueven los objetos. En la última serie experimental pretendíamos determinar hasta qué punto las tareas que utilizan contextos estáticos y dinámicos presentan mecanismos análogos de orientación temporal. Esto nos permitiría obtener una concepción más precisa del funcionamiento real del mecanismo atencional, así como realizar extrapolaciones más validas sobre su funcionamiento en contextos naturales.

Para ello, utilizamos una aproximación original para investigar si el mecanismo atencional puede generar expectativas temporales basadas en objetos que se mueven, de una manera flexible, es decir, a través de un rango amplio de velocidades de movimiento. En este sentido, algunas situaciones cotidianas ilustran el papel de la atención, por ejemplo, cuando alguien quiere anticipar cuándo y por dónde aparecerá un objeto que se mueve y que de repente queda oculto detrás de otro objeto en la escena visual. De hecho, en la mayoría de los deportes con pelota se dan situaciones similares a la descrita.

Nobre y colaboradores han desarrollado recientemente una tarea nueva que simula las demandas atencionales en contextos dinámicos de forma más verosímil que las tareas clásicas de orientación espacial y temporal que emplean contextos estáticos (Doherty et al., in press). En la pantalla aparece un estímulo (una 'bola') que se mueve de izquierda a derecha y acaba ocultándose tras una franja (véase Figura 7.1). Una vez que sobrepasa la franja, la bola puede aparecer con un pequeño punto negro en el centro. Los participantes debían pulsar una tecla lo más rápidamente posible si la bola aparecía con dicho punto. El movimiento que seguía la bola antes de ocultarse servía para inducir expectativa temporal, expectativa espacial o no expectativa. Las expectativas ayudaban a los participantes a predecir el momento o el lugar en que reaparecía la bola después de atravesar la franja.

Los datos de TR revelaron beneficios atencionales análogos a los observados en los estudios clásicos sobre orientación espacial (Posner et al., 1978) y orientación temporal (Nobre, 2001). Concretamente, los participantes fueron más rápidos cuando el estímulo seguía una trayectoria espacialmente predecible (v.g., una línea recta) o temporalmente predecible (v.g., un ritmo a velocidad constante), comparados con la condición en la que el patrón de movimiento no podía ser predicho (v.g., trayectorias o ritmos aleatorios). Este resultado sugiere que el mecanismo de orientación atencional puede aplicarse a situaciones cotidianas que contienen estímulos dinámicos.

Sin embargo, la condición temporal de este estudio sólo incluía una única expectativa temporal, generada a partir de movimientos con la misma velocidad en todos los ensayos. De esta manera, aún quedaba por investigar la flexibilidad del mecanismo para generar una diversidad de expectativas temporales. Nuestros experimentos pretendían extender los resultados del estudio de Doherty y cols. utilizando un rango más amplio de velocidades de movimiento para inducir expectativa temporal.

En el Experimento 6.1 se manipuló el ritmo de movimiento para inducir expectativa temporal (ritmo constante y predecible) o expectativa neutral (ritmo aleatorio e impredecible). En cambio, en el Experimento 6.2 se manipuló el tiempo que el estímulo permanecía oculto. Esto nos permitía comparar condiciones válidas e inválidas, que es el procedimiento habitual en los estudios de orientación atencional. De este modo el procedimiento ganaba en refinamiento, pues al mantener constante el ritmo de movimiento previo al ocultamiento, las condiciones quedaban igualadas en estimulación perceptual, y así únicamente diferían en el tiempo de ocultamiento. Entonces, la condición temporal se componía de ensayos válidos en los que la bola aparecía en el momento esperado de acuerdo a una velocidad constante de movimiento previo a su ocultamiento, ensayos inválidos en los que la bola aparecía antes de lo esperado (prematuros) e inválidos en los que aparecía después de lo esperado (demorados).

Los resultados mostraron efectos robustos de validez en la ejecución de la tarea al comparar válidos con inválidos prematuros (véase Gráfica 4A). Los ensayos inválidos demorados no constituían una condición adecuada de ‘no atención’, ya que eran susceptibles de predicción temporal (v.g., procesos de reorientación temporal). Por tanto, los datos comportamentales nuevamente apoyaban la concepción de un mecanismo flexible de orientación en el tiempo. En el caso presente, este mecanismo permitía la generación de expectativas temporales diversas, a partir de un amplio rango de velocidades de movimiento de los estímulos.

Una vez que la tarea estaba lista para observar claros efectos atencionales, el objetivo del Experimento 6.3 fue estudiar los correlatos electrofisiológicos de la habilidad para generar una expectativa temporal mediante el seguimiento atencional de objetos que se mueven con diversas velocidades. Los datos electrofisiológicos mostraron que la atención temporal produjo menor latencia y mayor amplitud en los componentes tardíos N2 y P300 (véanse Gráficas 4B y 4C). Estos resultados presentan gran parecido con los observados en el Experimento 5.1, que utilizó el procedimiento clásico de presentar un contexto estático, lo que sugiere que hay aspectos comunes del mecanismo de orientación que se ponen en juego tanto en contextos estáticos como en contextos dinámicos.

7.5. Conclusiones finales

En la Figura 7.3 se representa el esquema general que guiará la discusión general y que resume los aspectos más relevantes de la tesis. Se estructura en tres elementos básicos: los determinantes, los atributos y las consecuencias que ejerce sobre el procesamiento el mecanismo de orientación temporal de la atención.

7.5.1. Determinantes del mecanismo de orientación temporal

Haciendo una recapitulación de los principales resultados, podemos concluir que el mecanismo atencional mediante el cual las personas son capaces de anticipar, y en consecuencia de prepararse para el momento clave de ocurrencia de un evento relevante, depende de una serie de factores que determinan su funcionamiento. Entre los determinantes más importantes que hemos hallado, en primer lugar se encuentra el *valor predictivo de una señal temporal* para indicar la futura ocurrencia de los estímulos, es decir, su efectividad para inducir expectativas temporales fiables en los participantes. La obtención de beneficios en la ejecución de tareas sobre aquellos estímulos que aparecen en el momento más probable indicado por la señal, revela que los participantes son sensibles a las contingencias temporales del ambiente. Esto es un requisito básico que les permite el uso de estrategias para desarrollar un estado de preparación máxima que esté en sincronía con el momento anticipado de aparición de los estímulos.

Nuestros resultados además demuestran que las personas pueden realizar cómputos de probabilidades sobre la frecuencia con la que ocurren los estímulos y que valoran esta información a la hora de estimar y generar el grado de preparación más adecuado a la situación dada. Cuando los participantes perciben que el objetivo, más pronto o más tarde, va a ocurrir con total certeza, su grado de preparación es tan firme que son capaces de generar una preparación adicional aunque no se cumpla su expectativa inicial de aparición temprana del estímulo (reorientación).

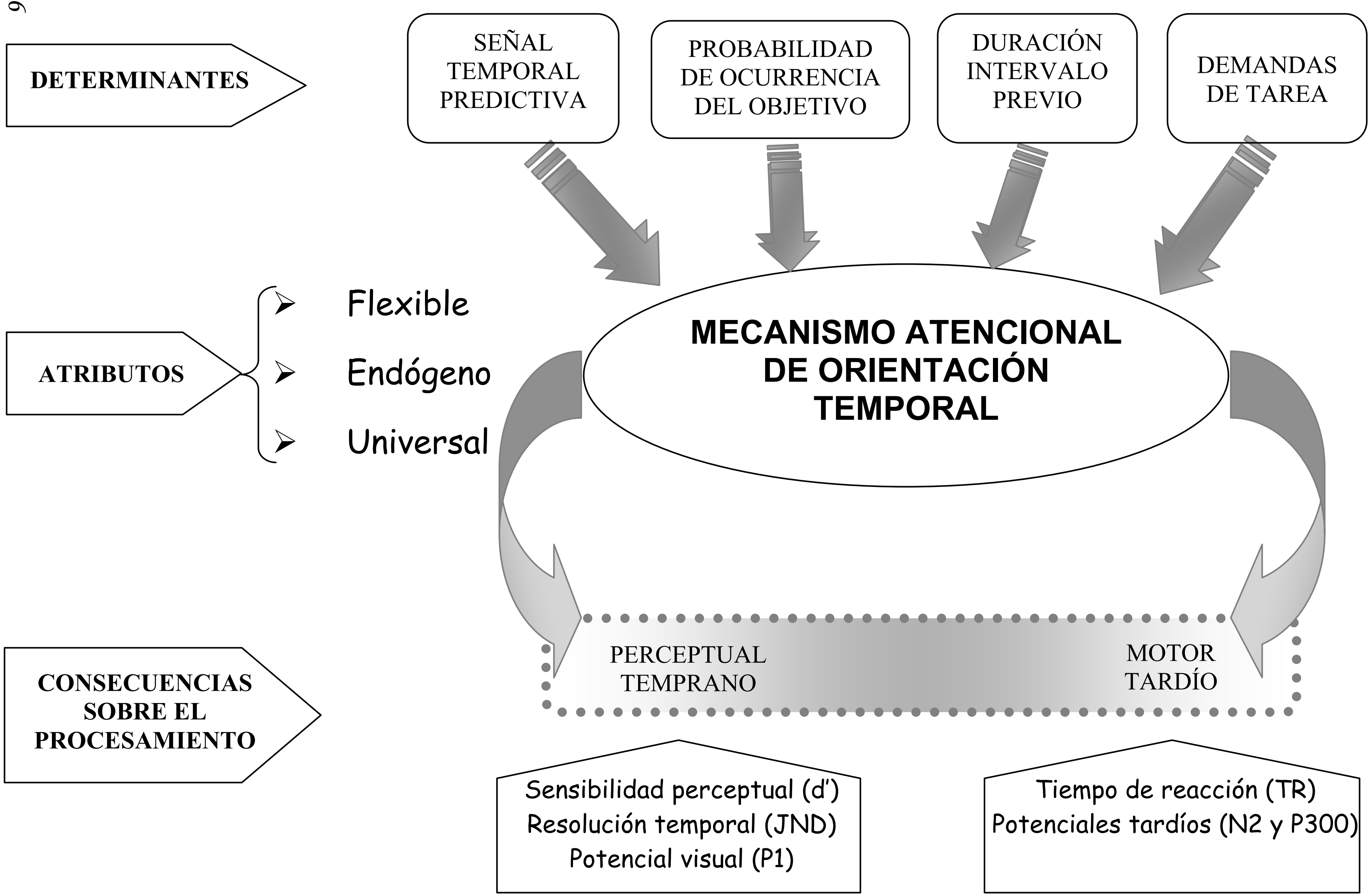
DETERMINANTES
SEÑAL TEMPORAL PREDICTIVA
PROBABILIDAD DE OCURRENCIA DEL OBJETIVO
DURACIÓN INTERVALO PREVIO
DEMANDAS DE TAREA
ATRIBUTOS
Flexible
Endógeno
Universal
MECANISMO ATENCIONAL DE ORIENTACIÓN TEMPORAL
CONSECUENCIAS SOBRE EL PROCESAMIENTO
PERCEPTUAL TEMPRANO
MOTOR TARDÍO
Sensibilidad perceptual (d')
Resolución temporal (JND)
Potencial visual (P1)
Tiempo de reacción (TR)
Potenciales tardíos (N2 y P300)

Figura 7.3

En cambio, si los participantes contemplan la posibilidad de que el estímulo no siempre aparezca, como ocurre en un contexto de catch trials, su nivel de preparación general en el experimento disminuye conforme la probabilidad a priori de ocurrencia del estímulo es menor. Además, el proceso dinámico de preparación que se desarrolla a lo largo de un ensayo concreto se resiente conforme más tiempo pasa sin que el estímulo ocurra (despreparación), pues la probabilidad condicional de que éste ocurra disminuye con el paso del tiempo. De este modo, la *probabilidad de ocurrencia* de los estímulos también determina las estrategias que los individuos siguen para prepararse hacia un momento específico. Estudios como el de Ghose y Maunsell (2002) demuestran que los monos poseen la habilidad para atender en el tiempo a eventos que son anticipados a partir del cálculo de probabilidades condicionadas (es decir, la probabilidad de que ocurra el evento en un instante específico dado que éste no ha ocurrido todavía). Así, esta habilidad podría ser generalizable a diversas especies.

Siguiendo con los factores de tipo fundamentalmente intencional, las *demandas de tarea* también parecen determinar la cantidad de recursos centrales de procesamiento disponibles para controlar el proceso de preparación. Los datos sugieren que el nivel de preparación que es capaz de alcanzar intencionalmente un individuo depende del nivel de exigencia de la tarea que se ha de llevar a cabo. Así, en condiciones de alta exigencia, la capacidad de obtener un beneficio atencional por el hecho de atender a un instante preciso en el tiempo queda mermada debido a las limitaciones del sistema cognitivo. Esto puede explicarse asumiendo que los procesos implicados en el mecanismo de orientación atencional en el tiempo son de carácter controlado, de modo que compiten por los recursos que también demanda la realización de una tarea compleja. Además, cabe la posibilidad de que no sólo los procesos de generación de expectativas y de su mantenimiento en la memoria de trabajo se vean deteriorados en condiciones de alta demanda, sino que también los procesos de estimación temporal de intervalos, necesarios para la orientación temporal, sufran de una mayor imprecisión (Brown, 1985). Como veremos más adelante, las demandas de la tarea en cuanto al tipo de procesamiento requerido, perceptual frente a motor, también es un factor a considerar para comprender las consecuencias que la orientación temporal tiene sobre el procesamiento de estímulos.

En último lugar, hay que destacar la contribución de otro factor, más bien de tipo automático, como son los *efectos secuenciales*. Los efectos secuenciales producidos por la duración del intervalo del ensayo previo también influyen sobre el proceso dinámico de preparación que tiene lugar en el ensayo actual. En este trabajo hemos asumido que los efectos secuenciales ejercen influencias automáticas sobre la preparación, por ejemplo, la duración del intervalo previo ejercería una especie de inercia o de *priming* de repetición sobre el curso temporal de la preparación para el ensayo actual. En este sentido, algunos autores han desarrollado modelos teóricos para explicar los efectos secuenciales según un proceso automático de condicionamiento de trazo (Los & Van den Heuvel, 2001). No obstante, también encontramos en la literatura sobre preparación atencional posturas que defienden el carácter estratégico de los efectos secuenciales (v.g., Drazin, 1961; Karlin, 1959; Niemi & Näätänen, 1981). Básicamente, la postura estratégica considera que los participantes generan una expectativa sobre la duración del intervalo actual esperando que ocurra una repetición del intervalo previo. Sea automática o sea estratégica la contribución de los efectos secuenciales, la relevancia de nuestros experimentos reside en haber aislado de tal contribución el efecto estratégico producido por la presentación de señales predictivas.

De este modo, podemos concluir que a pesar de la contribución de diversos determinantes sobre el proceso de preparación, el uso de señales temporales predictivas es suficiente por sí mismo para generar estrategias de preparación que conduzcan a beneficios atencionales en el comportamiento. A continuación, veremos que el estudio de los determinantes del mecanismo de orientación temporal ha dado lugar al descubrimiento de una serie de atributos que lo caracterizan.

7.5.2. Atributos del mecanismo de orientación temporal: Carácter flexible, endógeno y universal

En varias ocasiones a lo largo del presente trabajo, hemos constatado el *carácter flexible* del mecanismo de orientación temporal. Este mecanismo es flexible en tanto que permite la generación de expectativas temporales que no están limitadas ni a un intervalo rígido de tiempo ni a un valor específico de velocidad de movimiento de los objetos. Más bien, dicha flexibilidad permite la focalización de la atención hacia un rango amplio de instantes en el tiempo de acuerdo con las expectativas temporales, ya sean éstas producto de señales explícitas predictivas o de información implicita que subyace a un patrón regular de movimiento de los objetos.

Esta flexibilidad para modificar el curso temporal de la preparación y sincronizarlo con el momento más relevante para el individuo la hemos deducido a partir de los beneficios atencionales observados en medidas comportamentales. Pero igualmente importante es haber encontrado un referente directo en el cerebro, la modulación atencional del curso temporal de la CNV, que es reflejo de la flexibilidad del proceso de preparación.

A favor de la flexibilidad también encontramos el proceso de reorientación. No sólo es posible dirigir la atención hacia intervalos cortos o largos de forma global en un experimento, sino que a lo largo de un ensayo los participantes son capaces de variar dinámicamente el foco de atención de un intervalo corto hacia un intervalo más largo.

Otra manera de entender este atributo es el hecho de que la atención temporal facilita el procesamiento de una manera flexible, tanto en etapas tempranas como tardías. En el siguiente apartado veremos este aspecto con mayor detalle.

El *carácter endógeno o estratégico* es otro atributo fundamental del mecanismo de orientación temporal que hemos investigado. Así, nuestro objeto básico de estudio consiste en un proceso de preparación que los individuos intencionalmente controlan en función de las probabilidades que perciben tanto de que aparezca el estímulo relevante como de que aparezca en un momento dado. En otras palabras, cuanto más probable perciban la aparición del estímulo en un momento particular, mayor es el nivel de preparación que desarrollan los individuos hacia ese momento.

Como se comentó anteriormente, una contribución valiosa ha sido el disociar procesos endógenos y exógenos que han influido de manera independiente en el proceso de preparación. La distinción entre atención exógena (controlada por los estímulos) y endógena (controlada por las expectativas o metas del individuo) es clásica desde los orígenes del estudio de la atención (James, 1890). Más recientemente, los estudios sobre orientación espacial de la atención han especificado las características diferenciales de los mecanismos exógenos y endógenos implicados en la orientación de la atención hacia posiciones espaciales concretas (v.g., Müller & Rabbitt, 1989).

Análogamente, creemos que tiene sentido asumir mecanismos exógenos y endógenos para focalizar la atención a instantes particulares en el tiempo (v.g., véase Coull, Frith, Büchel et al., 2000 para una aproximación parecida). Esta distinción se ajusta adecuadamente para explicar nuestros resultados, de manera que los efectos secuenciales disparan el mecanismo exógeno de preparación y las señales temporales predictivas disparan una preparación endógena. De las características citadas para la orientación espacial endógena (véase Introducción), encontramos dos que son especialmente relevantes para el caso de la orientación temporal. Primero, la atención endógena es sensible a las manipulaciones del valor predictivo de la señal, de modo que señales altamente predictivas motivan a los sujetos a utilizar la señal, orientando voluntariamente su atención. Además, la atención endógena resulta deteriorada cuando se sobrecargan las demandas cognitivas, por ejemplo, durante la realización de tareas duales.

Esta última característica nos interesa especialmente, pues explicaría nuestros resultados de que las demandas de tarea o el efecto de bloquear la expectativa determinan el tamaño de los efectos de orientación endógena temporal. Así, podemos asumir que el mantenimiento de un *set* de tarea complejo, a la vez que se produce la orientación temporal ensayo tras ensayo, es una situación de tarea dual. Esto supondría una evidencia del carácter controlado de los procesos implicados de estimación temporal, y de generación y mantenimiento de expectativas en la memoria de trabajo. Es igualmente interesante el hecho de que estos dos factores que han mostrado que perjudican la preparación endógena no influyen sobre la preparación exógena producida por los efectos secuenciales. Por tanto, la manipulación de las demandas en procesamiento central, mediante el tipo de tarea o la manera de inducir la expectativa, aportó evidencia adicional para disociar el carácter controlado de los procesos de preparación endógena temporal de otros procesos exógenos.

En relación con estos últimos, podemos encontrar otros procedimientos más elegantes para estudiar la preparación temporal exógena, aparte de los efectos secuenciales. Por ejemplo, la preparación exógena puede basarse en la inducción de ritmos visuales mediante la presentación de objetos que se mueven a una velocidad previsible (véase Experimento 6.1, o Doherty et al., in press), o en la inducción de ritmos auditivos mediante la presentación regular de sonidos (Jones et al., 2002).

En último lugar, merece ser destacado el *carácter universal* del mecanismo de orientación temporal. El beneficio que este mecanismo aporta al comportamiento se ha expresado en una diversidad de tareas, tales como tareas de detección, de discriminación o de identificación de estímulos visuales, y en tareas de juicios de orden temporal. Además hemos comprobado que se trata de un mecanismo general que es igualmente aplicable tanto a contextos artificiales que implican la presentación de estímulos estáticos, como a contextos más próximos a situaciones naturales donde los estímulos típicamente se mueven en la escena visual.

Llevando aún más lejos tal universalidad, podemos plantearnos si la orientación temporal es un caso particular de un mecanismo atencional general que puede dirigirse selectivamente a aquellas propiedades de los objetos que son más relevantes para el individuo, ya sea su forma, color, identidad, significado semántico, localización espacial u ocurrencia temporal. En concreto, nos centraremos en la comparación entre atención espacial y temporal. Aunque la mayoría de las investigaciones han enfatizado sus efectos diferenciales sobre el procesamiento (Coull & Nobre, 1998; Griffin et al., 2002), también se han hallado efectos interactivos de sinergia entre atención espacial y temporal (Doherty et al., in press). En términos generales, pensamos que las diferencias residen en la medida en que difiere la naturaleza de las representaciones espaciales y temporales.

Así, creemos que a la base de los efectos de orientación espacial y temporal subyace un mecanismo universal que presenta unos atributos o propiedades generales, como las que aquí se han descrito. Obviamente, el funcionamiento de dicho mecanismo queda conformado por la naturaleza intrínseca de las representaciones implicadas. Por ejemplo, la representación del tiempo implica una secuencialidad, que puede ser impuesta por el ambiente (v.g., mediante ritmos) o internamente por el individuo, en cuyo caso se necesita cierto control cognitivo para generar y mantener endógenamente un conteo del paso del tiempo. El discurrir del tiempo además es asimétrico, unidireccional, de manera que con el paradigma que hemos empleado sólo es posible dirigir la atención hacia el futuro: se puede reorientar la atención de un intervalo corto hacia uno largo pero no a la inversa.

Sin embargo, la representación del espacio es más directa, pues las coordenadas espaciales son más permanentes, no hay que ir generándolas endógenamente. La orientación espacial no lleva impuesta la unidireccionalidad, en este sentido las representaciones espaciales y los movimientos de la atención guardan una simetría. Por otro lado, a nivel de implementación cerebral también hay importantes diferencias. La más clara es que existe una correspondencia directa entre el espacio externo a representar y el espacio representado, es decir, existe una codificación retinotópica que conserva las proporciones espaciales a varios niveles del sistema visual. Sin embargo, aún no se tiene evidencia de que exista una representación similar en el caso del tiempo, al menos en el sistema visual. Es más, parece más intuitivo postular dicha relación entre la representación temporal y la modalidad auditiva. Como veremos a continuación, estas constricciones biológicas han de considerarse para explicar las consecuencias diferenciales que producen la atención espacial y temporal sobre el procesamiento de los estímulos.

7.5.3. Consecuencias sobre el procesamiento ejercidas por el mecanismo de orientación temporal

Una vez conocidos los determinantes y las propiedades fundamentales de la orientación temporal, llegamos a la cuestión principal de la presente tesis, que ha consistido en estudiar qué efectos tiene sobre el procesamiento de estímulos visuales el estado de preparación óptima alcanzado mediante la anticipación temporal de tales estímulos.

Para su estudio apropiado, hemos comprobado que tanto el tipo de tarea como los índices de procesamiento que se registren son un aspecto de importancia capital en el diseño del experimento. El hecho de que una tarea enfatice la demanda de procesamiento perceptual o de procesamiento motor va a determinar la sensibilidad de dicha tarea para medir efectos atencionales sobre determinados niveles de procesamiento. En general, una tarea adecuada para estudiar si la atención temporal mejora el procesamiento perceptual debe suponer una gran demanda perceptual, ya que los efectos atencionales son más claramente observables cuando realmente hay necesidad de optimizar el procesamiento perceptual. De otro modo, tendríamos el problema de obtener un efecto techo que impida observar el beneficio atencional, ya que un procesamiento “sencillo” no requiere o no es susceptible de ser optimizado en mayor medida.

Por otro lado, está la importancia de la elección de índices de procesamiento adecuados para medir posibles modulaciones a nivel perceptual. Así, el TR no es una medida especialmente útil para disociar contribuciones perceptuales de motoras, mientras que medidas psicofísicas como la sensibilidad perceptual (d’) y el umbral diferencial sí que resultan más adecuadas para aislar procesamiento perceptual. Las medidas basadas en activación cerebral también se emplean de forma convincente para estudiar el locus de modulación atencional. No obstante, las neurociencias muestran que la disociación perfecta entre procesos perceptuales y procesos motores puros no deja de ser una utopía, ya que existen claras interacciones bidireccionales entre percepción y acción (Churchland, Ramachandran, & Sejnowski, 1994).

Comenzando por las consecuencias que la atención temporal tiene sobre el procesamiento de los estímulos a niveles tardíos, hemos observado que procesos de decisión y de ejecución motora de respuestas se ven potenciados por la atención. Como evidencia a favor encontramos una disminución de los TR tanto en tareas de detección como de discriminación de estímulos, así como una modulación de componentes electrofisiológicos cerebrales relacionados con procesamiento tardío, tales como el N2 y el P300. Creemos que lo más relevante de la atención temporal es la modulación de la latencia de dichos componentes, de modo que la facilitación de procesos tardíos puede ser resultado tanto de una sincronización como de un ahorro de tiempo en su ejecución.

En cuanto a las consecuencias de la atención temporal sobre el procesamiento perceptual, a pesar de la concepción dominante de que la atención temporal sólo potencia el procesamiento motor, hemos descubierto que también es posible observar una facilitación temprana sobre índices de procesamiento perceptual bajo condiciones de alta demanda perceptual. Nuestros resultados indican que tareas como las de discriminación de estímulos, identificación de estímulos que quedan enmascarados mediante el procedimiento de presentación visual serial rápida o tareas de juicios de orden temporal, son más sensibles para capturar modulaciones del procesamiento perceptual que las tareas clásicas de detección de estímulos. En particular, hemos observado que la atención temporal mejora la sensibilidad perceptual para identificar estímulos enmascarados, incrementa la agudeza o resolución temporal para discriminar el orden de ocurrencia de dos estímulos visuales casi simultáneos, e intensifica la respuesta electrofisiológica típicamente asociada con procesamiento visual de los estímulos sobre áreas occipitales. Esta evidencia obtenida a partir de diversas metodologías converge en la idea de que atender a un instante en el tiempo potencia el procesamiento perceptual de aquellos estímulos visuales que aparecen en el instante atendido.

Comparación entre atención temporal y atención espacial.

Acabamos de constatar que la atención temporal produce efectos sobre el procesamiento análogos a los de la atención espacial, de manera que facilita de forma flexible etapas tempranas y tardías de procesamiento. En cambio, algunos estudios psicofisiológicos, que han comparado directamente condiciones de atención espacial y temporal, muestran patrones de activación cerebral diferenciales que inducen a pensar que los procesos implicados no son exactamente idénticos. Mientras que la atención espacial claramente modula etapas tempranas y tardías de procesamiento, parece que la atención temporal produce efectos menos evidentes sobre procesos perceptuales tempranos, al menos en la modalidad visual.

Como se ha adelantado, pensamos que la raíz de estas diferencias está en la forma en que el tiempo y el espacio son representados en el cerebro. En el sistema visual el espacio es representado de forma más exacta y detallada que el tiempo, de acuerdo a una organización retinotópica. Así, las representaciones neurales de posiciones espaciales específicas pueden ser directamente amplificadas por la atención (Mangun, 1995), observándose sus efectos en áreas occipitales o parietales. En cambio, parece que el sistema visual carece de unas representaciones temporales tan específicas, lo que dificultaría la observación de efectos atencionales sobre el procesamiento visual similares a los que ocurren con representaciones espaciales, al menos en los estudios con neuroimagen que hay hasta la fecha (Coull, Frith, Büchel et al., 2000; Coull & Nobre, 1998), donde únicamente se utilizan presentaciones estáticas de estímulos visuales.

Así, creemos que las presentaciones de estímulos estáticos no son especialmente adecuadas para estudiar el efecto de la orientación temporal sobre el procesamiento visual, ya que no permiten al sistema visual un procesamiento temporal basado en claves visuales, análogo al de la orientación espacial. Es decir, en los estudios sobre atención espacial, la presentación estática de estímulos en diferentes localizaciones proporciona una extensión espacial que puede ser codificada directamente por el sistema visual y sobre la que se puede orientar la atención. La diferencia crucial que presentan los estudios sobre atención temporal es que la presentación de estímulos, aunque a diferentes intervalos de tiempo, no proporciona una extensión temporal comparable a la espacial, de modo que no puede ser codificada directamente por el sistema visual. En este caso, los procesos de cronometraje internos necesarios para la orientación temporal han de basarse en la participación de otras estructuras de cómputo más generales como el cerebelo, o de circuitos especializados para procesamiento motor o auditivo.

De este modo, un experimento interesante que nos planteamos realizar en un futuro con técnicas de neuroimagen consiste proporcionar al sistema visual una extensión temporal directa de los eventos mediante la presentación dinámica de estímulos de acuerdo a ritmos visuales, en conjunción con tareas adecuadas para medir el procesamiento perceptual. En estas condiciones sí que esperaríamos observar activaciones en áreas cerebrales relacionadas con procesamiento visual temprano, incrementadas por el efecto de la atención temporal. De hecho, estas condiciones experimentales son similares a las que utilizamos en el procedimiento RSVP, donde había ritmo visual y énfasis sobre la demanda de procesamiento perceptual, dando lugar a una facilitación atencional sobre la sensibilidad perceptual.

Por otro lado, el tiempo sí que es representado con gran detalle y exactitud en la modalidad auditiva, siguiendo la corteza auditiva una organización tonotópica (agrupada en función de frecuencias). La codificación temporal no sólo es fundamental para el procesamiento auditivo, sino que también está claramente implicada en la secuenciación de actos motores (Lewis & Miall, 2003; Nobre & O'Reilly, 2004). Esta prevalencia de la dimensión temporal en el procesamiento auditivo y motor sí que posibilitaría en mayor medida la acción amplificadora de la atención directamente sobre las representaciones neurales de tiempo. Esto explicaría el hecho de que los efectos de la atención temporal son claramente observados en niveles tempranos en la modalidad auditiva (Lange et al., 2003), así como en niveles tardíos cuando lo que se demanda es un procesamiento eminentemente motor (Miniussi et al., 1999).

En conclusión, parece que la exactitud y riqueza con la que un circuito cerebral (o modalidad sensorial) es capaz de representar la información espacial y temporal, va a determinar el tipo de modulación atencional que es posible observar en dicho circuito o modalidad sensorial. Así, la facilitación atencional del procesamiento espacial a niveles tempranos es clara en la modalidad visual, mientras que la facilitación atencional del procesamiento temporal es más obvia en la modalidad auditiva o cuando se demanda procesamiento motor. No obstante, como hemos comprobado a lo largo de la presente tesis, el sistema visual computa de alguna manera la dimensión temporal, de manera que también es posible observar facilitaciones del procesamiento visual en determinados momentos en los que se focaliza la atención. En la medida en que avancen nuestros conocimientos sobre los diferentes formatos que el cerebro utiliza para representar el tiempo en diferentes modalidades sensoriales o niveles de procesamiento, las relaciones entre atención espacial y temporal se irán clarificando.

7.5.4. ¿Qué es el mecanismo de orientación temporal: un control sobre el proceso de alerta, un foco atencional dinámico o un proceso de preparación?

A lo largo de la tesis hemos propuesto una explicación en términos de un proceso de preparación atencional. Esta preparación, según algunos autores (Los & Van den Heuvel, 2001), puede ser específica o inespecífica. La preparación inespecífica se relaciona con procesos de alerta fásica, que implica un estado de activación inespecífica desencadenado por la aparición abrupta de un estímulo o de una señal que avisa la llegada inminente de otro estímulo (Posner, 1978). Así, una forma de entender la orientación temporal asume que el proceso exógeno de alerta está abierto a influencias de arriba-abajo, de modo que puede ser controlado endógenamente por una expectativa temporal (v.g., Milliken & Lupiáñez, 2000).

No obstante, esta concepción no creo que sea la más adecuada para explicar las facilitaciones del procesamiento perceptual y motor que hemos observado, y que concuerdan con la idea de una preparación atencional específica (LaBerge, 1995). En cambio, la alerta induce un estado de activación muy general del organismo relacionado con la urgencia de una respuesta. Así, el efecto clásico que se observa en los estudios sobre alerta fásica (Posner, 1978) es una relación inversa entre el rapidez con que se emite la respuesta (TR) y la exactitud de la misma (v.g., tasa de aciertos). Nuestros datos no muestran evidencia sobre este tipo de relación, lo que nos lleva a pensar que la orientación temporal constituye un proceso independiente de la preparación inespecífica. Naturalmente, la presentación de señales de aviso o de alerta implican la actuación tanto de un proceso inespecífico de alerta como de una preparación temporal específica, debido a que el intervalo de tiempo entre la señal de alerta y el estímulo suele ser constante y permite predicciones temporales (Bertelson, 1967). No obstante, pienso que es posible disociar experimentalmente entre procesos de alerta y de orientación temporal, lo que supone un objetivo más de investigación para el futuro próximo.

Por otro lado, una explicación en términos de preparación atencional no implica la exclusión de otras concepciones basadas en los modelos dinámicos de la atención (Large & Jones, 1999). Realmente, creo que ambas explicaciones aluden a un mismo mecanismo atencional de potenciación del procesamiento con una característica básica clave: que la dinámica o curso temporal de este proceso atencional puede ser modificada en función de expectativas temporales sobre la ocurrencia de los eventos. Como resultado, aquel evento que ocurre, ya sea bajo el foco atencional dinámico o en el momento de preparación óptima, es procesado con mayor eficacia.

La diferencia más importante entre ambas explicaciones está en el origen de la expectativa temporal, es decir, en el agente que controla la dinámica del proceso atencional. La explicación del foco atencional dinámico enfatiza el hecho de que las expectativas temporales son generadas de manera automática a partir de la regularidad temporal que proporciona la presentación de ritmos externos. En cambio, la explicación que hemos defendido en esta tesis enfatiza la idea de que las expectativas temporales las genera el individuo de forma controlada e intencional a partir de la predictividad temporal que proporciona el uso de señales simbólicas.

Las diferencias entre ambas explicaciones están más ligadas a los procedimientos experimentales específicos que han servido para el estudio de la atención temporal (v.g., modalidad auditiva frente a visual, señales exógenas frente a endógenas para inducir expectativa, etc.), que a las concepciones teóricas sobre atención que se han aplicado. Así, podemos acortar estas diferencias si consideramos lo siguiente. Por un lado, en el procedimiento implícito para generar expectativa temporal podemos encontrar intencionalidad en el sentido de que la presentación de ritmos permite predictibilidad temporal, en la que los participantes pueden basar sus estrategias de preparación. Además, es indudable que en nuestros experimentos, a la base de la expectativa temporal no todo es explícito e intencional: también hay implícita una presentación regular de ritmos ‘exógenos’, es decir, secuencias de intervalos corto y largo. De hecho, uno de nuestros objetivos ha consistido precisamente en disociar ambos tipos de influencia en el proceso de preparación, ya que los efectos automáticos secuenciales pueden entenderse como un tipo de inducción implícita de ritmos.

En conclusión, las explicaciones basadas en el foco atencional dinámico y en el proceso de preparación fundamentalmente han aludido a dos formas de control sobre la atención temporal, pero ambas constituyen dos metáforas muy similares para comprender un mismo mecanismo. Sí que resulta interesante para futuras explicaciones incorporar conceptos clave del modelo dinámico, tales como el periodo o la fase, que resultan muy apropiados para describir de manera precisa las operaciones de un proceso, el atencional, cuya característica fundamental aquí es su extensión en el tiempo.

SUMMARY

Attentional preparation based on temporal expectancy, also referred to as *Orienting of attention in time*, involves a mechanism by which intelligent organisms achieve efficient and adaptive behaviour. In general, this mechanism implies the orienting or focusing of attention on specific instants in time, that is, it consists of developing preparation for that specific instant, at which the future occurrence of a relevant event is anticipated, in order to optimize the task concerning that event.

The thesis consists of experimental research regarding the attentional mechanism of temporal orienting, in particular, regarding the determinants, attributes and cognitive processes underlying its functioning, and the effects of this mechanism over processing of visual stimuli.

The thesis is organized according three major sections: introduction, experimental investigation and general discussion. The *Introduction* is framed over the two elemental concepts that encompasses our subject of research, attention and time, and includes four chapters which progressively achieve a more specific level of analysis, ending with our particular subject of research. Specifically, we outline how *time* is perceived and represented in the brain, the background of attention underlying our research, the mechanism of orienting of attention in space, some approaches to jointly study attentional and temporal aspects of cognition, and a review of research on temporal orienting of attention.

As a result, such a review raised the questions that motivated our *Experimental Research*. This section describes the questions and aims that provide the framework to the four experimental series we conducted. The major aim was to investigate the consequences on stimulus processing of attending to the moment in time at which the stimuli will occur, in particular, the question of whether temporal attention can enhance early perceptual processing. The experimental series consists of six chapters that correspond to six independent (published/under review) articles. The main result we have found in this thesis is illustrated in the painting of the cover: visual stimuli are perceived and identified more rapidly and accurately when they occur at the attended moment, according to the temporal expectancy induced by a predictive cue.

In the *General Discussion*, my endeavour was to integrate the partial knowledge separately achieved from each article, through an overall summary concerning the main results and contributions of the thesis, and then linking that knowledge to the main concepts developed in the introduction. As a final conclusion, the following aspects observed for the mechanism of temporal orienting are discussed: its determinants (predictive temporal cues, probability of target occurrence, duration of the preceding interval and task demands), attributes (flexible, endogenous and universal character) and its consequences over stimulus processing (enhancement of early perceptual processes, as indexed by the perceptual sensitivity -d'-, just noticeable difference -JND-, and event-related potential related to visual processing -P1-; and enhancement of late decisional and motor processes, as indexed by reaction times -RTs- (presumably), event-related potential related to processes involved in responding -N2 and P300-). The thesis ends with my personal view on the mechanism of temporal orienting. There, I try to argue that temporal orienting is more than endogenous modulations of unspecific activations related to phasic alertness. Moreover, I suggest that explanations based on the dynamic attentional focus and on the preparation process just differ in that they involve two types of controlling temporal attention (exogenous vs. endogenous control). However, both explanations share the very same attentional function of processing enhancement with the following key feature: the dynamics or temporal course of this attentional process can be modulated as a function of temporal expectancies regarding the future occurrence of events, and consequently, the event occurring either under the dynamic attentional focus or at the moment of optimal preparation, is efficiently processed. In any case, some concepts of the dynamic attending models, such as the period or the phase, seems promising to accurately describe this attentional process, which fundamental feature here is the extension in time.

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