TESIS DOCTORAL

ATTENTIONAL CONTROL AND SOCIO-EMOTIONAL REGULATION DURING CHILDHOOD

(Control atencional y regulación socio-emocional durante la infancia)

DOCTORADO EUROPEO

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Attentional Control and Socio-emotional regulation during childhood.

Tesis Doctoral presentada por **Purificación Checa Fernández** en el *Departamento de Psicología Experimental y Fisiología del Comportamiento*, para aspirar al grado de Doctor en Psicología, en el programa de doctorado de *Psicología Experimental y Neurociencias del Comportamiento*, de la Universidad de Granada.

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La doctoranda

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A mis padres, por confiar en mí y por

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CAPÍTULO I

INTRODUCCIÓN Y OBJETIVOS DE LA TESIS

Imaginemos que hoy es el primer día de colegio para muchos niños. Cuando esto sucede podemos ver niños que desconsoladamente lloran alrededor de sus padres, gritando y pataleando, mientras otros sin embargo se muestran felices enseñando sus nuevos zapatos a sus compañeros o mirando el estuche lleno de lápices de colores. Esta simple observación muestra que entre estos niños existen diferencias individuales en la forma de ejercer el control sobre su emoción y sobre su comportamiento. Pero, ¿de qué depende que unos niños se comporten de un modo tan diferente a otros? Podría ser que unos sean de mayor edad que otros, lo que nos llevaría a pensar que los más mayores han desarrollado los recursos necesarios para hacer frente de forma eficaz a estas situaciones. Pero, ¿y si ambos niños tienen la misma edad, y presentan estos comportamientos tan dispares? Entonces, podríamos pensar que factores como la experiencia o las características biológicas pueden estar influyendo en su comportamiento.

Una vez que entran en el colegio, me pregunto, si estas diferencias en control influirán en aspectos como las relaciones con sus compañeros y en su rendimiento académico.

Con este ejemplo, he querido de forma sencilla plantear cuáles son los intereses que promovieron el trabajo de tesis que voy a presentar. Por un lado, sabemos que la capacidad de control es un campo de estudio psicológico por el que se han interesado los investigadores desde el XIX hasta nuestros días. Debemos mencionar a la Psicología de la Atención y a la Psicología de la Personalidad por el inmenso trabajo que han realizado entorno a esta temática, y que nos han ayudado a entender este proceso de control. Con esto en mente nosotros, hemos planteado el estudio de la capacidad de control desde ambas perspectivas la cognitiva y la temperamental. En particular nos interesa conocer cómo se desarrolla esta capacidad y cómo las diferencias individuales en la misma se relacionan con el comportamiento incluso en situaciones donde la afectividad está implicada. Un tema importante de este trabajo será por otro lado, conocer cómo las diferencias individuales en la capacidad de control pueden influir en contextos más naturales como los centros escolares.

En este capítulo de introducción, haremos una revisión sobre cómo se ha llevado a cabo el estudio de la capacidad de control desde la Psicología Cognitiva y desde la Neurociencia, así como desde la Psicología de la Personalidad en concreto del temperamento. Revisaremos algunas de las investigaciones que se han realizado para estudiar el desarrollo de la capacidad de control. Posteriormente, pondremos en relación la capacidad de control con la autorregulación, y finalizaremos con un análisis de las influencias de dicha capacidad en la educación.

ATENCIÓN

Con el nacimiento de la Psicología Científica en el último cuarto del siglo XIX, la Atención empieza a tener un papel preponderante en las explicaciones psicológicas, Autores de la época la definen como "… el tomar posesión por parte de la mente, de forma clara y vívida, de uno de varios posibles objetos del pensamiento. Su esencia está constituida por la focalización, la concentración y la conciencia. Atención significa dejar ciertas cosas para tratar de forma efectiva otras…" (James, 1890). Ya en esta época existía gran interés por temas de investigación relacionados con la Atención, lo que se evidencia en el hecho de que muchos investigadores se dedicaran activamente a estudiar aspectos como la amplitud de la atención (Jevons, 1871), la ejecución en tareas concurrentes (Paullhan, 1887) y el papel de la práctica y los automatismos (Bryan y Harter, 1899). De estos primeros intentos por estudiar la Atencion y conceptualizarle puede desprenderse que la Atención es un proceso multivariado más que un proceso único.

Sin embargo, durante la primera mitad del siglo XX el concepto de Atención fue borrado de la teoría psicológica. Con el nacimiento de la doctrina Conductista en Norteamérica la Atención desapareció de las explicaciones psicológicas o quedó reducida a meros descriptores de relaciones particulares entre el estímulo y la respuesta. En Europa también se produce un abandono del interés por la Psicología de la Atención. Tal es el caso de la Psicología de la Gestalt, que empieza a desvincularse de la psicología de la atención para considerar que la conducta está determinada por las características de los estímulos que provocan directamente una respuesta. La investigación gestáltica se limitó a estudiar dichas características olvidando las modulaciones internas sobre el procesamiento perceptivo.

En oposición al conductismo, en la década de los 50 surgió la Ciencia Cognitiva con la que se devolvió a la Atención su papel en el estudio de los procesos psicológicos. Despiesta de nuevo el interés por el estudio experimental de la Atención con la irrupción de la Teoría del Procesamiento de la Información. Se inicia así una etapa rica en el estudio de los procesos relacionados con la atencón.

Prueba de ello, y ligado a los intereses militares de la época surge, durante la Segunda Guerra Mundial, el estudio de la atención en situaciones de vigilancia (atención sostenida). Mackword (1969) inició el estudio formal de la función atencional de vigilancia con la denominada prueba del reloj. Dicha prueba consistía en una tarea de discriminación en la que los participantes tenían que observar los movimientos de la aguja del reloj, que cada segundo se desplazaba 7mm, pero en ocasiones se desplazaba 14mm. La tarea duraba 2 horas ininterrumpidas y el participante debía presionar un botón cada vez que la aguja se desplazara 14mm. Los resultados señalaron que los participantes tenían más dificultad para detectar las señales infrecuentes (desplazamientos de 14mm) conforme pasaba el tiempo, y que dicha detección declinaba más rápidamente desde la primera a la segunda media hora (Mackworth y Mackworth, 1956). Además de los estudios de vigilancia, diferentes investigadores pusieron de manifiesto las limitaciones de capacidad del sistema (Cherry, 1953; Welford, 1952). Telford (1931) y posteriormente Welford (Welford, 1952) observaron que cuando los participantes tenían que responder rápidamente a estímulos que se presentaban en una sucesión temporal rápida, la respuesta se enlentecía si el estímulo se presentaba con menos de un segundo de intervalo después del estímulo previo, al que también se debía responder. Welford denominó a este enlentecimiento en el tiempo de reacción al segundo estímulo "Periodo Refractario Psicológico". Este efecto se atribuyó a la limitación de capacidad del mecanismo que producía que ciertas operaciones sólo se pudieran llevar a cabo de forma secuencial, lo que daría lugar a una demora en el procesamiento (Craik, 1948; Welford, 1952). Los estudios de Cherry (1953) utilizando tareas de escucha dicótica, evidenciaron también los límites en la capacidad para seleccionar la información. La tarea de escucha dicótica, consistía en presentar dos mensajes auditivos simultáneamente por los dos oídos (canales), instruyendo al participante para atender al mensaje emitido por un oído, mientras ignoraba el mensaje emitido por el otro. Los resultados mostraron que mientras los participantes eran capaces de recordar la información emitida por el canal atendido, el recuerdo del mensaje que se emitía por el canal no atendido era nulo o se limitaba a la detección de cambios en función de los rasgos físicos, tales como la voz (masculina/femenina) o la presencia de un tono auditivo.

La imposibilidad de realizar determinadas tareas de forma concurrente, llevó a los estudiosos de la época a una concepción de la atención como filtro de selección de la información. Este filtro dejaría pasar la información relevante y dejaría fuera del procesamiento a la irrelevante. Surgieron, entonces, los modelos estructurales y la polémica sobre el lugar del filtro. Dentro de estos modelos, existen dos grandes modelos: modelos de selección temprana y modelos de selección tardía. Los primeros proponen que la Atención puede ser un mecanismo situado en las primeras etapas del procesamiento donde sólo los rasgos físicos más superficiales de los estímulos, como la localización o la intensidad son analizados en paralelo (Broadbent, 1958). En estos modelos no se contemplaba la posibilidad de que la información ignorada (filtrada) alcanzara a niveles de procesamiento superiores a las meras características físicas. Entonces, ¿cómo en ocasiones usando tareas de escucha dicótica las personas podían darse cuenta de que su nombre se decía por el canal ignorado (Moray, 1959)? Para dar respuesta a esta pregunta se plantearon modelos alternativos, de selección tardía, que proponían que el filtro atencional selectivo operaba sobre la base de los estímulos u objetos analizados en función de sus características semánticas (Deutsch y Deutsch, 1963). Sería en el acceso a consciencia donde estos modelos ubican el filtro.

A finales de los años 60, Anne Treisman romperá con la concepción del filtro rígido de ubicación fija en la sucesión de estadios del procesamiento de la información, proponiendo un filtro selectivo que actuaría atenuando el procesamiento de la información ignorada. Entonces, el acceso de la información del canal ignorado a niveles superiores de procesamiento no era totalmente bloqueado pudiendo alcanzar ciertos niveles de activación, aunque inferiores a los alcanzados por la información atendida. Treisman (1969) planteó la idea del filtro flexible, de modo, que el filtro podría actuar en fases tempranas del procesamiento, limitando el número de estímulos de entrada analizados, o en lugares más tardíos del procesamiento, determinando el número de características relevantes y/o los resultados del análisis perceptivo que se tiene en cuenta para las respuestas. A partir de este momento, se cae en la cuenta de la necesidad de postular la existencia de un sistema de control.

Es en este contexto en el que surgen los modelos de recursos atencionales, entre los que se encuentra el modelo de Kahneman (1973). Según este modelo, las personas poseen una cantidad limitada de recursos atencionales que pueden distribuirse simultáneamente para realizar las tareas. Cuando el participante tiene que realizar dos o más tareas de forma simultánea, los recursos atencionales disponibles en un momento dado, se asignan prioritariamente a la tarea principal, quedando la posibilidad de que queden recursos atencionales libres, lo que hará posible la ejecución de varias tareas a la vez. Este modelo abre la puerta al estudio de la ejecución simultánea de más de una tarea, en función de la dificultad de cada tarea, de la interferencia específica entre ellas y de la prioridad asignada a cada una de las tareas. Norman y Bobrow (1975) elaboraron una teoría general de la administración de los recursos atencionales, a partir del análisis mediante curvas POC (Performance Operating Characteristic), donde se trazan los límites de ejecución de una tarea en función de la otra.

Sin embargo, determinados resultados experimentales comenzaron a poner de manifiesto que conceptualizar la atención como una fuente central de recursos común a todos los procesos era insuficiente. Por ejemplo, el grado de interferencia entre tareas concurrentes varía en función de variables como la práctica o la modalidad estimular o de respuesta (Tudela, 1992). Además, si la capacidad (o los recursos) es central, es decir, es la misma para todas las tareas, una tarea difícil debería interferir más sobre otra tarea que una tarea fácil. Sin embargo, Wicker (1976) demostró que una tarea difícil no interfería más sobre otra tarea que una tarea fácil, por lo que se propone la idea de la existencia de recursos múltiples específicos para cada tarea en lugar de un único recurso disponible en un procesador central de capacidad limitada (Navon y Gopher, 1979; Wickens, 1984).

En los años 70, y de forma casi paralela a los modelos de recursos, surgen una serie de modelos que postulan la existencia de dos formas de procesamiento cualitativamente distintas: los procesos automáticos y los controlados-conscientes (Posner y Snyder, 1975). Entre ellos se encuentra el modelo propuesto por Norman y Shallice (1986). Estos autores asumieron que para coordinar las acciones, múltiples subsistemas interactuarían y serían controlados por dos mecanismos diferentes. El primero de estos mecanismos serían los "esquemas", que son como programas que coordinan los procesos llevados a cabo por subsistemas cognitivos con un objetivo concreto. Para controlar las acciones bien aprendidas estos esquemas compiten y sólo el esquema que más se active actuará permaneciendo activo hasta alcanzar su meta o bien hasta que otro esquema exceda la activación del esquema actual. Este mecanismo es bueno para explicar acciones rutinarias, es decir, bien establecidas y aprendidas, pero, ¿qué ocurre cuando la situación es novedosa o altamente competitiva? Los autores proponen un segundo mecanismo que se encargaría de controlar acciones en situaciones en las que las respuestas deben determinarse de forma voluntaria, en función de las metas y objetivos del individuo. Este segundo sistema implica a la atención y se denomina "sistema atencional supervisor" (SAS). Según Norman y Shallice, el SAS es necesario para a) planificar o tomar decisiones, b) corregir errores, c) enfrentarse con respuestas novedosas o que no están bien aprendidas; d) afrontar condiciones juzgadas como difíciles o peligrosas, y e) superar respuestas habituales para dar una respuesta alternativa.

Hemos de decir que junto a Norman y Shallice (1986), Michael Posner (1978), ha sido un de los principales exponentes de la concepción de atención como un mecanismo de control. Desde la perspectiva de estos autores, la atención se concibe como una estructura de control que activa e inhibe a los sistemas encargados de procesar la información en función de los objetivos y metas del individuo. En opinión de Tudela (1992) la atención es: "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).

Dado que como hemos visto parece haber distintas variedades de atención, atención como estado (vigilancia o alerta), atención como selección y atención como control, ineludivelmente surge la pregunta de si es la atención un proceso único o está compuesta por un número de procesos separados que actúan de forma integrada. El modelo sobre atención propuesto por Michael Posner intenta dar respuesta a esta pregunta.

El modelo neurocognitivo de Michael Posner

El modelo neurocognitivo de Michael Posner expone una visión integrada de la atención presentandola como un sistema modular compuesto por tres redes neuro-anatómicas que se relacionan con las diferentes funciones de la atención: la Red Alerta, la Red de Orientación y la Red de Atención Ejecutiva.

A la Red de Alerta, se le ha atribuido las funciones de vigilancia y mantenimiento del nivel de receptividad a la estimulación, necesario para la realización de una tarea en la que se requieren respuestas continuas y rápidas (Posner, Nissen, y Odgen, 1978). El circuito cerebral que parece estar implicado en el estado general de alerta está formado por áreas del lóbulo frontal principalmente derecho que recibe conexiones del locus coeruleus usando el neurotransmisor de norepinefrina (Posner y Petersen, 1990). La implicación de la norepinefrina en la alerta viene avalada por la estudios que indican que al ingerir medicación que reduce la liberación de noradrenalina incrementan los "lapsus atencionales" y el efecto se revierte con la administración de fármacos que incrementan la liberación de noradrenalina (Smith y Nutt, 1996). Estudios con PET muestran que el flujo sanguíneo en el frontal cuando el sujeto está en situaciones de alerta (Posner y Petersen, 1990).

La segunda red propuesta por el modelo es la Red de Orientación. Esta red sería la encargada de orientar a los receptores hacia la fuente estimular, de controlar el procesamiento perceptivo y de seleccionar la información relevante. Posner distingue entre la orientación de los receptores hacia la fuente estimular (orientación abierta) y la orientación del sistema atencional (orientación encubierta) (Posner, 1980). La existencia de la orientación encubierta se demostró con el paradigma de costes y beneficios. Este paradigma es un procedimiento experimental en el se presenta un punto de fijación en el centro de la pantalla y dos cuadrados a los lados. La tarea de los participantes es responder a un estímulo en cualquiera de los cuadrados sin mover los ojos del punto de fijación central. Antes de cada ensayo puede que aparezca una señal. Esta señal puede indicar la posición donde posteriormente aparecerá el estímulo al que hay que responder (señal válida) o puede indicar una ubicación diferente a la que con posterioridad aparecerá el estímulo objetivo (señal inválida). El beneficio se manifiesta en la reducción en el tiempo de reacción en los ensayos con señal válida comparados con los ensayos en los que no aparece señal. Por otro lado, el coste se manifiesta en un incremento en el tiempo de reacción en los ensayos con señal inválida comparados con los ensayos en los que no aparece la señal. Posner (1980) propone que la señal provoca un movimiento de la atención produciendo un beneficio o ventaja para la detección del estímulo objetivo cuando la señal es válida, y un coste o retraso en dicha detección cuando la señal es inválida. Esta red atencional se ha relacionado con ciertas partes del córtex parietal, los núcleos pulvinar y reticular del tálamo, y partes del cerebro medio como los colículos superiores (Posner, Inhoff, Friedrich, y Cohen, 1987; Posner, Walker, Friedrich, y Rafal, 1984) y parece estar modulada por la acetilcolina (Voytko, y cols, 1994).

Posner incorpora el modelo de Norman y Shallice (1986) a su teoría atencional para explicar la función que cumple la Red de Atención Ejecutiva. Sugieren que esta red es necesaria cuando las rutinas establecidas son insuficientes para resolver la tarea que se está realizando o cuando los subsistemas tienen que ser ignorados debido a cambios en el ambiente o en las metas. Por tanto, la Red de Atención Ejecutiva permite procesar información novedosa o acontecimientos inesperados, así como suprimir respuestas o tendencias muy habituales cuando éstas no son apropiadas (Posner y DiGirolamo, 1998). Dos áreas cerebrales diferentes están a la base de esta red atencional: el cíngulo anterior y el córtex prefrontal lateral. Diferentes estudios han mostrado que la dopamina está relaciona con esta red atencional y que dicha sustancia se asocia con problemas relacionados con el control como es el caso del trastorno por déficit de atención e hiperactividad (TDAH) (Cook, y cols., 1995; Madras, Miller, y Fischman, 2005; Swanson, y cols., 2000).

Aunque estas tres redes tienen una base neural distinta y son funcionalmente diferentes existe una interconexión entre ellas. Normalmente, se encuentra que las redes no trabajan de forma independiente en todas las situaciones. Por ejemplo, como hemos mencionado, cuando las personas están en una situación de alerta parece que el flujo sanguineo al área frontal aumenta, sin embargo este flujo disminuye en el CCA (Cohen y cols., 1988). La explicación que se da a este hallazgo es que las señales de aviso preparan al sistema para responder rápidamente a un objeto que aparecerá en cualquier momento, interrumpiendo momentáneamente al sistema de Atención Ejecutiva para beneficiar la detección del estímulo. Sin embargo, la red de Alerta parece facilitar la orientación de la Atención incrementando la rapidez del cambio atencional. Por otro lado, usando una señal espacial, que permite dirigir la atención antes que el target aparezca, potencialmente reduce la influencia de la información conflictiva. La red de Orientación actúa como un filtro de información, desechando información irrelevante y potenciando la función de la red de Atención Ejecutiva.

De las tres redes atencionales propuestas en el modelo atencional de Posner, la Red de Atención Ejecutiva parece ser que es la que cumple con la función de regular la cognición y el comportamiento en base a las metas y los objetivos de las personas. Diariamente las personas se enfrentan a situaciones donde se requiere algún tipo de control o regulación, es decir, situaciones donde se requiere de la actuación de la Red de Atención Ejecutiva. Dado que el núcleo principal de interés de este trabajo es el estudio de la regulación y el control, y que la red de Atención Ejecutiva parece cumplir con esta función, nos adentraremos en un análisis más pormenorizado de dicha red. Por tanto, en las siguientes secciones expondremos cuales son algunas de las tareas de laboratorio que se han diseñado para su estudio, cuáles son los mecanismos a través de los cuales la Atención Ejecutiva actúa, y cómo la Neurociencia Cognitiva a través de los datos de neuroimagen proporciona información muy revelante en cuanto a las áreas cerebrales implicadas en dicha Red cerebral. Por último, analizaremos el desarrollo de la Atención Ejecutiva ya que esta función muestra un desarrollo particularmente rápido en la infancia.

ATENCIÓN EJECUTIVA

Tareas para estudiar la Atención Ejecutiva

La función de Atención Ejecutiva (AE) se ha estudiado mediante diferentes tareas experimentales llamadas "tareas de conflicto". Las características comunes a estas tareas son que inducen conflicto entre tendencias de respuesta y que los participantes han de inhibir una respuesta dominante y emitir una respuesta no dominante para llevarlas a cabo de forma eficaz (Botvinick, Braver, Barch, Carter, y Cohen, 2001). Algunas de las más conocidas y utilizadas son la tarea Stroop, la tarea de Flancos y la tarea Go/No-go. Brevemente expondremos cada una de ellas.

En la tarea Stroop (1935) se presenta una palabra, que designa un color, escrita con tinta de color. El participante debe indicar el color de la tinta en la que está escrita dicha palabra, mientras que debe ignorar el significado de la palabra, es decir, el color que designa la palabra. En la condición congruente la palabra designa un color que coincide con el color de la tinta con la que se ha escrito, por ejemplo, la palabra "AZUL", escrita con tinta azul. En la condición incongruente, el color de la tinta con el que está escrita la palabra es diferente al que indica la propia palabra, por ejemplo, la palabra "ROJO", escrita con tinta verde. En esta situación es donde se produce el conflicto entre las dos respuestas competitivas leer versus nombrar. Cuando la persona se enfrenta a una condición incongruente debe inhibir la respuesta dominante, leer el color que designa la palabra, para emitir la respuesta correcta, nombrar el color de la tinta. Una variación de esta tarea es la tarea de Stroop espacial donde se induce conflicto entre dos dimensiones visuo-espaciales, la dirección a la que apunta la flecha y la localización donde esta se presenta. En esta tarea una flecha que apunta a la izquierda o la derecha, se presenta bien a la izquierda o bien a la derecha del punto de fijación. En la condición congruente, la dirección a la que apunta la flecha y la localización en la que aparece coinciden. En la condición incongruente, la dirección a la que apunta la flecha y la localización en la que aparece no coinciden. Los participantes tienen que responder a la dirección hacia la que apunta la fecha mientras ignoran la localización donde aparece. Generalmente, se encuentra un enlentecimiento en la respuesta y un mayor porcentaje de errores en la ejecución en condiciones incongruentes comparadas con condiciones congruentes.

En la tarea de flancos (Eriksen y Eriksen, 1974) aparece un estímulo objetivo (target) en una posición central. La tarea del participante consiste en contestar al target tratando de ignorar los flancos que se presentan de forma simultánea a ambos lados del target y que pueden contener información congruente o incongruente con el target. Lo que normalmente sucede es que los participantes son más rápidos y precisos cuando los flancos son idénticos al target (situación congruente), sin embargo cuando el target y los flancos llevan asociados respuestas incompatibles (situación incongruente) es cuando se produce el conflicto, efecto que se refleja en un mayor número de errores y en tiempos de reacción también mayores

En la tarea Go/No-go se requiere que los participantes respondan ante una serie de estímulos (Go), generalmente presionando una tecla con la mayor rapidez posible, y no emitir respuesta ante otros estímulos menos frecuentes ("No-go"). Para incrementar la tendencia de respuesta a los estímulos "Go" y a su vez incrementar el esfuerzo necesario para inhibir apropiadamente la respuesta ante estímulos "No-go" se presenta un porcentaje más elevado de estímulos "Go" que de estímulos "No-go". Generalmente, se mide el porcentaje de respuestas ante estímulos "No-go" (falsas alarmas) como una medida de la capacidad de inhibir la respuesta dominante.

Mecanismos y neuroanatomía de la Atención Ejecutiva.

Un amplio número de estudios de neuroimagen con adultos han utilizado tareas de conflicto, como las anteriormente mencionadas, con el objetivo de analizar diversos mecanismos implicados en la AE (Botvinick, Nystrom, Fissell, Carter, y Cohen, 1999; Braver, Barch, Gray, Molfese, y Snyder, 2001; Casey, Giedd, y Thomas, 2000; Fan, Flombaum, McCandliss, Thomas, y Posner, 2003).

Un mecanismo importante de la AE es la monitorización y resolución del conflicto. Tanto en la tarea de flancos como en la tarea Stroop, se puede calcular el efecto de conflicto o interferencia sustrayendo el tiempo de reacción (TR) o porcentaje de errores de condiciones congruentes del TR o porcentaje de errores de las condiciones incongruentes. Este efecto refleja el grado de dificultad que se experimenta cuando se realiza una tarea con estimulación conflictiva con el estímulo objetivo. Se asume que la dimensión irrelevante (flancos y palabra) se procesa junto con la dimensión revelante, y que ambas dimensiones compiten para acceder a la respuesta. Cuando las dimensiones irrelevante y relevante inducen respuestas distintas y competitivas, se produce el conflicto y es cuando se debe suprimir la tendencia de respuesta predominante, para que se pueda dar una respuesta acorde con la dimensión relevante. Fan y colaboradores (2003), partiendo de la suposición de que todas las tareas de conflicto implican la activación de la Red de AE, se preguntaron si distintas tareas que inducen conflicto, como la tarea de flancos, la tarea Stroop y la tarea Stroop espacial, activan dicha red. Usando la técnica de Resonancia Magnética Funcional (RMf) identificaron ciertas áreas cerebrales que sistemáticamente se activaban para el procesamiento del conflicto durante las tres tareas. Estas áreas fueron el córtex cingulado anterior y el córtex pre-frontal lateral, demostrando con ello la implicación de estas áreas en el procesamiento del conflicto. Sin embargo, aunque estas áreas comúnmente se activan para el procesamiento del conflicto parece ser que estas estructuras desempeñan roles diferentes y complementarios en la supervisión de las situaciones que requieren control y en el modo en que implementan dicho control. En concreto, hay estudios que señalan que las áreas mediales y el cíngulo anterior parecen estar relacionadas con la detección y la supervisión del conflicto mientras las áreas de córtex prefrontal lateral están principalmente relacionadas con el procesamiento necesario para resolverlo (Botvinick, y cols., 1999). Un estudio particularmente importante en dilucidar la función de control atencional atribuida al córtex cingulado anterior y al córtex prefrontal es el realizado por MacDonald y su equipo (2000). Tomaron medidas de actividad cerebral mientras los participantes realizaban una tarea Stroop, con la peculiaridad de que indicaban a sus participantes, a través de una señal, si tenía que leer la palabra o nombrar el color. Ante la señal de nombrar el color el córtex prefrontal dorsolateral izquierdo se mantenía activo de modo que a mayor demanda (nombrar el color) mayor actividad, mientras que el cíngulo no mostró actividad. Por otro lado, la activación del cíngulo cambiaba en función de la congruencia en la tarea de nombrar el color, es decir, se producía una mayor activación ante ensayos incongruentes que ante ensayos congruentes. Estos resultados indican la implicación del córtex prefrontal en la representación y mantenimiento de las demandas atencionales de la tarea y la implicación de córtex cingulado anterior en la supervisión del conflicto.

Otro de los mecanismos que se han asociado con la función de la AE ha sido la la inhbición. En el dominio de la atención la inhibición parece ser un proceso necesario tanto para la selección atencional (orientación) como para el control ejecutivo. Nosotros nos vamos a centrar en la importancia de este proceso en el control ejecutivo. La inhibición es un proceso necesario para retener respuestas dominantes pero inadecuadas al momento actual. En la tarea Go/No-go, mencionada anteriormente, lo que se produce es una fuerte tendencia a una determinada respuesta que ha sido primada por la práctica. Cuando la estimulación señala otra respuesta, que no se ha practicado, es cuando se debe inhibir la tendencia de respuesta dominante con el fin de emitir una respuesta adecuada a la situación.

Por tanto, para monitorizar y resolver el conflicto entre estas dos respuestas incompatibles, caso de tareas Stroop y flancos, o para inhibir una respuesta preponderante pero inadecuada dadas las circunstancias actuales, tarea Go/No-go, es necesario el control de la acción de forma voluntaria, es decir, es necesaria la actuación de la AE. La AE intervendrá inhibiendo la información irrelevante o la respuesta preponderante para que no interfiera en la tarea que se esté llevando a cabo (Posner y DiGirolamo, 1998).

Un importante número de estudios han usado el electroencefalograma, para registrar la actividad del cerebro que provoca un determinado evento, dicha actividad es conocida como potencial relacionado con el evento, que se resume en las siglas ERPs (del inglés Event-Related Potentials). Con bastante frecuencia los ERPs se han utilizado para evaluar el curso temporal de los procesos de monitorización de acción. Uno de los ERPs que mayor atención ha recibido por parte de los investigadores interesados en la inhbición de la respuesta y la monitorización del conflicto ha sido el N200 (Eimer, 1993; Koop, Rist, y Mattler, 1996). El N200 se caracteriza por un deflexión negativa en el ERP que se produce entre los 200-400 ms. después de la presentación del estímulo y que es mayor para ensayos que implican conflicto (ensayos incongruentes y No-go) que para ensayos que no lo implican (ensayos congruentes y Go). Este componente, generalmente, se relaciona con el hecho de retener o inhibir una respuesta preponderante pero inadecuada a la tarea. La distribución de la actividad asociada con los ERPs se puede asociar a una fuente de activación cerebral mediante analisis de localización de la fuente. Utilizando estos análisis, diversos estudios, sugieren que la parte dorsal del cortex cingulado anterior (CCA) puede estar implicada en la generación del N2 (Bekkera, Kenemansa, y Verbatena, 2005; Herrmann, Rommler, Ehlis, Heidrich, y Fallgatter, 2004; van Veen y Carter, 2002) lo que apoyaría la conexión entre los índices electrofisiológicos y la Red de AE.

Otro de los mecanismos de control particularmente interesante para la monitorización de la acción es la detección de respuestas erróneas. Los errores parecen producirse por una falta de control a la hora de emitir una respuesta, ya que, generalmente, se encuentra que el tiempo de reacción ante respuestas erróneas es menor que ante respuestas correctas (Pailing, Segalowitz, Dywan, y Davies, 2002). Después de la comisión de un error se procuce un enlentecimiento en la respuesta, este enlentecimiento se considera un indicador comportamental de la detección del error y su corrección (Falkenstein, Hohnsbein, y Blanke, 1990; Gehring, Gross, Coles, Meyer, y Donchin, 1993).

Hay una serie de componentes electrofisiológicos que generalmente se observan después de la comisión del error: la negatividad asociada a la respuesta errónea (ERN: del inglés “error related negativity”) y la positividad asociada al error (Pe: “positividad asociada al error”.

El ERN se caracteriza por una deflexión negativa en los ERPs que se produce 80 ms después de la respuesta error. El ERN se observa en canales fronto-mediales, generalmente en aquellos canales alrededor del canal Fcz (Falkenstein, y cols., 1990; Gehring, y cols., 1993). Análisis de localización de la fuente sugieren que el ERN podría generarse en el córtex cingulado anterior (CCA) (Herrmann, y cols., 2004). Estudios usando el fMRI han revelado una activación en el CCA rostral para respuestas erróneas mientras que esta área no se activa para respuestas correctas (Kiehl, Liddle, y Hopfinger, 2000). Datos de un estudio reciente con monos también han mostrado que la actividad de las neuronas en el CCA rostral es mayor después de una acción errónea que después de una acción correcta (Michelet, Bioulac, Guehl, Goillandeau, y Burbaud, 2009).

El Pe aparece entre los 200-500 ms después de la respuesta y es mayor para respuestas erróneas que para respuestas correctas. Este componente parece generarse en la parte rostral del CCA (Herrmann, y cols., 2004). Otros estudios muestran activaciones en estructuras corticales, incluyendo el CCA y áreas prefrontales, para el Pe y el ERN, sugiriendo que ambos componentes tienen un origen cerebral común(Brazdil, y cols., 2002).

Cabe decir que mientras que el ERN ha sido investigado de modo exhaustivo, el Pe no ha sido tan ampliamente investigado. Hoy en día, se asume que el ERN y el Pe son dos componentes relacionados con el error, claramente disociables. Se ha observado que ambos componentes parecen ser sensibles a diferentes factores experimentales. En 1997 Kaiser examinó el ERN y el Pe bajo condiciones de hipnosis donde el estado de conciencia estaba alterado o ausente. Encontró que mientras el ERN no se alteraba en la condición de hipnosis, el Pe no se apreciaba en esta condición. Adicionalmente, algunos estudios han mostrado que cuando los participantes son conscientes del error la amplitud del ERN es parecida a la amplitud del ERN cuando los participantes no son conscientes del mismo. Sin embargo, la amplitud del Pe aumenta cuando los participantes son conscientes de sus errores (Kaiser, Barker, Haenschel, Baldeweg, y Gruzelier, 1997; O'Connell, y cols., 2007; Shalgi, Barkan, y Deouell, 2009).

Por último, hemos de señalar que la AE también parece estar implicada en la evaluación de situaciones novedosas. A nivel comportamental, se ha observado que los niños miran durante más tiempo a un estímulo inesperado que a un estímulo esperado. La prolongación de la mirada ante un estímulo inesperado parece indicar que los niños han detectado una trangresión en las expectativas (Berger, Tzur, y Posner, 2006; Cohen y Marks, 2002). A nivel cerebral, el P300 un componente electrofisiológico relacionado con la evaluación del estímulo, parece ser sensible a la evaluación de la novedad. Diversos estudios han mostrado que el P300 es sensible a la ruptura de la expectativa, lo que se refleja en un aumento en la amplitud del P300 ante estímulos inesperados comparados con estímulos esperados. La generación de estos componentes se ha relacionado con la activación de zonas fronto- mediales, zonas relacionadas con la regulación (Luu, Shane, Pratt, y Tucker, 2009; Tenke, Kayser, Stewart, y Bruder, 2010).

DESARROLLO DE LA ATENCIÓN EJECUTIVA

Muchas son las investigaciones que señalan a la infancia como una etapa importante en el desarrollo de la AE.

Una de las habilidades relacionadas con la AE que experimenta un importante desarrollo en los primeros años de vida y que ha sido extensamente documentada, es la habilidad para suprimir una respuesta dominante inadecuada, con el fin de ejecutar una respuesta no dominante pero adecuada (Clohessy, Posner, y Rothbart, 2001; Diamond, 1991; Diamond, 2001; Rothbart, Ellis, Rueda, y Posner, 2003). Una de las tareas que se utiliza para medir la inhibición de la respuesta en bebés es la tarea de alcance. En esta tarea, un objeto atractivo para el niño se introduce en una caja transparente. La caja se encuentra abierta por un lateral. La tarea del niño es alcanzar el objeto que previamente se ha introducido en la caja. Niños menores de nueve meses guiados por la visión del objeto intentan alcanzarlo directamente, sin reparar en que este movimiento les llevará a chocar con la caja. Esta respuesta de alcance guiada por la línea de visión es una respuesta dominante, que ha sido reforzada y, por tanto, es una respuesta difícil de inhibir. Pero después de los nueve meses de edad, los niños son capaces de encontrar la abertura de la caja e inhibir la tendencia de la visión lineal (Diamond, 1991). La dificultad para ejercer inhibición sobre respuestas dominantes puede estar también a la base del patrón de ejecución que los niños menores de ocho meses manifiestan en la ejecución de la tarea clásica A-no B de Piaget (Diamond, 1991). En dicha tarea se oculta alternativamente un objeto en una de dos cajas idénticas dispuestas sobre una mesa y equidistantes del niño. Primero, se esconde el objeto en una de las cajas y se le permite al niño recuperar el objeto. Todos los niños son capaces de recuperar el objeto sin dificultades. Nuevamente, y siendo visto por el bebé, se esconde el objeto esta vez en la otra caja. Después de unos segundos de demora, se le permite al niño que recupere el objeto. En esta nueva situación los bebés de siete a nueve meses normalmente fallan en recuperar el objeto, perseverando en la búsqueda del objeto en la localización previa. Con esta respuesta los niños pueden estar reflejando una dificultad para inhibir una tendencia de respuesta dominante, es decir, ir a la localización previamente reforzada (Diamond, 1985). La ejecución en la tarea A no B se ha asociado con la maduración en las funciones del circuito dorsolateral en el córtex prefrontal (Diamond, 2001).

A partir de los dos años de edad se evidencia un rápido desarrollo de la AE. Una tarea que se ha utilizado para medir dicho desarrollo es la tarea de secuencias visuales (Clohessy, y cols., 2001). En esta tarea, se proyectan estímulos de forma secuencial en 3 pantallas de ordenador dispuesta en triángulo. En cada ensayo un estímulo aparecerá en una de las tres pantallas. El ensayo termina cuando el participante mira el estímulo. Entonces, el experimentador presiona una tecla para que desaparezca el estímulo y se inicia un periodo de demora. Después de esta demora aparecerá el siguiente estímulo. La posición donde aparecen los estímulos seguirá una secuencia que ha sido fijada previamente por el experimentador. Hay dos tipos de secuencias en la tarea: secuencia no ambiguas y secuencia ambiguas. La secuencia será no ambigua cuando cada localización del objeto sea seguida de una, y sólo una, localización subsiguiente, por ejemplo, 123123…, donde el número indica la posición donde aparecerá el estímulo. La secuencia será ambigua cuando la posición del estímulo dependa de la posición previa del estímulo (dependa del contexto) dentro de la secuencia, por ejemplo, 12131213. Con esta tarea se mide el movimiento anticipatorio de los ojos hacia el lugar donde aparecerá el objeto. Un hecho importante en las secuencias ambiguas es que para anticipar correctamente el movimiento de los ojos es necesario que se resuelva la tendencia de respuesta de mirar a la localización dos en lugar de mirar a la localización tres cuando el estímulo anterior se presentó en la localización primera. Se ha observado que niños de tan solo cuatro meses son capaces de aprender una secuencia no ambigua. Sin embargo, aprender una secuencia ambigua requiere de la monitorización del contexto, habilidad que parece surgir alrededor de los dos años de edad (Clohessy, y cols., 2001; Rothbart, y cols, 2003). En secuencia ambiguas, esta mirada anticipatoria se piensa que refleja el desarrollo de una atención más voluntaria la cual depende de la red de orientación, pero que se considera también como la manifestación temprana de la red de AE (Haith, Hazan, y Goodman, 1988). Hay datos que señalan en esta dirección. Rothbart y cols. (2003) utilizando una tarea de secuencia visual y una tarea de conflicto espacial, encontraron que los niños de entre 2 y 3 años que mejor resolvían la ambigüedad en secuencias de aprendizaje complejas eran aquellos que mostraban menos interferencia en la tarea de conflicto. Este dato puede estar señalando que el esfuerzo por anticipar el movimiento de los ojos en una tarea de secuencia visual puede ser un precursor de la aparición de la AE (Rothbart, y cols, 2003).

En los años preescolares, los niños incrementan su capacidad para controlar acciones, mostrando una menor impulsividad en sus conductas. Por ejemplo, en la ejecución de la demora de la gratificación, donde el niño ha de elegir entre una recompensa inmediata pero pequeña o una recompensa mayor pero demorada, los niños muestran una progresiva mejora en la ejecución que se evidencia en el aumento de elecciones de demora (Mischel, Shoda, y Rodriguez, 1989). Así mismo, alrededor de esta edad, los niños son capaces de realizar tareas de conflicto simples en las cuales se puede medir su tiempo de reacción. Algunas de las tareas de conflicto que se diseñaron para su uso con adultos se han adaptado para su uso con niños. Un ejemplo de ello es la adaptación de la tarea de conflicto espacial (Gerardi-Caulton, 2000), donde se induce conflicto entre la identidad del objeto y la localización donde aparece. En esta tarea se utiliza una pantalla táctil en la que aparecen dos dibujos de dos casas que corresponden a dos animales (un gato y un pato). En la pantalla se presenta un dibujo de una de las casas a la izquierda y otra de las casas a la derecha de la pantalla. Ambos dibujos de las casas están presentes en todos los ensayos. En cada ensayo, uno de los animales aparece, bien en la izquierda o bien a la derecha de la pantalla. La tarea del niño consiste en tocar la casa que corresponde al animal. En cada ensayo se pueden producir dos situaciones, bien que el animal aparezca en la posición donde está su casa (ensayo compatible), o bien que el animal aparezca en la posición contraria a la posición donde se encuentra su casa (ensayo incompatible). En la ejecución de esta tarea se evidencia una mejora progresiva desde los dos a los cuatro años, observandose que niños de tres años realizan la tarea con un nivel de precisión alto, aunque como ocurre con los adultos, los niños también responden más lentamente y con un nivel de precisión menor ante estímulos incompatibles que ante estímulos compatibles (Gerardi-Caulton, 2000).

Aproximadamente a la misma edad en la que surge la habilidad de los niños para resolver conflicto, aparece la habilidad para detectar el error. Evidencia de ello son los resultados del estudio de Jones, Rothbart y Posner (2003) usando una versión modificada de la tarea "Simon dice". En este juego hay dos muñecos que dan instrucciones al niño. La tarea del niño consistirá en responder a la instrucción dada por un muñeco mientras inhibe la respuesta a la instrucción dada por un segundo muñeco. Encontraron que los niños de 36 a 38 meses no inhibían sus respuestas a la instrucción del segundo muñeco y no mostraban enlentecimiento de la respuesta después de responder a las instrucciones del muñeco que debía ignorar, es decir, no mostraban enlentecimiento después de la comisión de un error. Este enlentecimiento se considera como la expresión de un mecanismo de control compensatorio que ayuda a mejorar la ejecución en las acciones posteriores (Gehring y Fencsik, 2001). Pero a partir de los 39 meses, los niños muestran tanto la habilidad para inhibir, como un enlentecimiento en el tiempo de reacción después de la comisión del error(Jones, Rothbart, y Posner, 2003).

Aunque los datos aportados por los diferentes estudios señalen el periodo de preescolar como la época de máximo desarrollo de la AE, esta habilidad continuará desarrollándose a lo largo de la niñez (Rueda, y cols., 2004) y no alcanzará un desarrollo pleno hasta la adolescencia tardía o principios de la edad adulta lo que se evidencia en datos que muestran diferencias entre distintos grupos de edad cuando las demandas de la tarea son más complejas o cuando se requiere de la planificación o de una mayor flexibilidad cognitiva (Davidson, Amso, Anderson, y Diamond, 2006).

Por otra parte, el desarrollo de los mecanismos cerebrales a la base de la AE en niños se ha examinado utilizando los potenciales evocados por el evento (ERPs). Estudios de ERPs utilizando una tarea de flancos muestran que tanto los adultos como los niños presentaron un N2 mayor para ensayos incongruentes que para ensayos congruentes. Algunos estudios señalan que la diferencia entre la amplitud del N200 para ensayos congruentes e incongruentes es mayor en niños que en adultos (Abundis, Checa, y Rueda, en preparación; Rueda, Posner, Rothbart, y Davis-Stober, 2004) y esta diferencia en amplitud parece reducirse con la edad (Jonkman, 2006). Esta reducción en amplitud parece estar relacionada con el incremento en la eficacia del sistema de control (Lamm, Zelazo, y Lewis, 2006). Sin embargo, otros estudios muestran el efecto contrario, es decir, un aumento de la amplitud con la edad, interpretando que es el aumento en amplitud lo que indicaría un mejora en la eficacia del sistema de control (Ladouceur, Dahl, y Carter, 2007). Además, se observa que los niños muestran un N2 más sostenido y tardío que los adultos, y que la distribución del efecto es más prefrontal para los niños que para los adultos (Rueda, Posner, Rothbart, y cols, 2004). Análisis de localización de la fuente muestran que el CCA parece ser el área responsable de la generación del N2 en adultos (van Veen y Carter, 2002), mientras que el CCA y zonas orbito-frontales podrían explicar la generación del N2 en niños (Lamm, y cols., 2006).

Recientemente, ha crecido el interés por estudiar la respuesta cerebral a los errores en el curso del desarrollo. Davies, Segalowitz y Gavin (2004) estudiaron el curso evolutivo del ERN y el Pe en niños de entre siete y diecinueve años y un grupo de adultos. Sus resultados mostraron que mientras que en el Pe no se produjeron cambios significativos entre los siete y veinticinco años, el ERN presentó un progresivo incremento desde la niñez a la adolescencia. Se vio que los niños pequeños, de siete a ocho años, no muestran el ERN, mientras que los niños a partir de trece años presentan un ERN parecido al de los adultos. Otros estudios utilizando diferentes grupos de edad encuentran resultados similares (Ladouceur, y cols., 2007; Santesso, Segalowitz, y Schmidt, 2005; Wiersema, van der Meere, y Roeyers, 2007). Los datos disponibles hasta el momento sugieren un desarrollo tardío del ERN y una maduración temprana del Pe (Wiersema, y cols., 2007). Análisis de localización de la fuente indican que la parte caudal del CCA parece ser el área que genera el componente ERN, mientras que la parte rostral del CCA parece ser la responsable de la generación del Pe (Herrmann, y cols., 2004), lo que quizá podría estar detrás de las diferencias evolutivas encontradas.

El conjunto de datos expuestos, tanto conductuales como de neuroimagen, muestra como la AE se va desarrollando desde los primeros años de vida hasta bien entrada la adolescencia. Por tanto, si tenemos en cuanta que la AE desempeña funciones de regulación y control, podremos esperar que el desarrollo de esta función implique también una mejora en conductas de regulación de la vida diaria.

En el siguiente apartado nos detendremos en analizar cómo se ha estudiado la autorregulación tomando para ello estudios que han relacionado la autorregulación con el mecanismo de control atencional, y estudios que han estudiado la autorregulación desde una perspectiva de las diferencias individuales en temperamento.

LA AUTORREGULACIÓN

Según Vohns y Baumeister (2004) "la autorregulación se refiere a los procesos por los que la psique humana ejerce control sobre sus funciones, estados y procesos internos[…]. De un modo más extenso, la autorregulación es esencial para trasformar la naturaleza interna del animal en un ser humano civilizado" (pag.1).

Como hemos mencionado, desde el modelo neurocognitivo de Michael Posner se considera que la AE es la encargada de regular la acción y la emoción, lo que entronca bien con la función de autorregulación. Por otro lado, el estudio de la autorregulación ha sido un tema de gran interés en las investigaciones de la Psicología de la Personalidad y el temperamento. Ambas perspectivas, atencional y temperamental, comparten un objetivo común, estudiar cómo las personas ejercen control sobre sus propias conductas.

LA ATENCIÓN Y LA AUTORREGULACIÓN

Desde los primeros modelos teóricos el control del pensamiento y las acciones, ha sido una de las funciones atribuidas a la atención. El sistema atencional no es un sistema de procesamiento de la información per se, sino que es un sistema que regula y controla el funcionamiento de otros sistemas directamente implicados en el procesamiento de la información (Tudela, 1992). El sistema atencional no está relacionado con un dominio mental específico, sino que su funcionamiento es considerado de domino general.

La formulación más explícita de la atención como sistema de control fue propuesta por Posner y Synder (1980) distinguiendo entre el procesamiento controlado-consciente y procesamiento automático. Como hemos mencionado al hablar del sistema neurocognitivo atencional propuesto por Posner, a la AE se le atribuye la función de control del sistema atencional de cara a alcanzar metas deseadas, cuando las acciones rutinarias o automáticas son insuficientes o se muestran inadecuadas en una situación dada. Con la práctica se requiere menos atención para que el procesamiento se lleve a cabo. Una vez que la respuesta se automatiza, si se quiere introducir un cambio se exige un esfuerzo atencional extra. Prueba de ello es el caso de la interferencia Stroop. En la tarea Stroop se ha de inhibir la respuesta automática de leer, y activar la respuesta de nombrar el color. Para controlar el proceso automático se hace necesaria la implicación atencional para inhibir la respuesta elicitada de forma automática por el estímulo (leer palabra), cuando se muestra inadecuada para los objetivos actuales de procesamiento (nombrar color). Otro ejemplo del coste atencional ante acciones rutinarias o primadas por la práctica es el caso de la tarea Go/No-go. En un momento dado, la tendencia de respuesta aprendida deja de ser efectiva (ensayos No-go) por lo que la AE ejercerá su influencia inhibiendo la respuesta predominante, que se muestra inadecuada en la situación actual. Generalmente, la implicación atencional se observa por un mayor tiempo de reacción y un porcentaje de errores más elevado cuando hay que controlar el procesamiento que ha sido de algún modo automatizado. El control de la AE no se limita a estas situaciones, sino que se extiende a situaciones en las que hay que planificar la acción, evaluar la novedad o monitorizar los errores. En el caso de la monitorización del error la AE necesita controlar el sistema de acción para que la respuesta error no se vuelva a producir, para ello enlentece la respuesta después del error como mecanismo de control. Este enlentecimiento se ve acompañado neuralmente de una activación de zonas relacionadas con la regulación, como el CCA.

Estos mecanismos de control también están presentes para regular la información afectiva. En un meta-análisis de estudios de neuroimagen, Bush y cols. (2000) mostraron que mientras la parte dorsal del cortex cingulado anterior (CCA) se activa con tareas cognitivas tales como la tarea Stroop, la parte ventral o rostral del CCA se activa en tareas con contenido emocional o afectivo, como la tarea Stroop emocional. Esta versión de la tarea difiere de la versión original color-palabra, en que incluye palabras de contenido emocional. Los participantes han de contestar al color con el que está escrita la palabra e ignorar el contenido emocional. Lo que se suele encontrar es un mayor TR cuando las palabras están asociadas a contenido emocional que cuando no lo están, lo que sugiere que de algún modo el contenido emocional de la palabra esta interfiriendo en la tarea de nombrar el color de la tinta. Parece ser que mientras la parte dorsal del CCA tiene unas conexiones fuertes y recíprocas con otras áreas en el córtex frontal y parietal, la parte más ventral del CCA tiene conexiones con el sistema límbico, incluyendo la amígdala (Posner, Sheese, Odludas, y Tang, 2006). Esta diferenciación de las activaciones del cíngulo anterior en función del contenido emocional o cognitivo de la estimulación, ha llevado a la distinción de dos divisiones en el CCA, la división cognitiva en una distribución dorsal, y la división emocional en una distribución ventral.

La capacidad de control de estados afectivos de foma más voluntaria se observa en la infancia, mostrando ciertas conductas como chupar la ropa u objetos o cambiando el foco de su atención del estímulo que le genera estrés hacia otros objetos más neutrales en el ambiente (Gianino y Tronick, 1985; Koop, y cols., 1996). Se ha observado que aquellos niños que juegan conjuntamente con sus madres durante más tiempo en una sesión de juego libre, interpretando este hecho como el reflejo de una mayor capacidad para mantener la atención, son aquellos que muestran mejores estrategias para regularse a sí mismos, en una situación estresante, e invierten menos tiempo en buscar a sus padres para regular el estrés (Dunham y Dunham, 1995). Estos resultados sugieren que habilidades atencionales pre-existentes en los niños pueden contribuir a la aparición de la autorregulación en edades tempranas. En esta misma línea existen datos que señalan que niños de tan sólo veintisiete meses que realizaron con éxito una tarea de conflicto espacial fueron descritos por sus padres como niños con menos tendencias a mostrar reacciones de frustración (Gerardi, 1997). Este mismo patrón de datos se sigue encontrando en niños un poco más mayores. Niños de cuatro años de edad que mostraron una mayor interferencia Simon obtuvieron altas puntuaciones en ira (González, y cols., 2001). Mayores niveles de interferencia en niños de siete a ocho años, en una tarea Stroop, se asocian con una mayor impulsividad, ira, malestar y tristeza (Gonzalez, Fuentes, Carranza, y Estevez, 2001).

Como hemos mencionado, a nivel cerebral se ha observado que la regulación emocional se relaciona con activaciones en la red de AE. Se ha evidenciado que la hiperactivación del cíngulo, tomando como medida indirecta la amplitud del ERN, se ha relacionado con trastornos psicológicos en los que la regulación emocional se encuentra afectada, como la depresión (Mayberg, y cols., 1999). También se ha observado que personas que ejercen un control desproporcionado sobre su conducta, como ocurre con los pacientes obsesivo-compulsivos, activan en mayor medida el cíngulo anterior que las personas que no muestran dicha patología, variando el nivel de activación en función de la severidad de los síntomas (Ursu, Stenger, Shear, Jones, y Carter, 2003). Además, esta estructura parece estar implicada en la regulación de la emoción en participantes normales. En estudio de Resonancia Magnética funcional (RMf) se observó que las actividad de cíngulo era mayor en los participantes a los que se les pedio que regularan su emoción ante el visionado de una película erótica, que en los participantes a los que no se les instruyó (Beauregard, Levesque, y Bourgouin, 2001). Además, parece ser que la parte rostral del CCA ejerce control durante la modulación del pánico (Rainville, Duncan, Price, Carrier, y Bushnell, 1997). Rainville y colaboradores usaron la hipnosis para manipular la percepción de dolor ante estimulación nociva. Cuando los participantes eran sugestionados para percibir la estimulación nociva como más dolorosa hubo un incremento en la actividad del CCA significativamente mayor que cuando los participantes eran sugestionados para percibir de una manera menos dolorosa esa misma estimulación (Rainville, y cols., 1997).

EL TEMPERAMENTO Y LA AUTORREGULACIÓN

Para describir las diferencias individuales en el carácter y en la forma de reaccionar de las personas, los médicos griegos ya utilizaban el término temperamento. Definiciones más recientes del término lo conceptualizan como "diferencias individuales tanto en las reacciones emocionales y comportamentales, como en la regulación de las mismas" (Rothbart y Derryberry, 1981).

Las diferencias individuales en reactividad y en regulación se han medido comúnmente usando cuestionarios en los estudios de temperamento. Análisis factoriales de dichos cuestionarios han identificado tres dimensiones temperamentales: Extraversión (EX), Afecto Negativo (NA) y Control Voluntario (CV) (Ellis y Rothbart, 2001; Rothbart y Bates, 2006; Rothbart y Hwang, 2002). La primera dimensión describe diferencias individuales de aproximación y está relacionada con el factor de personalidad de Extraversión, factor que refleja la sociabilidad del individuo y la búsqueda de estimulación. . La segunda engloba las diferencias individuales de evitación y está relacionada con el factor de personalidad Neuroticismo, factor que refleja un estado emocional que incluye la ira, la culpa, el temor y el nerviosismo, la inestabilidad emocional y la espontaneidad. Estas dos dimensiones representan características de los individuos relacionadas con reactividad emocional y con los impulsos derivados de ella. Finalmente, el CV es el constructo de temperamento que describe diferencias individuales en habilidades de autorregulación. Este constructo refleja el esfuerzo de los individuos para controlar la reactividad acorde con las instrucciones, las metas y las normas sociales (Ellis y Rothbart, 2001; Rothbart y Bates, 2006; Rothbart y Hwang, 2002).

Estudios que han evaluado el CV con niños de seis a siete años, han encontrado que un alto CV se relaciona con niveles bajos de reactividad emocional tanto negativa (Afecto negativo) como positiva (Extraversión) (Rothbart, Ahadi, y Hershey, 1994). Esta relación está en consonancia con la idea de que el CV debe ayudar a regular el afecto negativo y la tendencia de aproximación.

En línea con lo anterior, en la infancia altos niveles de CV se relacionan con una baja incidencia de problemas externalizantes de conducta, los cuales se caracterizan por altos niveles de agresión, impulsividad, ira y frustración (Olson, Sameroff, Kerr, Lopez, y Wellman, 2005; Rothbart, Ellis, y Posner, 2004; Valiente, y cols., 2003). Por su parte, se ha observado que los niños con alto nivel de CV se enfrentan al enfado utilizando métodos no hostiles (Eisenberg, Fabes, Nyman, Bernzweig, y Pinuelas, 1994), sugiriendo que niños con CV alto manifiestan una mayor capacidad para cambiar el foco de atención de los factores gratificantes de la agresión. Esta relación se aprecia en todas las edades. Por ejemplo, en la adolescencia la falta de control se ha relacionado negativamente con la amabilidad, el interés y la determinación, el buen comportamiento, el entusiasmo, la creatividad, la confidencia, el sentido del humor, la popularidad y la cooperación. En la adultez temprana, a los 21 años, personas que mostraban más conductas antisociales habían sido definidas como antisociales en la infancia (Newman, Caspi, Moffitt, y Silva, 1997). A esta edad la falta de control se ha relacionado con condenas criminales, y esta relación era más fuerte en personas que habían abandonado el colegio (Henry, Caspi, Moffitt, Harrington, y Silva, 1999). Estos datos en su conjunto indican que el CV es un factor importante para el ajuste y la competencia social.

Asimismo, niños con un alto CV también exhiben mayores conductas empáticas (Rothbart, y cols., 1994; Valiente, y cols., 2004). La empatía se define como una "respuesta afectiva que contiene la compresión de los estados emocionales de los demás, y que es idéntica o muy similar a lo que la otra persona está sintiendo o uno espera que sienta" (Eisenberg, Wentzel, y Harris, 1998). Por ejemplo, si una persona ve a un niño triste, y esto le hace sentirse triste, esto significa que esta persona está experimentando empatía. Para que una persona pueda mostrar empatía hacia otros, es necesario por un lado interpretar las señales emocionales de la otra persona. Para ello ha de atender a los sentimientos de la otra persona, y a su vez controlar los suyos propios (Posner, y cols., 2002). En consonancia con la influencia que el CV ejerce en la empatía, el CV también parece jugar un papel importante en el desarrollo de la conciencia moral (Kochanska, Murray, Jacques, Koenig, y Vandegeest, 1996). Evidencia de ello son los datos que muestran que la culpa y la vergüenza se han relacionado positivamente con el CV en niños de 6 a 7 años. Esto puede indicar que el CV puede facilitar la internalización de principios morales proporcionando la flexibilidad atencional necesaria para darse cuenta de estos sentimientos de culpa y vergüenza, y poder relacionarlos con la responsabilidad que uno tiene y con las consecuencias negativas que provoque en terceras personas (Rothbart, y cols., 1994).

En relación al circuito neural que parece estar a la base del CV, varios estudios han mostrado una relación positiva entre la ejecución de tareas cognitivas relacionadas con la AE y las informaciones que los padres proporcionan sobre el CV de sus hijos. Gerardi-Caulton (2000) encontró una relación positiva entre la ejecución en una tarea de conflicto espacial y el CV de niños de entre 2 y 3 años. Por su parte, en niños de 7 años se ha observado que una interferencia mayor en una tarea Stroop se relaciona puntuaciones altas en impulsividad y bajas en control inhibitorio, medidas con cuestionarios de temperamento. Simonds (2007) también encuentra una relación positiva entre AE, medida con una tarea de flancos, y el CV informado por los padres. En la adolescencia, entre los 16 y 17 años, también se ha encontrado que el CV informado por las madres se relaciona con la interferencia en una tarea de flancos y en la tarea Stroop, aunque las informaciones de los propios adolescentes sobre su CV no correlacionen con la interferencia medida en ninguna de las dos tareas (Ellis, 2002). La relación entre interferencia y CV puede estar indicando que la red de AE puede estar a la base del CV. Esta relación por su parte no es sorprendente si tenemos en cuenta que al CV se le atribuyen habilidades tales como detener una respuesta dominante y activar una respuesta subdominante, planificar, y detectar errores, las habilidades atribuidas a la AE. Recientemente, datos de un estudio muestra una conexión directa entre la red de AE y el CV. En este estudio se observa que un mayor volumen en ciertas áreas relacionadas con la red AE, en concreto de las zona orbito-frontales, se relaciona con altos niveles de CV informado por los padres (Whittle, y cols., 2008).

Los datos presentados hasta el momento, apunta que un mejor CV y una buena eficacia de la AE, se expresa en un comportamiento más controlado y regulado en situaciones de la vida diaria. Nosotros estamos interesados especialmente en conocer, cómo las diferencias individuales en esta eficacia pueden afectar a la educación del niño.

ATENCIÓN Y EDUCACIÓN

La posibilidad de que las investigaciones dentro del área de la Neurociencia Cognitva puedan tener implicaciones para la educación de los niños es una idea de creciente interés (Posner y Rothbart, 2005). En la Neurociencia Cognitiva se están haciendo descubrimientos importantes en áreas como la atención, la memoria y el lenguaje que son relevantes para la educación (Fiez y Petersen, 1998; Goswami, 2006; Posner y Rothbart, 2005, 2007). En concreto, en el área de la atención se conoce que una pobre capacidad atencional se convierte en un autentico hándicap para que los niños adquieran las conocimientos que se enseñan en el colegio. Los niños con problemas atencionales son impulsivos, y con facilidad dejan de atender a lo que se enseña en la clase, lo que hace que sea más difícil educarlos (Goswami, 2006). Ya que creemos que la atención es un factor fundamental en el contexto educativo, vamos a hacer una breve revisión sobre ciertos estudios que establecen una relación entre la atención, el ajuste socio-emocional en el colegio y el rendimiento académico.

ATENCIÓN Y REGULACIÓN SOCIO-EMOCIONAL

La capacidad de regulación es especialmente importante durante la infancia ya que los niños están aprendiendo a regular sus emociones y comportamientos, adaptándose a contextos fuera del hogar (Eisenberg y Morris, 2002). Cuando un niño se enfrenta a situaciones sociales, tiene que actuar siguiendo las normas establecidas, por lo que en muchas ocasiones tendrá que regular su comportamiento y su emoción en base a dichas normas. Esta capacidad de adaptación puede estar relacionada con el desarrollo de la eficacia de los mecanismos atencionales y con el desarrollo del CV.

La relación entre la capacidad atencional y la regulación emocional en contextos sociales se ha estudiado en el laboratorio usando tareas para medir la capacidad del niño de regular la expresión emocional de decepción cuando se le da un regalo no deseado(Saarni, 1984; Simonds, Kieras, Rueda, y Rothbart, 2007). Un ejemplo de ello es el estudio realizado por Simonds y cols. (2007), donde los niños clasifican 8 juguetes desde el que más le gusta hasta el que menos le gusta. Pasado un tiempo, se le ofrece el regalo que no le gusta y el experimentador se mantiene en silencio ante la reacción del niño al juguete durante 15 segundos. Después de este periodo el experimentador dice que han cometido un error al darle el regalo y entonces le da el regalo que el niño había elegido como su favorito. Se graban las reacciones emocionales de los niños ante dichas situaciones. Como medidas de respuesta emocional, en este estudio, se tomaron el número de sonrisas y la duración de la sonrisa ante los regalos deseado y no deseado. Estas medidas fueron evaluadas por dos jueces independientes. Los resultados mostraron que la sonrisa duraba más en niños mayores que en niños pequeños, lo sugiere que se produce una progresiva mejora con la maduración en la eficacia para controlar la reacción emocional de decepción. A su vez, un mayor nivel de control emocional ante la decepción en niños de 7 a 10 años se relacionó con una mejor eficacia de la AE evaluada con el nivel de interferencia en una tarea de flancos. Este hallazgo fue interpretado por los autores como que una mayor eficacia del mecanismo de control proporciona la flexibilidad atencional necesaria para enfrentarse al afecto negativo, controlando la emoción de disgusto ante el regalo no deseado en una situación social. Una mejor eficacia de dicho mecanismo también parece contribuir a la cooperación social (Ciairano, Visu-Petra, y Settanni, 2007) y a la internalización de las normas sociales que nos ayuda a comportarnos adecuándonos a ellas en cada momento, como cuando se reacciona sonriendo y agradeciendo el regalo aunque no sea de nuestro agrado.

Además, la capacidad de CV y el control atencional tienen un valor predictivo en el funcionamiento social y en la manifestación de conductas pro-sociales que manifiestan los niños en la escuela (Eisenberg, Fabes, y Murphy, 1995; Eisenberg, Fabes, Shepard, y cols., 1997). Puntuaciones en demora de la gratificación, tarea en la que los niños han de esperar un tiempo para obtener un regalo o para obtener una recompensa mayor, a los cuatro y cinco años predicen el desempeño social, así como la forma en que los alumnos se enfrentan a los problemas cuando llegan a la adolescencia (Mischel, y cols., 1989). En la misma línea, un estudio reciente muestra que un pobre desempeño social en la escuela, bajo la expresión de problemas de conducta externalizantes, se puede predecir varios años antes a través de variables como la impulsividad y el déficit en el CV ejercido sobre la atención y la inhibición (Eisenberg, y cols., 2009).

El sistema escolar, es un sistema social con una estructura dada y con una serie de normas a las cuales el niño también tiene que adaptarse. Cuando los niños entran en la escuela deben acomodar sus comportamientos a las reglas sociales establecidas dentro del contexto escolar. La adaptación a dichas reglas posiblemente se vea influenciada por las diferencias individuales en el sistema reactivo y el sistema regulador, lo que puede afectar tanto al aprendizaje como a la dinámica de la clase. Habilidades interpersonales inadecuadas pueden producir conflictos entre el niño y el profesor (Newcomb, Bukowski, y Pattee, 1993) reduciendo quizá la participación de los niños en la clase, lo que a largo plazo puede afectar al rendimiento académico (Ladd, Birch, y Buhs, 1999).

Diferentes estudios señalan que los niños a los que sus profesores y padres definen como niños con una baja capacidad de control atencional y con un alto nivel de afecto negativo son aquellos que muestran más dificultades para adaptarse al colegio (Nelson, Martin, Hodge, Havill, y Kamphaus, 1999). Por otra parte, la habilidad de los niños para regular sus emociones y comportamientos puede afectar a la prevalencia y a la calidad de la interacción con los profesores y compañeros de clase (Myers y Morris, 2009; Rothbart y Jones, 1998). Por ejemplo, niños con un bajo CV pueden ser vistos como niños más disruptivos, lo que incrementará la probabilidad de tener una relación más negativa con los profesores y compañeros y por tanto puede llegar a generar problemas de conducta en la escuela. En apoyo a esta idea hay estudios que muestran una relación negativa entre el CV de los niños y la incidencia de problemas de conducta externalizantes, (Eisenberg, Fabes, y Guthrie, 1997; Eisenberg, y cols., 1995). Lemery, Essex, y Snider (2002) encontraron que bajos niveles de focalización atencional y control inhibitorio informado por los padres, a los tres años y medio y a los cuatro años y medio de edad de los niños, predijeron problemas de conducta externalizantes y un déficit de atención con hiperactividad a los cinco años y medio. En niños más mayores, de nueve y doce años, los problemas conductuales se relacionaban negativamente con la focalización atencional (Lengua, West y Sandler, 1998). Por otra parte, alumnos con un buen CV, informado por los profesores, se ha asociado con la manifestación de conductas socialmente apropiadas, con el estatus social que el alumno posee entre sus compañeros, así como con la forma en la que los alumnos se regulan para hacer frente a situaciones de la vida diaria que implican emociones negativas (Eisenberg, y cols., 1993). Parece por tanto, que los niños con un alto CV pueden ser percibidos por los profesores y compañeros como niños mejor adaptados y que se involucrarán más en las actividades de clase. La relación entre control y ajuste socio-emocional en el colegio parece establecerse a edades muy tempranas. Evidencia de ello es que los niños de preescolar que usan más estrategias de control, como la auto-distracción, durante una tarea de demora de la gratificación son considerados por sus profesores como niños con un desempeño social mayor. Además, sus compañeros de colegio tienden a verlos como más populares que aquellos niños que son rechazados o descuidados (Raver, Blackburn, Bancroft, y Torp, 1999).

Por otro lado, el ajuste socio-emocional en el colegio parece afectar al rendimiento escolar. Niveles altos de agresión y ansiedad se han relacionado con un bajo rendimiento académico en niños que asisten a la guardería (Normandeau y Guay, 1998). Sin embargo, un buen rendimiento académico se relaciona con conductas pro-sociales y con una baja tasa de abandono escolar (Risi, Gerhardstein, y Kistner, 2003). En un estudio longitudinal en el que se tomaron medidas de apreciación social, de agresión, de rendimiento académico y desempeño educativo (abandono escolar antes de graduarse), se vio que los alumnos que se graduaron fueron aquellos a los que sus compañeros evaluaron como más apreciados y menos agresivos, siendo el nivel de agresión el único predictor del desempeño educativo a largo plazo (Risi, y cols., 2003). Por ello, algunos autores han propuesto que las relaciones sociales positivas en el colegio constituyen el factor principal para promover el desempeño escolar (Mashburn y Pianta, 2006).

Datos electrofisiológicos con niños y adultos normales también señalan la importancia del sistema de control en la socialización. Por ejemplo, el ser capaz de detectar un error es una habilidad necesaria para la monitorización de la conducta pudiendo ser de gran valor para la socialización. Uno de los componentes electrofisiológicos relacionados con la detección del error es el componente electrofisiológico ERN. Recordemos que mayores amplitudes en el componente ERN se han relacionado con una mayor eficacia del mecanismo de control. Diferentes estudios han relacionado la amplitud del ERN con la conducta social. Por ejemplo, se ha observado que una pobre sensibilidad social, ya sea en niños (Santesso, y cols., 2005) o en adultos (Dikman y Allen, 2000), se asocia con una amplitud menor en el ERN. Sin embargo, una mayor amplitud en el ERN se relaciona con mayores puntuaciones en conductas empáticas (Santesso y Segalowitz, 2009).

Llegados a este punto, nos preguntamos si la buena eficacia en el mecanismos de control, tanto atencional como temperamental, no sólo hará a los niños más competentes a nivel social, sino también los hará más competentes a nivel académico.

ATENCIÓN Y RENDIMIENTO ACADÉMICO

Ya a comienzos del siglo XX, Alfred Binet (1900) se interesó por estudiar las capacidades atencionales en niños en edad escolar. Binet relacionó la capacidad atencional de los alumnos con el nivel de inteligencia en una muestra de 11 alumnos de una Escuela Primaria de París. Dividió a los niños en dos grupos: 1) inteligentes y 2) menos inteligentes en función del criterio de los profesores. Se les aplicó una prueba en la que debían tachar ciertas letras cada vez que las encontraran en la lectura de un texto. El procedimiento de esta prueba es semejante al que se utiliza actualmente en los test de tachado (Toulouse y Pieron, 1972). Se tomó como medida tanto la rapidez con que se realizaba el trabajo, como el número de errores, olvidar tachar la letra que se ha pedido o tachar otra letra que no se ha pedido. Los resultados obtenidos sobre el número de letras tachadas mostraron que los dos grupos de alumnos tenían una ejecución idéntica en la tarea. Sin embargo, el número de errores cometidos a lo largo de la prueba, que se puede considerar como un índice de distracción, fue muy distinto en ambos grupos. El grupo de los niños menos inteligentes cometió siempre más errores que el grupo con mayor inteligencia, sobre todo en los primeros ensayos de la tarea. Parece, por tanto, que los más inteligentes ejercían una mejor capacidad para inhibir los elementos distractores de la tarea (Binet, 1900). Binet puso de manifiesto la importancia de la adaptación del mecanismo de control en la escuela, aunque habría que esperar a estudios más recientes para conocer con mayor profundidad como dicho mecanismo influye en el contexto escolar (Boujon y Quaireau, 1999).

Más recientemente, diferentes estudios han puesto de manifiesto la importancia del mecanismo de control en el contexto del aprendizaje (Blair, 2002; Bull, Espy, y Wiebe, 2008; Espy, 2004). Es razonable pensar que para tener éxito a nivel académico los alumnos deben tener la capacidad de mantener la atención en las tareas de clase para continuar trabajando cuando hay otras opciones más atractivas en el ambiente como, por ejemplo, jugar con sus compañeros o mirar lo que sucede al otro lado de la ventana.

Cuando los niños se escolarizan tienen que utilizar ciertas habilidades básicas para regular sus conductas en el colegio, para lo que necesitan prestar atención, seguir instrucciones e inhibir acciones inapropiadas. Además, no todos los niños entran en el colegio con las mismas habilidades para hacer frente a las demandas que en el colegio se les presentan. Algunos niños muestran dificultades para permanecer sentados, para seguir las directrices de los profesores, para trabajar de forma independiente o para participar apropiadamente en grupo, como por ejemplo, manteniendo su turno para hablar (McClelland, Morrison, y Holmes, 2000).

Blair (2002) sugiere que el CV y particularmente la regulación atencional, están relacionados con el desempeño académico. Propone que los estudiantes que tienen dificultades para dirigir su atención y su comportamiento, probablemente tengan la experiencia de un desafío mayor cuando tratan de aprender en la escuela y cuando tratan de concentrarse en el trabajo de clase. Esta explicación tiene sus raíces en la literatura cognitiva (Ruff y Rothbart, 1996) y se apoya en resultados que revelan que los niños que tienen dificultades con la atención, con frecuencia muestran dificultades en lenguaje, en lectura (McGee, Partridge, Williams, y Silva, 1991) y en habilidades matemáticas (Blair y Razza, 2007; Bull, y cols., 2008; Bull y Scerif, 2001). Esto quizá se deba a que con frecuencia estos alumnos cambian su atención y se mueven entre diversas tareas, lo que interfiere en el proceso de aprendizaje en general y, particularmente, con el hecho de completar con éxito la tarea principal que estén realizando (Valiente, Lemery-Chalfant, Swanson, y Reiser, 2008).

Por otra parte, ciertas características temperamentales, como la persistencia, el nivel de actividad y la ausencia de distracción informados por los profesores, están relacionadas con el éxito académico en la escuela elemental (Martin, Drew, Gaddis, y Moseley, 1988). Niños con un alto CV probablemente tengan muchas de estas habilidades, por lo que no se distraerán fácilmente de la tarea (Zimmerman, 1998) y procesarán en detalle las situaciones con más precisión que los compañeros con bajo nivel de CV (Lemerise y Arsenio, 2000). Recientemente, Valiente y colaboradores (2008) muestran que el CV informado tanto por los padres como por los propios alumnos se relaciona con el rendimiento académico (media de las notas en matemáticas, vocabulario y lenguaje).

Diferentes estudios han examinado la relación entre el control inhibitorio, las habilidades matemáticas y la alfabetización, la cual hace referencia a las habilidades necesarias para que surjan la lectura y la escritura, como puede ser el conocimiento de letras y de vocabulario. McClelland y su equipo (2007) realizaron un estudio para examinar la relación entre la regulación conductual y las habilidades matemáticas, de vocabulario y alfabetización, así como las habilidades sociales en niños de cuatro años. En este estudio, utilizaron la tarea denominada “Head to Toes” para medir la regulación conductual. En esta tarea se instruye al niño para que realice la acción que el experimentador le encomienda: “toca tu pie” o “toca tu cabeza”. Después de varios ensayos, se instruye al niño para que realice la acción contraria a la que se le ordena, por ejemplo, cuando el experimentador ordena “toca tu pie” el niño deberá tocar su cabeza. Esta tarea requiere integrar tres habilidades básicas: a) prestar atención a la orden del experimentador, b) mantener la regla durante un tiempo, y por último, c) inhibir la respuesta natural de seguir las instrucciones del experimentador, para dar una respuesta apropiada. Los resultados mostraron que aquellos niños con mayor regulación conductual también manifestaron significativamente mejores puntuaciones en vocabulario, alfabetización y matemáticas (McClelland, y cols., 2007). Blair y Razza (2007) encontraron resultados similares en su estudio con niños de tres a seis años. En su estudio tomaron medidas de CV, de control inhibitorio y el cambio atencional y posteriormente las relacionaron con la habilidad matemática y con el alfabetismo. Los resultados mostraron que el control inhibitorio se relacionaba positivamente con las habilidades matemáticas y con la alfabetización, indicando además que el único predictor significativo de las habilidades matemáticas fue el control inhibitorio. Este mismo patrón de resultados se obtuvo evaluando a niños más mayores de once y doce años (St. Clair y Thompson, 2006).

Ciertos datos señalan que la supresión de la información irrelevante parece ser un factor clave para resolver problemas matemáticos. Passolunghi y cols (1999; 2001) examinaron la memoria de trabajo y la capacidad inhibitoria en dos grupos de niños, uno formado por niños con buenas habilidades para resolver problemas matemáticos, y otro formado por niños con malas habilidades para resolver problemas matemáticos. La inclusión a los grupos se determinó por los informes de los profesores sobre las habilidades matemáticas de los alumnos, y por las puntuaciones de los alumnos en un test matemático estandarizado (Amoretti, Bazzini, y Reggiani, 1994). Controlando variables como el género, la edad, el vocabulario y la comprensión lectora, los datos mostraron que los niños con dificultades para resolver los problemas matemáticos, eran aquellos que recordaban menos información relevante pero más información irrelevante en tareas de memoria de trabajo. Este resultado indica que los alumnos con peor capacidad para inhibir la información irrelevante tienen dicha información más disponible lo que produce una mayor interferencia a la hora de resolver problemas de matemáticas (Passolunghi, Cornoldi, y De Liberto, 1999; Passolunghi y Siegel, 2001).

Recientemente, Hirsh y Inzlicht (2009) examinaron la relación entre la magnitud del ERN, como índice de una mayor habilidad para movilizar procesos de control cognitivo, y el rendimiento académico en estudiantes universitarios. Usando la tarea Stroop estándar encontraron que la magnitud del ERN estaba significativamente asociada con el rendimiento académico, medido por las notas académicas oficiales. Este resultado sugiere que los individuos que son mejores monitorizando sus acciones y manejando los mecanismos de control cuando es necesario, son aquellos que alcanzan mejores resultados en los programas de educación universitaria (Hirsh y Inzlicht, 2009).

OBJETIVOS DE LA TESIS

Dada la importancia que parece tener la AE y el factor temperamental de CV en la regulación, y que esta regulación parece influir en la competencia escolar, el trabajo de esta tesis va encaminado a estudiar el sistema de control en el curso del desarrollo y su relación con la autorregulación, especialmente poniendo el énfasis en cómo dicha regulación afecta a la desempeño escolar.

Analizamos el sistema de control en distintos niveles: nivel temperamental con cuestionarios de temperamento y a nivel cognitivo con tareas de conflicto. Así mismo en el estudio 1 y 3 analizamos el sistema de control también a nivel cerebral tomando medidas electrofisiológicas. Todo este conjunto de datos nos dará una visión más amplia sobre el funcionamiento del sistema de control.

En el primero de los estudios se examina el desarrollo en el procesamiento del conflicto y del error y su relación con la autorregulación. Participan en el estudio niños de entre 4 y 13 años (n=36) y un grupo de adultos (n=14). Se usa una tarea de flancos adaptada a niños para evaluar las diferencias que se producen en el curso del desarrollo en el procesamiento del conflicto y del error, mientras la actividad cerebral se registra con el EEG. En base a la evidencia revisada en la introducción (Davies y cols., 2004; Diamond, 2001; Rueda, Posner, Rothbart, y cols., 2004; Wiersema, y cols., 2007) esperamos encontrar una mejora en la capacidad para monitorizar la acción con la edad, que se traduciría en una mejora en el procesamiento de los errores así como en una mejora en el control de la interferencia y en el control de conductas impulsivas. Además, estamos interesados en explorar los mecanismos cerebrales que están a la base de la monitorización de la acción en el curso del desarrollo, por lo que analizamos diferentes componentes electrofisiológicos que en la literatura se han relacionado con dicho proceso, como el N200, el ERN y el Pe. En el curso del desarrollo algunos de estos componentes parecen no sufrir cambios, como es el caso del Pe, mientras que otros si se modulan con la edad. En concreto, se produce el aumento de la amplitud del ERN alrededor de la adolescencia, aumento que los autores interpretan como una mejora en los mecanismos de control en la monitorización del error (Davies, Segalowitz, y Gavin, 2004; Wiersema, y cols., 2007). Esperamos que el Pe esté presente en todos los grupos de edad, es decir, que este componente no se module por la edad y que el ERN aparezca a partir de los 10- 13 años, lo que replicaría los hallazgos existentes en la literatura. En cuanto, al componente electrofisiológico relacionado con la monitorización del conflicto, el N200 (al cual nosotros llamamos ERPs $_{i\text{-}c}$), en base a la evidencia podemos esperar bien un aumento en la amplitud del

N200 con la edad (Ladouceur, y cols., 2007) o bien una disminución de la amplitud del componente con la edad (Lamm, y cols., 2006; Rueda, Posner, Rothbart, y cols., 2004). Tanto en un caso como en el otro, los autores lo interpretan como un reflejo de la mejora en el mecanismo cerebral relacionado con la monitorización de la acción. Si nuestros datos apoyan los hallazgos de Rueda (2004) y Lamm (2006) esperamos encontrar que la amplitud del ERPs $_{i-c}$ sea menor en el grupo de adultos que en el grupo de niños, viendose quizá una progresiva disminución con la edad. Si por el contrario nuestros datos apoyaran la hipótesis de Ladouceur (2007), esperaríamos encontrar un aumento progresivo de la amplitud del ERPs $_{i-c}$ con la edad.

Por otro lado, si la amplitud de los ERPs tanto relacionados con el procesamiento del conflicto (ERPs $_{i-c}$) como con el procesamiento del error refleja cambios en el control cognitivo, entonces esperamos que las amplitudes de los ERPs se asocien con conductas de autorregulación. Para ello correlacionamos los índices cerebrales relacionados con el conflicto y el error con medidas temperamentales de autorregulación, con medidas de impulsividad y con elecciones de demora en una tarea afectiva. En concreto, esperaríamos que el aumento de la amplitud del ERN, indicativo de una mejor eficacia atencional, se asociara con conductas más reguladas. En cuanto al ERPs $_{i-c}$, si realmente, como afirman Rueda (2004) y Lamm (2006) la disminución en la amplitud del ERPs $_{i-c}$ es el reflejo de la mejora en el mecanismo cerebral relacionado con la AE, entonces deberíamos encontrar que una disminución en la amplitud del componente se asociara con conductas más reguladas. Por el contrario, si el aumento de la amplitud del ERPs $_{i-c}$ es interpretado como un índice de mejora en la eficacia del sistema atencional (Ladouceur, y cols., 2007), entonces lo que deberíamos encontrar sería que una mayor amplitud del ERPs $_{i-c}$ se asociara con conductas más reguladas.

Por su parte, nos preguntamos cómo las diferencias individuales en el sistema de control pueden afectar a la regulación en contextos más naturales como el contexto escolar. En concreto nos preguntamos cómo afecta este sistema de control al ajuste socio-emocional en el colegio y al rendimiento escolar. Para ello, en el siguiente estudio además de tomar medidas del sistema de control a nivel temperamental y cognitivo, evaluaremos la competencia escolar con medidas de rendimiento académico y de habilidades necesarias para un buen aprendizaje, y del ajuste socio-emocional del alumno. Como hemos mencionado en la introducción, parece que existen relaciones entre la eficacia del sistema de control y la competencia escolar (Blair, 2002; Bull y Scerif, 2001) así como con la regulación socio-emocional (Eisenberg, y cols., 1993; Nelson, y cols., 1999; Simonds, y cols., 2007).

Nosotros esperamos por tanto que la eficacia del sistema de control se refleje en una mejor regulación social informada por los compañeros de clase, y una mejor regulación emocional, informada tanto por los propios alumnos como por sus padres. Además, esperamos que la eficacia del sistema de control también se relacione con un mejor rendimiento escolar, informado por los profesores, y con la puesta en marcha de habilidades escolares que favorezcan el aprendizaje, informado por los propios alumnos. Trateremos, por otra parte, de dilucidar cuál es el papel específico que juega el sistema de control en las interacciones entre la regulación socio-emocional y la competencia escolar. Mientras que algunos autores piensan que es control social el factor clave en el desempeño escolar (Mashburn y Pianta, 2006), nosotros creemos es el sistema de control, ya se relaciona tanto con el competencia escolar como con el ajuste socio-emocional.

Por último, ya que existen pocos estudios que hayan analizado la relación entre la competencia escolar y medidas cerebrales relacionadas con la funcionalidad de la red de AE, nosotros diseñamos el último de nuestros estudios. En él se analiza a nivel electrofisiologico ciertos componentes relacionados con la AE. Por su parte, ya que en la introducción se ha señalado que tanto la inhibición de la respuesta como la supresión de la interferencia parecen contribuir al desempeño escolar también en este estudio tenemos como objetivo disociar la contribución específica que estos dos procesos tienen para la competencia escolar. Se utiliza para ello una tarea que combina el paradigma de flancos con la tarea go/no-go, mientras se registra la actividad cerebral con EEG. Evaluamos, además, las habilidades escolares, el CV y la inteligencia. De nuevo, asumiendo que la AE está implicada en la competencia escolar, esperamos que los alumnos que muestren una mayor eficacia de la atención ejecutiva, medida tanto a nivel comportamental como a nivel neurocognitivo, sean también los que muestren un mejor ajuste al colegio y unas mejores habilidades escolares. Esperamos, por su parte, que la habilidad para suprimir la información irrelevante sea un factor clave para el aprendizaje, reflejándose en mejores resultados académicos y mejores habilidades escolares.

La figura siguiente presenta una visión general de las medidas de atención y temperamento tomadas en este estudio, y las hipótesis de las relaciones con varias dimensiones de la regulación y la competencia escolar consideradas en el presente trabajo.

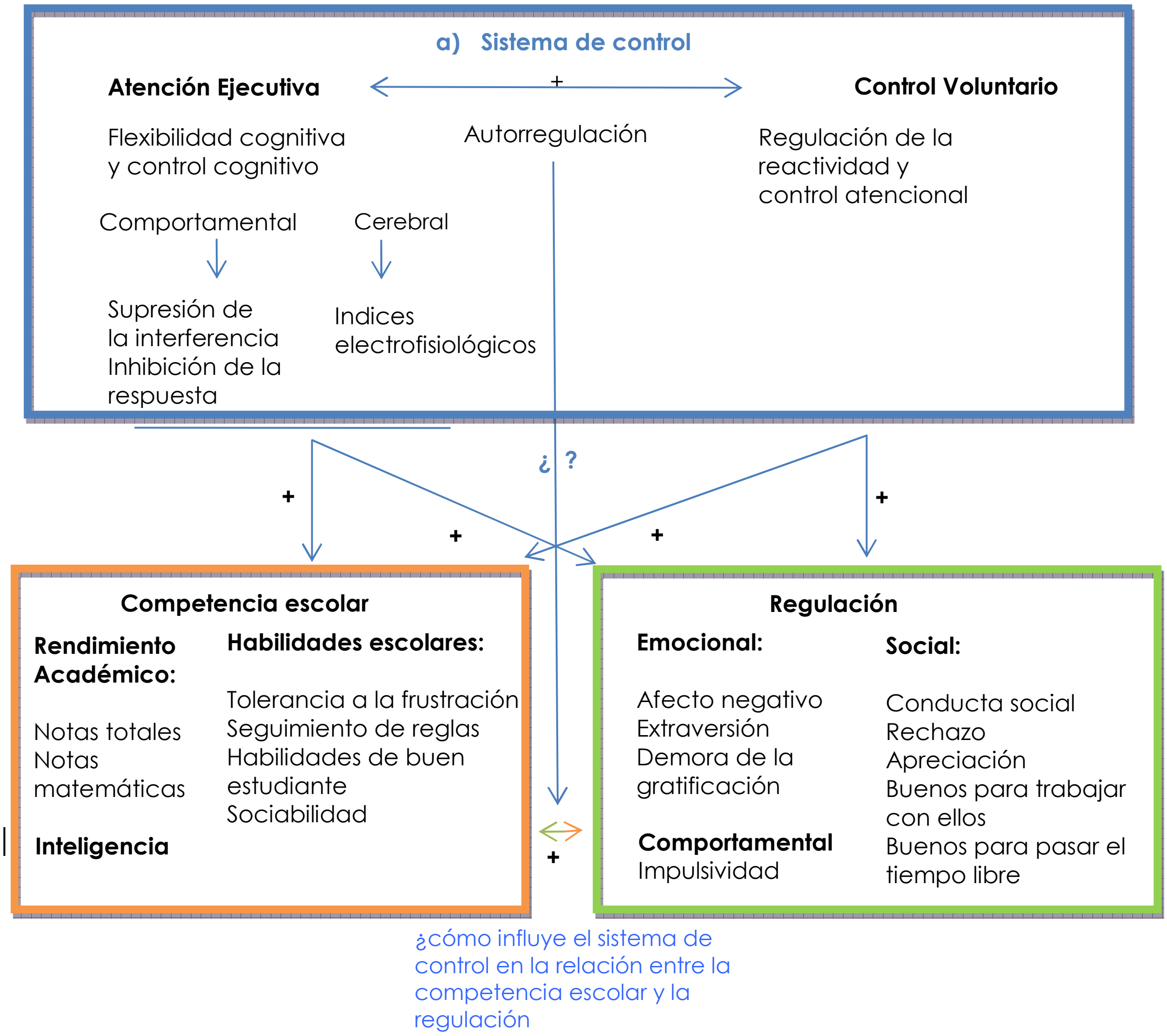

Figura 1. Relaciones esperadas entre las distintas variables en el estudio

CHAPTER II

BRAIN RESPONSE TO CONFLICT AND ERRORS AND THE DEVELOPMENT OF SELF-REGULATION

ABSTRACT

The aim of the study was to investigate the development of conflict and error monitoring processes and their relation to self-regulation. For this purpose, 3 groups of children of 4 to 7 years old, 7 to 10 years old, 10 to 13 years old and a group of adults (mean age of 26 years) performed a child-friendly version of Flanker task while their brain activation was registered using a high-density electroencephalography system. Behavioral and electrophysiological data indicated a progressive increased efficiency in resolving conflict with age. Error processing appears to develop mainly in the adolescence, although at young age shows some signals of error recognition. Finally, our results show that conflict and error processes are related to self-regulation even in affective situations.

INTRODUCTION

In order to monitor our actions, it is required appropriate performance adjustment in terms of tasks demands, and some crucial components of this process are the abilities to detect errors and monitor conflict situations. These abilities are part of a system that guides our behavior and permits adjusting to the situations. This systems is conceptualized by the Posner's model of attention as a executive attention system (Posner & DiGirolamo, 1998)

One of the most common measure of executive attention in the laboratory is provided by tasks involving conflict among possible responses, such as the Flanker task. In this task, participants are asked to respond to a central stimulus (target). The target is surrounded by flankers associated to either the same (congruent) or the opposite (incongruent) response. Behavioral studies have shown that participants involuntarily process surrounding flankers despite their irrelevance for the task requirement of responding to the central target. Participants are slower and less accurate to respond to incongruent trials than to congruent ones (Eriksen & Eriksen, 1974). One of the most studied event-related potentials (ERPs) associated to conflict monitoring is the N200. This component is a negative deflection observed around 200 - 400 ms post-stimulus at medial-frontal sites. This component is larger in situations where it is necessary to inhibit irrelevant information or inappropriate responses, such as in incongruent trials. The amplitude difference between the ERPs related to congruent and incongruent trials is usually taken as a brain measure of efficiency of conflict resolution (Lamm, et al., 2006). Functional MRI (fMRI) research (Botvinick, et al., 1999) and source modeling of the N200 (van Veen & Carter, 2002b) have suggested that conflict monitoring is critically associated with activity in the anterior cingulate cortex (ACC).

Detecting errors is another form of monitoring our actions. When participants commit errors, reaction times (RTs) are faster than when a correct response is given (Falkenstein, et al., 1990). This suggests that execution errors are often caused by premature elicitation of the response, and thus may also be regarded as instance of impulsive responses (Pailing, et al., 2002). A considerable number of ERPs studies (Falkenstein, Hoorman, Christ, & Hohnsbein, 2000; Gehring, et al., 1993; Holroyd & Coles, 2002; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003) have found that response-locked ERPs are modulated by the commission of errors. Commonly, a negative deflection is observed around 80 ms the commission of an error at mid-frontal electrodes, which is called the Error Related Negativity (ERN). The ERN is interpreted as an error detection signal resulting from a mismatch between the intended response and the outcome of response selection (Falkenstein, et al., 1990; Gehring, et al., 1993). It is supposed that the monitoring system may compare the current response with the correct action. When the comparison results in a mismatch it can be used by a error-correction or error compensation system, whose function is to correct the error, or reduce the likelihood of future errors (Milter, Braun, & Cole, 1997). A different hypothesis is that the ERN reflects response-conflict monitoring processes, based on evidence showing that errors reflect instances of high response conflict (Carter, Botvinick, & Cohen, 1999; Yeung, Botvinick, & Cohen, 2004). Although there is some diversity of theories that try to explain the functional meaning of the ERN, all of them point out the relevance of the ACC as the most likely source of the ERN. Studies using fMRI (Kiehl, et al., 2000; Mathalon, Whitfield, & Ford, 2003), source modeling of the ERN (Herrmann, et al., 2004; Ladouceur, et al., 2007; Luu, et al., 2003) and single neurons recording in monkeys (Michelet, et al., 2009) have revealed implication of the anterior cingulate cortex for error responses.

The ERN is frequently followed by a positive deflection, the Pe, which has a centro-parietal distributions and a maximum amplitude around 200 to 500 ms after the erroneous response (Kaiser, et al., 1997). The Pe seems to be an error-specific component, associated with a later aspect of error processing. The Pe seems to be associated with awareness of the commission of the erroneous response (Kaiser, et al., 1997; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; O'Connell, et al., 2007; Shalgi, et al., 2009) and can also be associated with the motivational significance of an error (Leuthold & Sommer, 1999; Ridderinkhof, Ramautar, & Wijnen, 2009). Source modeling of the Pe shows that this component could be generated in the rostral part of ACC (Herrmann, et al., 2004).

The P300 is another ERPs component that has been associated with a large variety of cognitive and affective processes. The amplitude of the P300 has been assumed to reflect the subjective meaning or impact of the eliciting stimulus (Donchin, 1981). In recent years, differential effects on the P300 have been also observed in tasks involving decision-making or outcome evaluation (Luu, et al., 2009; Yeung, Holroyd, & Cohen, 2005). Theses effects are thought to reflect the evaluation of the functional significance of feedback stimuli. One aspect of the significance of feedback is the probability of the positive or negative outcome experienced by the participants. This probability would allow the participant to create expectancies towards a particular outcome and hence could affect brain responses to upcoming feedback. Hajcak and colleagues provided evidence that the P300 is modulated by the expectancy violations, with more positive amplitudes for unexpected feedback compared to expected feedback (Hajcak, Holroyd, Moser, & Simons, 2005; Hajcak, Moser, Holroyd, & Simons, 2007)

Different studies using conflict tasks have shown a considerable development of conflict resolution between four and seven years of age, with a striking consistency in performance after age 7 to adulthood (Rueda, Posner, Rothbart, et al., 2004). The brain mechanism underlying the differences in conflict resolution between adults and children has been investigated in ERP studies using a flanker tasks adapted to children (Rueda, et al., 2004). Althougt adults and children showed a larger negative deflection in the ERPs related to incongruent compared to congruent trials, some differences were reported between adults and children. Compared to adults, the childrens' effect had a larger size, greater amplitude, was extended over a longer period of time and had more anterior distributions. This frontal effect decreased in amplitude with age consistent. Some authors consider the amplitude decrease of this frontal effect as index of improvement of efficiency of executive attention (Lamm, et al., 2006). Evidence from fMRI indicates that the difference between children and adults in the performance of conflict tasks may be related to differences in the ability to effectively recruit areas implicated in cognitive control, such as the ventro-lateral prefrontal cortex (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Durston, et al., 2002).

Some studies have focused on investigating the development of the error processing during childhood (Davies, et al., 2004a; Torpey, Hajcak, & Klein, 2009; Wiersema, et al., 2007). Adults and children are faster to respond in error than in correct trials, which is interpretived as index of impulsive response in errors. However, compared to adults, children showed larger RT difference between correct and error responses indicating that children have more trouble to inhibiting preponderant responses (Wiersema, et al., 2007). It has been also shown that the ERN is not clearly visible until thirteen. However, the Pe does not seem to change with age (Davidson, et al., 2006; Wiersema, et al., 2007). Studies using dipole modeling show that ERN is generated in medial prefrontal areas whereas Pe is localized nearby but more rostrally within the ACC (Herrmann, et al., 2004; van Veen & Carter, 2002a).

The anterior cingulate cortex, one of the main nodes of executive attention, has been linked to a variety of specific functions in attention (Fan & Posner, 2004) emotion (Bush, et al., 2000) and error detection (Herrmann, et al., 2004; Ladouceur, et al., 2007; Phan Luu, et al., 2003). The ACC seems to be involved in control processes by facilitating or inhibiting the functioning of others brain networks (Fan & Posner, 2004; Posner & Petersen, 1990). The connections between ACC, lateral prefrontal cortex and limbic structures provides a brain circuit for self-regulation (Rueda, Posner, & Rothbart, 2004). Data coming from neuroimaging studies seem to support such idea. For instance, individuals who are less concerned about their errors, such as low-socialized persons (Santesso & Segalowitz, 2009; Santesso, et al., 2005) and psychopaths (Dikman & Allen, 2000; Munro, et al., 2007), show smaller ERNs, which suggests that they activate the ACC to a lesser degree than individuals who are more concerned about their errors.

Links between attention and self-regulation have also been found in "temperament" research. Individual differences in reactivity and regulation are commonly measured using questionnaires. Research in the past years has come to identify three broad dimensions that characterize temperament during childhood and adolescence (Rothbart, 2007; Rothbart & Bates, 2006), namely, Extraversion/Surgency, Negative Affect and Effortful Control. Extraversion and Negative affect represent the reactivity systems and describe individual differences in approach and avoidance reactivity, respectively. The behavioural characteristics that group into the concept of Effortful Control constitute a major form of self-regulation. Effortful control allows individuals to regulate their behaviour in relation to current and future needs. The Executive Attention Network might be the neural substrate supporting EC (Rothbart, et al., 2004; Rothbart & Rueda, 2005).

Aims of the study

The main goal of this work was to study the rate of development of executive attention in children and to compare it with adults' performance. To do this, we examined conflict monitoring and error monitoring using a child-friendly version of the flanker task while the brain activation was recorded. Our sample was composed by children between 4 and 13 years of age and one group of adults. We selected children between these ages because it is known that is during this time is when the conflict monitoring and error monitoring are being developed (Davies, et al., 2004a; Rueda, et al., 2004).

To study the time course of conflict processing we examined the amplitude differences between the ERPs for congruent and incongruent trials. Then, we examined the time course of error processing inspecting the amplitude differences between the ERPs for correct and error responses. We expected to find a development in the monitoring action reflected in a brain measured associated with this process. In particular, we expected that the amplitudes difference between ERPs components related to conflict (incongruent) and not conflict (congruent) trials decreased as functions of age, which has been interpreted by some authors as a improvement in monitoring conflict (Lamm, 2006). With regard to error processing we expected to find the clear ERN in children between 10 and 13 years old and in adults group, as other studies have been shown (Davies, Segalowitz & Gain, 2004). We also expected to replicate the results related to Pe, anticipated that the Pe was observed in all groups of age.

We provided three different feedbacks, one associated to correct responses, another associated to error commission responses, and the last one linked to responses that were given out of time. We examined the amplitude difference between the ERPs locked to feedback associated to correct response and those locked to feedback associated to correct response given out time. We were interested to examine the P300 that is thought to reflect the expectancy violations of the particular outcome in the development course. Some behavior data have shown that young children could detect the expectancy violations (Wynn, 1992) therefore we expected that the P300 did not show modulation by age, as reflected of early development of expectancy detections.

A further aim of this study is to compare changes in the ERPs to self-regulation. If the amplitudes of the ERPs components related to conflict and error processing reflect changes in cognitive and affective control, then ERPs amplitudes should be associated with individual difference of self-regulation. We examined this idea by correlating the cerebral indexes of error and conflict processing to temperamental measures of self-regulation, impulsive behaviors, conflict resolution scores and choice in the "Delay of Gratification" task. We expected that better efficiency of the attentional network measured by electrophysiological measures would be related to better self-regulated behavior even in affective situation

METHOD

PARTICIPANTS

A total of 50 participants were included in this study: 12 children in the age range 4- 7 years (7 girls and 5 boys, mean age: 5.1 years; SD: 0.9;), 14 children in the age range 7- 10 years (6 girls and 8 boys, mean age: 8.1; SD: 0.93), 10 children in the age range 10- 13 years (3 girls and seven boys mean age: 11.5; SD: 1.1; three girls), and 14 adults, (9 women, and 5 men, mean age: 26.5; SD: 5.3). All participants came from Granada's urban area in South Spain and had a similar social background. The families of the children were contacted by phone and invited to participate in the study. Adults were under- and post-graduate students of the University of Granada and were recruited thru announcements at the web-site of the Department of Experimental Psychology. Participation was voluntary, and both caregivers of the children and adults gave written consent to be involved in the study.

MEASURES

Flanker task

We designed a child-friendly flanker task using pictures of round and squared robots as stimuli (see Figure 2). Each trial started with a fixation point of variable duration. The duration of the fixation was randomly selected between 600 to 1200 ms. Subsequently, a row of five robots was presented at the center of the screen either above or below the fixation point. Participants were asked to focus on the robot in the middle and indicate its shape (either round or squared) by pressing the corresponding key. Robots on the sides could be of the same (congruent) or different (incongruent) shape than that of the middle robot. The response button was counterbalanced across participants. The response could be made during presentation of the target or up to 800 ms after it disappeared.

The duration of the presentation of the target was adjusted in each trial according to performance in the previous trial. The stimulus duration was increased with each omission, error responses or responses given out time and decreased with each correct response. The stimulus duration after correct response was determined by the stimulus duration in the previous trial (n-1) minus 50 ms. The stimulus duration after error response, response given out of time and omission response was calculated by the stimulus duration in the previous trial (n-1) plus 50 ms. This procedure was intended to provide the same level of challenge for all participants at all ages and obtain a sufficient number of errors in each group for ERP averaging.

Following the response, a 600 ms-lasting feedback was provided. The feedback consisted of a visual animation of the central figure plus an auditory word ("yes" for correct response, "no" for incorrect response, and "late" for omission or responses given out of time).

Participants completed 192 trials divided in eight blocks of 24 trials each, half of them congruent, and the other half incongruent being randomly selected at each trial.

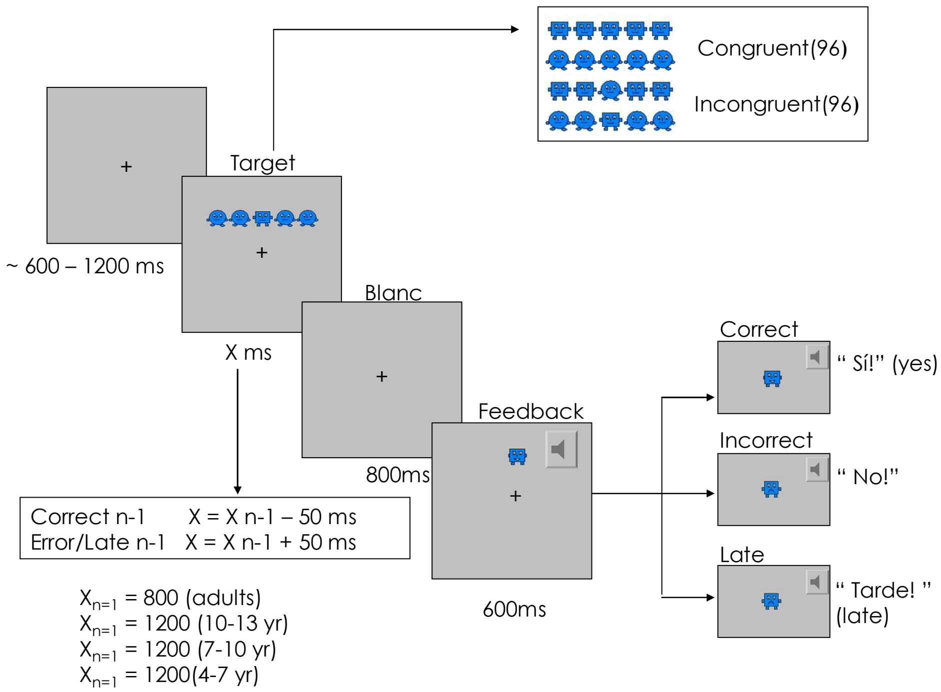

Figure 2. Schematic representation of the flanker task used in the experiment

Temperament Questionnaires

The parent-reports version of the Children Behavioral Questionnaire Short form (Putnam & Rothbart, 2006) was used for children between 4 and 8 years of age, the Early Adolescence Temperament Questionnaire – Revised (Ellis & Rothbart, 2001) was used for 9 to 13 years old children and the Adult Temperament Questionnaire (Rothbart, Ahadi, & Evans, 2000) was used for adults. Theses questionnaires consist of a number of questions about people's reactions in daily- life situations that can be grouped onto three main factors: Effortful control (EC), Extraversion/Surgency (E/S), Negative Affect (NA). The ATQ also includes a factor on Orienting Sensitivity (OS).

The internal reliability (measured by Cronbach's alpha) for the each factor in the different questionnaires was: α =.60 for EC; α = .77 for E/S, and α = .86 for NA in the CBQ; α = .85 for EC; α = .90 for AF; α = -.34 for E/S; and α = .63 for NA in the EATQ-R, and α = .53 for EC; α =.50 for E/S; α = .65 for NA and α =.82 for OS in the ATQ. Only the factors with α > 0.50 were included in the analyses.

Delay of Gratification task

We used a modified version of the Thompson, Barreri and Moore (1997) Delay of Gratification task. We included six test trial types, created by crossing three types of reward (stickers, pennies and candies) and two types of choice: delay for oneself (DS) or delay for other person (DO). In the first condition, children chose between obtaining a) one present for themselves immediately or b) two presents for themselves at the end of the task, while in the delay-for-other condition children chose between obtaining a) one present for themselves immediately or b) one present for themselves and one present for the experimenter at the end of the task. Each participant made 12 elections, 6 of each type. The dependent variable for this task was the percentage of delay choices in each condition.

PROCEDURE

As participants arrived at the lab, they were informed of the general procedure of the study and were given a few minutes to get comfortable with the lab setting before starting. Participants first completed the flanker task while their brain activation was registered by means of an EEG system using a high-density (128-channels) sensor net. Fitting the net on participant's heads and checking impedances took about 15 minutes. Completing the computer task took about 20 minutes, which included brief breaks between blocks of trials. Once the task was completed, the sensor net was taken-off, and participants were allowed to take a break for a few minutes. Finally, participants completed the self-report (adults) or parent-report (children's caregivers) version of the temperament questionnaire. All participants performed the different tasks in the same order. A T-shirt of the lab and other small presents were offered to the children at the end of the experimental session in appreciation for their collaboration. Adults received course credits in accordance to the norms of the Psychology Department of the University of Granada.

EEG RECORDING AND DATA PROCESSING

EEG was recorded using the 128- channels Geodesic Sensor Net (EGI Software: www.egi.com). Impedances for each channel were kept below 100 kΩ prior to recording. The EEG signal was digitized at 250 Hz. Recording in every channel was vertex referenced and the time constant value was 0.01 Hz. After recording, data were filtered using a 0.3-12 Hz band pass filter. Continuous data were segmented in various ways with the intention to examine brain activation locked to different events: target, response and feedback. The epochs were 600 ms long (-200ms to 400ms) for response and feedback-locked ERPs, and 900 ms long (-200 to 700 ms) for target-locked ERPs.

As Flakenstein et al (2000), for response- locked epochs no pre-response baseline was used, given that the activation prior to the response is likely affected by processing the target and selecting a response. For target-locked and feedback-locked epochs we used the 200 ms prior to the event as baseline.

Segmented files were scanned for artifacts with the artifact detection tool provided by the EGI software for analyses (Net Station). We used a threshold of 100 µV for eye blink or eye movements. Segments containing eye blinks or movements as well as segments with more than 25 bad channels were rejected. Data for each trial were also visually inspected to make sure the parameters of the artifact detection tool were appropriate for each participant. Individual ERPs data were included in the analyses as long as they had a minimum of 12 clean segments per experimental condition. A total of 50 participants reached this selection criterion: twelve children in the 4 to 7 years group, 14 children in the 7 to 10 years group, 10 children in the 10 to 13 years group, and 14 adults.

Source Localization Analysis

Source analyses were conducted in adult's data using GeoSource software provided by EGI (http://www.egi.com). Georce uses a Finite Difference Model (FDM) for Inverse Modeling in which a Minimum Norm Last Squares (MNLS) solution was sought to more accurately compute the lead field in relation to head tissues. The head model used was the Sun-Sock 4-shell sphere. To compute estimates of the sources we used LAURA (Local Auto-Regressive Average) as constraint (Grave de Peralta Menendez, et al., 2004). Weighting was placed equally across locations with regularization carried out via TSVD ($1x10^{-4}$). The radius of influence was set to 12.2 mm an exponent equal to 3. Although the Geosource has been used for children (Molfese et al., 2008) we reckon that it is not appropriated. The MNI database is based on adults, as are virtually all software based source analysis programs. In utilizing GeoSource to isolate neural sources in children the sources models invariably must be subject to error. Child brain size and level of maturation for cortical structures in terms of neurogenesis and myelination will differ from adults.

RESULTS

Descriptive statistics of the flanker task are presented in Table 1.

Table 1. Descriptive analysis of attentional task

	% Errors				RT (ms)			
	OV commission	OV omission	Cong	Incong	cong	incong	correct	error
Adults	18.04 (5.5)	4.8 (1.1)	12.9 (6)	23.1 (7.2)	384 (31)	408 (31)	393 (29)	356 (29)
10-13	20.8 (2.9)	1.5 (1.2)	17.7 (4.3)	24 (4.8)	500 (59)	527 (57)	513 (58)	433 (70)
7-10	17.7 (5.3)	2.4 (2.5)	14.9 (4.7)	20.4 (6.9)	656 (131)	694 (134)	676 (137)	574 (123)
4 -7	20.6 (5.4)	4.1 (3.3)	18.5 (6)	22.7 (7)	940 (205)	1000 (252)	965 (200)	794 (184)

SDs are shown in brackets

BEHAVIORAL RESULTS

Separate 4 (Age Group) x 2 (Flanker Type: congruent vs. incongruent) ANOVAs with median RTs and percentage of errors as dependent measures were conducted. For RT, results revealed a significant main effect of Age Group, ($F(3, 46) = 42.32$; $p<.001$). Planned comparison indicated that adults were faster than children of all age groups (for 4-7 years-old group ($F(1, 46) = 116$; $p<.001$); for 7-10 years-old group ($F(1, 46) = 30$; $p<.001$); for 10-13 years-old group ($F(1, 46) = 4.5$; $p<.05$). The 10-13 years-old group was faster than the 7-10 years-old group ($F(1, 46) = 8.3$; $p<.01$), and the 10-13 and 7-10 years-old groups were faster than the youngest (4-7 years-old) group ($F(1, 46) = 62$;

p<.001) and (F (1, 46) = 31; p<.001), respectively (see Figure 3a). The main effect of Flanker Type was also significant (F (1, 46) = 41; p<.001) indicating faster responses in congruent compared to incongruent trials. Although the Flanker Type x Age Group interaction was not significant, the Flanker Type effect (difference between RT in incongruent vs. congruent trials) was significantly larger for the 4-7 years-old group than for adults (F (1, 46) =5.12; p<.05, and marginally larger for the 4-7 years-old group compared to the 10-13 years-old group (F (1, 46) =3.7; p=.06) (see Figure 3 b).

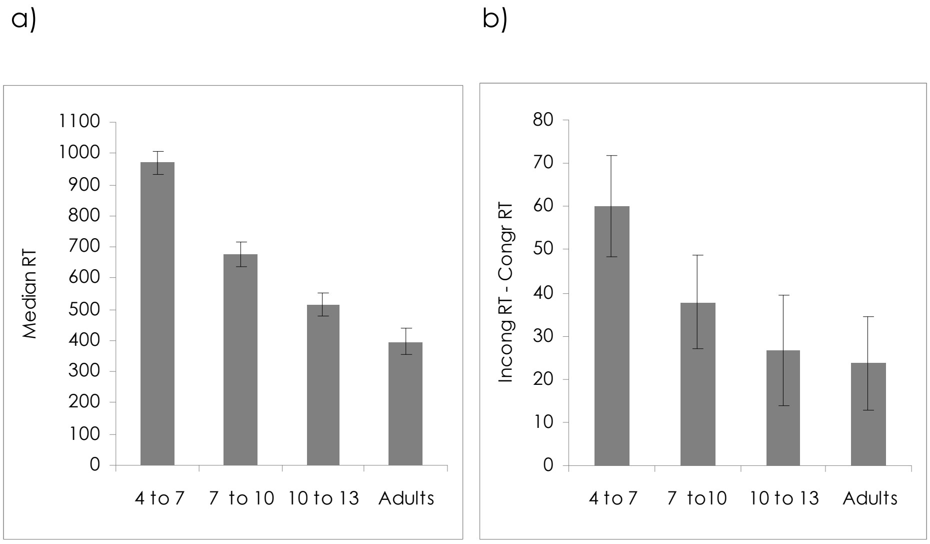

Figure 3. a) Median RTs (ms) in each Age-Group. b) Conflict effect in RTs (ms) (RTs in incongruent – RTs in congruent trials) in each Age-Group

With the percentage of error as dependent variable we found a significant main effect of Flanker Type,(F (1, 46) = 47.2; p<.001) indicating less percentage of errors in congruent compared to incongruent trials. The main effect of Age Group and the Flanker Type x Age Group interaction (F>1) were not significant (see Figure 4).

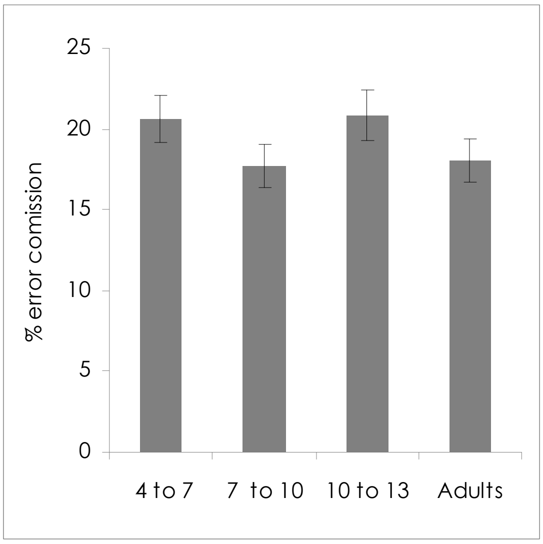

Figure 4. Percentage of commission errors in each Age-Group

We also compared RTs error vs. RT correct responses. We found a significant main effects of Age Group, (F (3, 46) = 39.7; $p<.001$). Planned comparisons indicated that adults were faster than children of all age groups, (for 4-7 years-old group (F (1, 46) = 108; $p<.001$); for 7-10 years group (F (1, 46) = 29; $p<.001$); for 10-13 years group (F (1, 46) = 3.7; $p=.05$)). Moreover,, the 10-13 years-old group was faster than 7-10 years group (F (1, 46) = 8.8; $p<.01$), and the 10-13 and 7-10 years-old groups were faster than 4-7 years-old group (F (1, 46) = 60; $p<.001$) and (F (1, 46) = 27; $p<.001$), respectively. The main effect of Response Type (correct vs. incorrect) was also significant(F (1, 46) =165; $p<.001$) indicating faster RTs to errors than correct responses. The Response Type x Age Group interaction was also significant (F (3, 46) =14.16; $p<.001$). Planned comparisons indicated that the Response Type effect (RT difference between erroneous and correct response) was larger for all children Age Groups compared to adults (for 4-7 years-old group (F (1, 46) = 41.26; $p<.001$); for 7-10 years-old group (F (1, 46) = 10.5; $p<.01$); for 10-13 years-old group (F (1, 46) = 3.7; $p<.05$). Also, the Response Type effect was larger for 4-7 years-old group than for 7-10 and 10-13 years-old groups (F (1, 46) =10.9; $p<.01$) and (F (1, 46) =16.1; $p<.001$), respectively, whereas there were no differences between 7-10 and 10-13 years-old groups, ($F>1$) (see Figure 5).

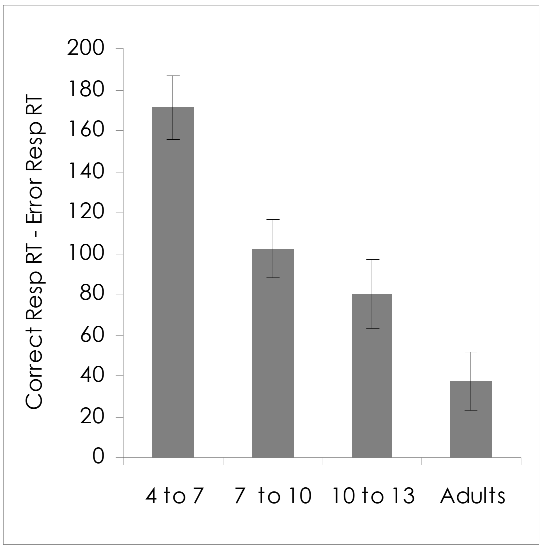

Figure 5. Impulsivity effect (RTs in correct responses –RTs in incorrect responses) in each Age-Group

ERPS RESULTS

Target- locked ERPs

Evoked potentials per congruency condition and Age Group are presented in Figure 6a. The Figure 6b illustrates the topographic distribution of the incongruent minus congruent difference (congruency effect) at particular time points. Finally, the Figure 6c shows the source location solution of the congruency effect for adults' data. The amplitude difference between congruent and incongruent trials appears to be largest between 350 and 450 ms for adults. However, the effect is shown at different time-window and topographic location for children. It appears around 450 ms for 10-13 years-old group and around 500 ms for the 7-10 and 4-7 years-old groups. In order to analyze the congruency effect in the different age groups, the mean amplitude of the wave per condition was calculated at particular time-windows: 350-450 ms post-target for adults and 500-600 ms post-target for all children groups. Also, the topographic distribution of the congruency effect is somewhat different between groups. While the effect is observed at mid-frontal parietal channels for adults and 10-13 year-old group, the distribution is more anterior for the younger groups (see Figure 6b). Therefore, two lead positions over the midline, Cz and Fcz, were included in the analysis.

We conducted a 4 (Age Group) x 2 (Flanker Type) x 2 (Electrode Position: anterior-Fcz and posterior-Cz) ANOVA using the mean amplitude in the time window specified above as the dependent variable. The main effect of Flanker Type was significant,($F(1, 46) = 6.23$; $p<.05$) indicating larger negative amplitude for incongruent (-

0.2 μVolts) compared to congruent (0.1 μVolts) trials. The Age Group x Flanker Type interaction was also significant ($F (3, 46) = 3.4$; $p<.05$). Planned comparisons indicated that the congruency effect was smaller for adults than for the 7-10 and for 4 -7 year-old groups, ($F (1, 46) = 5.93$; $p<.05$) and ($F (1, 46) = 7.73$; $p<.01$) respectively, while the 10-13 years-old group and adults did not differ (F>1).

Source location was performed at the time of maximum amplitude difference between congruent and incongruent condition (350 ms post-target) in the adults' data. Results showed medial frontal sources for the congruency effect, including the medial-frontal gyrus (BA10), and the lingual gyrus (BA18).

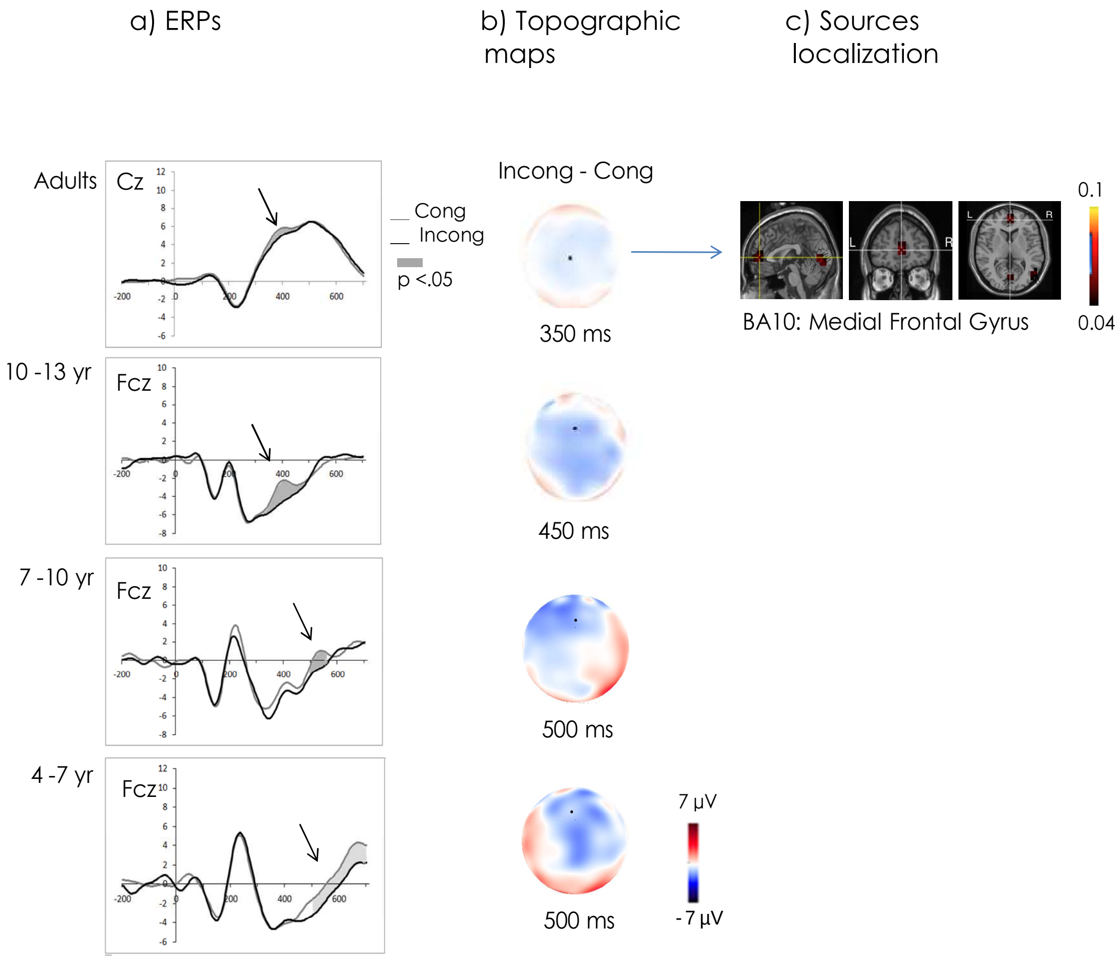

Figure 6. Comparison of children's and adults' target-locked ERPs

Response-locked ERPs

Evoked potentials per Responses Type (correct vs. error) and Age Groups are presented in the Figure 7a. The Figure 7b illustrates the topographic distribution of the error minus correct responses difference at particular time points corresponding to the ERN and Pe peaks. Finally, the Figure 7c shows the source location analysis of the ERN and Pe for adults' data.

As expected, we obtained a negative deflection for errors responses (Error related negativity effect-ERN), which appears to be largest at 80 ms post-response for adults and the10-13 years group. However, the ERN is not observed for the 4-7 and 7-10 years-old groups. The topographic maps of the error vs. correct difference show that the ERN is largest at mid-frontal channels for adults, while the distribution of the effect is more anterior for children. Therefore, two lead positions over the midline, Cz and Fcz, were included in subsequent statistical analysis.

A 4 (Age Group) x 2 (Response Type: correct vs. error) x 2 (Electrode Position: anterior-Fcz and posterior-Cz) ANOVA was conducted with the mean amplitude at the time window from 20 to 80ms post-response as dependent variable (see Table 2). We found a significant main effect of Age Group. Planned comparisons indicated larger negative amplitude for adults and 10-13 years-old group than for the 7-10 years-old group, ($F(1, 46) = 8.6$; $p<.05$) and ($F(1, 46) = 12$; $p<.001$), respectively, and than for the 4 -7 years-old group, ($F(1, 46) = 6.3$; $p<.05$) and ($F(1, 46) = 9.6$; $p<.01$), respectively. The main effect of Response Type was also significant indicating larger negative amplitude for erroneous responses (3.3 μVolts) compared to correct responses (4.2 μVolts). The main effect of Electrode Position was significant indicating larger negative amplitude for Cz (1.9 μVolts) than anterior Fcz (5.5 μVolts) electrode. The Age Group x Response Type interaction was also significant. The Response Type effect was larger for adults than for 4-7 and 7-10 years-old groups, ($F(1, 46) = 8.4$; $p<.01$) and $F(1, 46) = 16$; $p<.001$, respectively, while adults and the 10-13 years-old group did not differ ($F>1$). The Age Group x Electrode Position interaction was also significant. Planned comparisons indicated that the difference in amplitude between Cz and Fcz was larger for the10-13 and 7-10 years-old groups than for the 4 -7 years-old group, ($F(1, 46) = 30.63$; $p<.001$) and ($F(1, 46) = 7.5$; $p<.01$), respectively, and for the 10 -13 years-old group than for adults ($F(1, 46) = 15.85$; $p<.001$). In addition, the Response Type x Electrode Position interaction was significant. This was due to the fact that the effect of Response Type was significant at Fcz ($F(1, 46) = 10.4$; $p<.01$) but not at Cz channel. Finally, the Age Group x Response Type x Electrode Position interaction was also found significant. Planned comparisons showed that the effect of the Response Type effect was significant at Fcz for adults and for 10-13 years-old group, ($F (1, 46) = 14.92$; $p<.001$) and ($F (1, 46) = 4.89$; $p<.05$), respectively, whereas the effect of Response Type at Cz was only significant for adults ($F (1, 46) = 18.66$; $p<.001$).

Table 2. Summary of the ANOVA results for ERN component with the peak amplitude as DV

	F	df	P
Age Group (G)	6.2	3	.01
Response Type (R)	4	1	.05
Electrode Position (E)	92.9	1	.001
G*R	5.87	3	.01
G*E	10.6	3	.001
R*E	28.3	1	.001
G*R*E	3.3	3	.05

The source location analysis identified in three frontal regions as generator f the ERN effect: 1) orbital gyrus (BA11), 2) medial frontal gyrus (BA10) and 3) dorsal ACC (BA 24) (see Figure 7).

All age groups showed later larger positive amplitude for error compared to correct responses (Pe effect), a difference that was peaking at about 230ms post-response for adults and 10-13 years-old group and about 150 ms post-response for the 4-7 and 7-10 years-old groups. This Pe effect has a mid- frontal distribution as observed in the topographic map (see Figure 7a). In order to analyze the Pe effect, mean amplitude for correct and error response was calculated in a 150 to 270 ms post-response time windows, at two midline channels, Cz and Fcz, for each age group. Then a 4 (Age Group) x 2 (Response Type) x 2 (Electrode Position: anterior-Fcz and posterior-Cz) ANOVA was conducted (see Table 3). The main effect of Response Type was significant, indicating larger positive amplitude for error responses (6.9 μVolts) than for correct ones (2.9 μVolts). The main effect of Electrode Position was also significant, ($F (1, 46) = 46.8$; $p<.001$), indicating that the positive amplitude was larger at Cz (6.1 μVolts) than for Fcz (3.7 μVolts). The interaction Age Group x Electrode Position was also significant, showing that the amplitude difference between Cz and Fcz was larger for the10-13 years-old group than for adults ($F (1, 46) = 17.8$; $p<.001$). The Response Type x Electrode Position interaction was also significant, indicating that the effect of Response Type was larger at Cz ($F (1, 46) = 78$; $p<.001$) than at Fcz ($F (1, 46) = 25.6$; $p<.001$). Further analyses indicated that the effect of Response Type at Cz was larger for the 7-10 years-old group than for 4-7 years-old group (F (1, 46) =4.7; p<.05). The same effect was only marginally different between 4-7 years-old group and 10-13 years-old group (F (1, 46) =3.6; p=.06). The effect of the Response Type was also larger for adults compared to 10-13 years-old group at Cz (F (1, 46) =5.17; p<.05). There were no differences between groups in the effect of Response Type at Fcz.

Table 3. Summary of the ANOVA results for Pe component with the peak amplitude as DV

	F	df	p
Age Group (G)	0.5	3	.63
Response Type (R)	51.6	1	.01
Electrode Position (E)	46.8	1	.001
G*R	1.49	3	.22
G*E	9.7	3	.001
R*E	28	1	.001
G*R*E	5.6	3	.01

The source localization analysis was performed at the time of maximum amplitude difference between correct and error response (230 ms post-response) in the adults data. Results showed two generating regions at the frontal mid-line, including the dorsal ACC (BA32) and the medial frontal gyrus (BA8-BA6) (see Figure 6c).

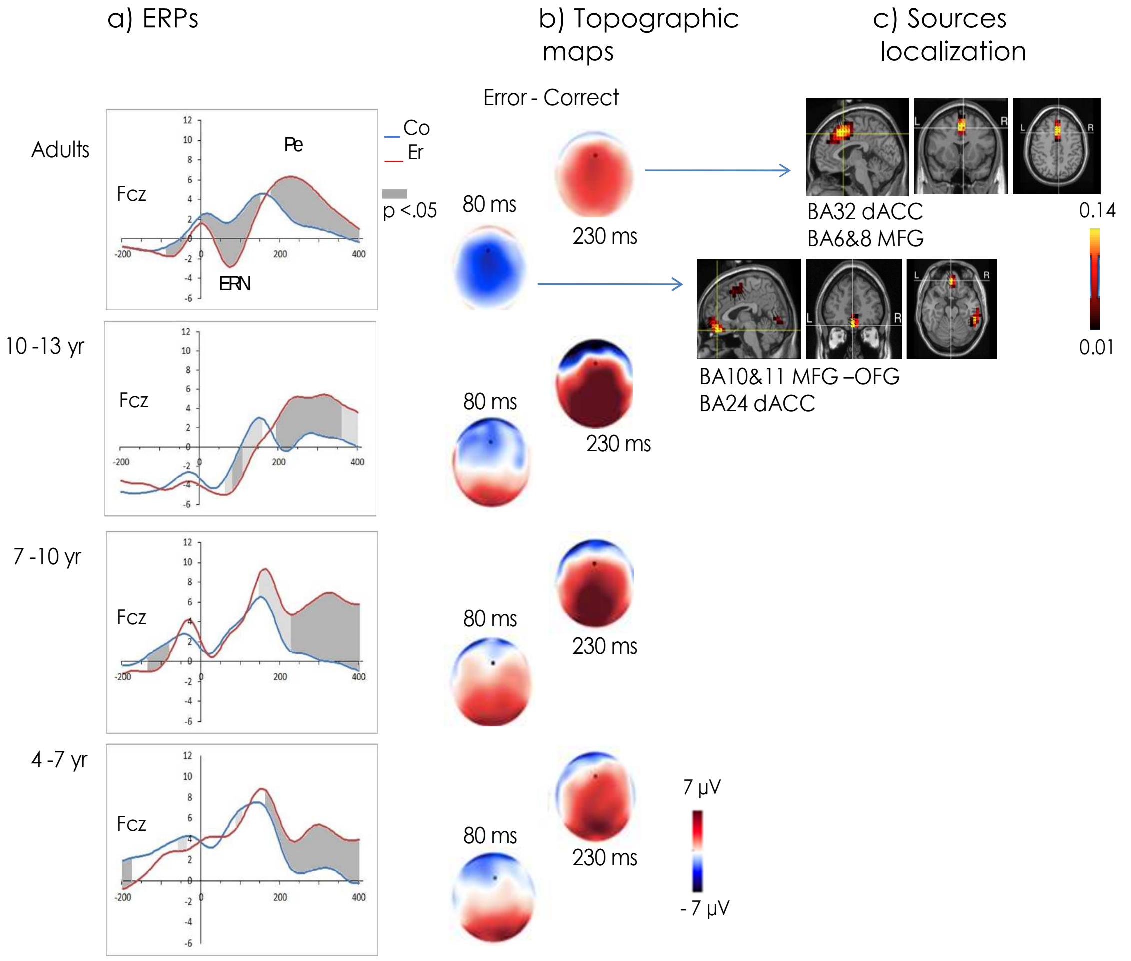

Figure 7. Comparison of children's and adults' response-locked ERPs

Feedback-locked ERPs

Evoked potentials for the different type feedbacks and age groups are presented in Figure 8a. All groups showed a late positive deflection peaking at about 230 ms post-feedback (P_{fdb}). As can be observed in the figure, the amplitude of this positive deflection was modulated by the type of feedback (late vs. correct) and has a mid-frontal distribution (see Figure 8b). Figure 8c depicts the source solution of the P_{fdb} (late feedback minus correct feedback) for adults' data.

In order to analyze the feedback-related positivity (P_{fdb}), we obtained mean amplitudes for late (feedback associated to correct response given out time) and correct(feedback associated to correct response given on time) feedback within a time window of 200 to 260 ms post-feedback for all age groups at channel Cz. We conducted a 4 (Age Group) x 2 (Feedback Type: correct vs. late) ANOVA. We found a significant main effect of Feedback Type, $F(1, 46) = 68.9$; $p < .001$, indicating larger mean amplitude for late feedback (4.8 μVolts) compared to correct feedback (9.9 μVolts). The Age Group x Feedback Type interaction was not significant ($F > 1$).

Source localization was performed at the time of maximum amplitude difference between the late and correct feedbacks (at 230 ms post-feedback) in the adult's data. Results showed medial frontal sources including the medial frontal gyrus (BA11-BA6) and the cingulate gyrus (BA24).

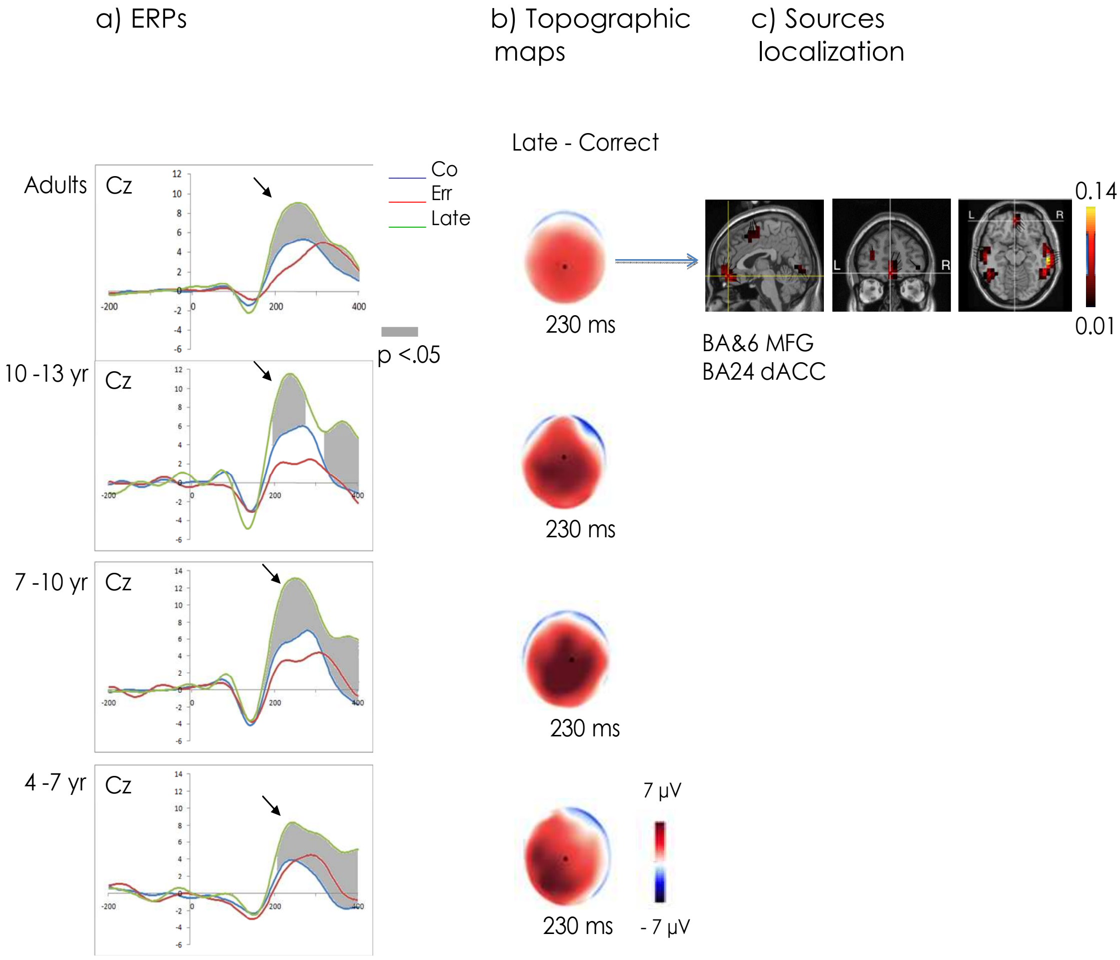

Figure 8. Comparison of children's and adults' feedback-locked ERPs

Correlations

Two scores related to performance of the experimental task were obtained or each participant. First, the conflict score was calculated subtracting the median RTs (or % of errors) for congruent trials from the median RTs (or % of errors) for incongruent trials. We also obtained an index of impulsivity by subtracting the median RTs for correct responses from the median RTs for error responses. Subsequently, we calculated Pearson's correlations between these scores and the other measures taken in the study.

Conflict scores were positively correlated with impulsivity ($r = .52$; $p<.05$) a correlation that remained significant after controlling by age ($r = .47$; $p<.05$). The percentage of delay choices at the Delay of Gratification task did not correlate with neither of the conflict and impulsivity scores. We also obtained a statistically significant correlation between the conflict score measured with the percentage of errors and

Effortful Control in adults and children whom parent reported the Effortful Control thru CBQ ($r = .-.58$; $p<.05$) and ($r = -.72$; $p<.001$) respectively. The conflict score was correlated with the CBQ parent-reported of Negative Affect ($r = .51$; $p<.05$) and with Surgency ($r = .46$; $p<.05$). The Percentage of delay choices at the Delay of Gratification task did not correlate with any of the temperamental factors.

Additionally, we calculated the ERPs index of conflict (ERP_{i-c}) and error processing (ERN and Pe). The ERP_{i-c} index was obtained by subtracting the mean amplitude for congruent trials from the mean amplitude for incongruent trials at the following time-windows: 350-450 ms post-target for adults at Cz and 500-600 ms post-target for all children groups at Fcz. The ERN and the Pe indexes were calculated by subtracting the mean amplitude for correct responses from the mean amplitude of the error responses at different time windows at Fcz: 20 to 80 ms post-response for ERN, and 150 to 270ms post-response for the Pe component. As for the feedback, we subtracted the mean amplitude for the late feedback from the average amplitude of correct feedback at channel Cz.

Correlations between ERP indexes and the rest of measures taken in the study showed a positive relation between ERP_{i-c} and the impulsivity score ($r = .41$; $p<.05$) and as well as with the RT conflict score ($r = .68$; $p<.01$) and these relation were maintained after controlling by age ($r = .46$; $p<.05$) and ($r = .74$; $p<.001$) respectively. Also, the ERP_{i-c} was negatively related to the percentage of delay choices for oneself (DS) at Delay of Gratification task both not controlling ($r = -.45$; $p<.01$), as well as controlling by age ($r = -.36$; $p<.05$). Both ERN and Pe indexes were negatively related to impulsivity only when controlling by age ($r = -.27$; $p<.05$, and $r = -.32$; $p<.05$, respectively). Significant positive correlations were also found between ERN and percentage of delay choices for oneself ($r = .36$; $p<.05$) and for others ($r = .34$; $p<.05$) in the Delay of Gratification task before controlling by age. Finally, we obtained a statistically significant correlation between ERPs and temperamental factor showed a statistically significant correlations were found between ERP_{i-c} and Negative Affect in adults ($r = .72$; $p<.01$).

DISCUSSION

The aim of the current study was to investigate the developmental trajectory of error and conflict processing, as part of executive attention functions and its relation to self-regulation. We used a child-friendly flanker task intended to provide the same level of difficulty for all participants at all ages. We achieved our purpose because children and adults did not differ in the percentage of errors committed during performance of the flanker task (see Figure 4). However, 4- 7 years group shows increased difficulty compared to adults and 10-13 years group in dealing with distracting information in incongruent stimulation. The greater difficulty for younger children was reflected in children's longer conflict effect (RT in incongruent trials minus RT in congruent trials). Our data also indicate that the RT of error responses compared to correct responses, a RT difference considered an index of impulsivity (Pailing, et al., 2002) was shorter in adults than in all groups of children (see Figure 5). Moreover, the children groups also differ between them. Middle age children (7-10 and 10-13 years old group) were less impulsive than younger ones (4-7 years-old group). These data indicate a progressive increase in the efficiency with which individual deal with conflict as well as in the ability to suppress preponderant or impulsive responses with age.

The results of the adults and children ERPs related to conflict monitoring observed in our study are similar to those obtained in previous studies using a similar paradigm (Rueda et al, 2004). We found that the manipulation of the congruency between relevant and distracting information produced effects in the ERPs elicited by the target. All groups of children and adults show an effect of congruency in the ERPs (ERP_{i-c}) over frontal leads, although several differences were observed (see Figure 6). First, in adults the ERP_{i-c} emerges at around 350 ms post-target; while in children this effect appears later, around 450 ms post-target in the 10-13 years-old group and around 500ms post-target in the 4-7 and 7-10 years-old groups. The difference in latency between children and adults suggests that children need more time to process the conflict. The second difference is that the effect is sustained for 100 ms in adults while in children it is sustained for about 200 ms. The observed difference may be suggesting that the maturational process reduces the time that the executive attention network needs to be engaged in order to resolve the conflict induced by the competing information. The third difference has to do with the distribution of the ERP_{i-c}. In adults this effect appears at midline leads, around the Cz channel, while the effect in children is observed in more anterior sites, around channel Fcz. We suggest that adults and children could be recruiting the same brain circuit to resolve conflict but it is less focal and refined in children compared to adults, as shown by prior studies using imaging methods with better anatomical resolution (Bunge, et al., 2002; Durston, et al., 2002). We also suggest that the brain circuit underlying conflict resolution involved the medial frontal gyrus in the frontal lobe (BA 10), as indicated by the source location analysis of the ERP_{i-c} in adult's. This area is part of the executive attention network in Posner's neurocognitive model (Posner & Pertersen, 1990)

Regarding the ERPs components related to error monitoring, we found that adults and 10-13 years old elicited a negative deflection after errors responses (ERN), while younger groups (4-7 and 7-10 years old) did not show the ERN effect. However, the distribution of the ERN is somewhat different between adults and the 10-13 years-old group. Although the ERN is frontally distributed for both children and adults, the 10-13 years-old group showed the ERN in fronto-anterior position (Fcz) while adults showed the ERN at both Fcz and Cz positions. We interpret this result as indicative of a difference in the ability to effectively recruit areas implicated in the error processing. A recent study Velona et al (2008) has reported that dACC showed increased and extended modulation for error vs. correct response in adults, which, in children (between 8 and 12 years old) and adolescents (between 13 and 17 years old) was significantly attenuated. The authors suggest that functional changes in dACC associated with errors regulation coupled with changes in the recruitment of "long-range" attentional network, underlie age-related improvements in performance. Moreover, no developmental changes in the magnitude of the Pe were observed. The Pe was shown in all age groups, even those not showing the ERN effect. Some studies using dipole modelling show that the ERN is generated by brain regions different from those that generate the Pe (Herrmann, et al., 2004; van Veen & Carter, 2002a). We suggest that the later maturation of the ERN effect compared to the Pe effect, may be due to differences in the maturation course of underlying brain regions. Our source modeling of the ERN and Pe in adults' data (see Figure 7) show that the ERN is generated in the medial frontal gyrus (BA10) and the dorsal part of the anterior cingulate cortex (BA24), while the Pe is generated in somewhat different regions of the frontal lobe: BA6-BA8 and BA32 (dACC). These findings suggest that the Pe may be at least partially generated in more posterior brain regions, which may explain why young children display a Pe and not a more frontally generated ERN. Also, the results suggest that children may be aware of the error and may be process error information at a later stage of the error processing, the one captured by the Pe. However, the absence of the ERN could indicate that children may not be using the frontal brain regions, as adults are, to process the same error information.

Moreover, in relation to the feedback-locked ERPs, we found a larger positive peak for late compared to correct feedback (P_{fdb} effect). This P_{fdb} component could be considered as a P300, which in previous studies has been shown to be sensitive to expectancy violations (Jonhson, 1980; Hajckack, 2007, 2005; Wu, 2009). The P_{fdb} as well as the P300 component could reflect the mental evaluation of surprising, "unexpected" but relevant events (Donchin, 1981; Donchin & Coles, 1988)).This hypothesis is consistent with different studies (Tenke, 2010; Luu; 2009) and with the source modeling in the present study (see Figure 8) which has shown that novelty P300 have been localized to the midline fronto-central region. We also found the P_{fdb} in all age groups which may suggest that forming rule-related expectancies and detecting the violations are developed early in the life. This idea is consistent with behavioral studies showing that infants look longer at unexpected events than expected ones (Wynn, 1992; Berger,Tzur & Posner 2006). The P_{fdb} shown in children could be interpreted as the evidence of control processes, suggesting that very early in the life the anatomy of the executive attention system is at least partly functional.

Another aim of the study was to investigate the relation between conflict and error processing and self-regulation. We believe that mechanisms of attention are very relevant to the development of self-regulatory skills. Also, we conceive executive attention and the temperamental factor of Effortful Control as two concepts representing different levels of analysis of the ability to exercise control over one's behaviour. Numerous empirical data (Gerardi-Caulton, 2000; Rueda, Posner, & Rothbart, 2004) together with the data of the present study support the connection between executive attention (which efficiency is indicated by the conflict score) and the temperamental factor of Effortful Control. In addition, we found a consistent pattern of correlation between the electrophysiological index of conflict ($ERP_{i\text{-}c}$) and error processing (ERN and Pe) and self-regulatory behaviors. Our data show that the $ERP_{i\text{-}c}$ amplitude effect is positively related to Negative Affect as well as, RT conflict and impulsivity scores. Moreover, the ERN and Pe are negatively associated to impulsivity scores. This finding is consistent with the role of the executive attention network in the Posner's model. One of the main nodes of this network, the anterior cingulate cortex (ACC), is involved in controlling cognitive and affectively-relevant information. The relationships found in our study indicate that the efficiency of the ACC in conflict tasks in the laboratory is in fact related to the ability of individuals exercising control over negative emotion and controlling behaviour (Posner, Rothbart, Shesse, & Tang, 2007). Interestedly, we found a relation between delay choice in the Delay of Gratification task performed by children and the $ERP_{i\text{-}c}$ and ERN effect. This data indicate that better efficiency of the executive attention network contribute to displaying more regulated behaviours when it comes to make affective decisions.

Conclusion

In this study, we provide evidence about the development of executive attention examining conflict and error processing, and its relation to self-regulation. The capacity to deal with distracting information seems to appear earlier than the capacity to process the error information in the development. However, compared to adult, children need more time to resolve conflict and they might not effectively recruit the brain regions involved in conflict resolution as effectively as adults. Moreover, the ability to process error is partially functional in younger children, as shown by the presence of the Pe even in the youngest group in our study. But the complete processing of the error might not be acquired until adolescence (ERN). This may be related to the relatively late maturation of the PFC and the ACC (Davies, et al., 2004a; Segalowitz, Unsal, & Dywan, 1992). Moreover, better efficiency of the executive attentional network in all ages is related to more regulated behaviours. These data indicate that patterns of brain activation that show better efficiency of executive attention is also reflected in better cognitive ability to control behaviour and affective decisions.

CHAPTER III

NEUROCOGNITIVE AND TEMPERAMENTAL SYSTEMS OF SELF-REGULATION AND EARLY ADOLESCENTS' SOCIAL AND ACADEMIC OUTCOMES

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ABSTRACT

Both efficiency of neurocognitive systems of attention and individual differences in reactivity and effortful control are related to the ability to self-regulate behaviour. The aim of the current study was to examine the role of individual differences in neurocognitive and temperamental systems of regulation in early adolescents' social and academic competence. Measures of attentional and temperamental systems of self-regulation included the Attention Network Test (ANT) (Fan, McCandliss, Sommer, Raz, & Posner, 2002) and the Early Adolescence Temperament Questionnaire (EATQ-R: Ellis & Rothbart, 2001). Social and academic aspects of school competence were examined using a peer-reported Social Status Questionnaire, a self-reported measure of Schooling Skills (HRI: Juvonen & Keogh, 1992) and information on grades obtained by the students in a variety of school subjects. Sixty-nine 12 year-old students and their families participated in this study. Our results showed that efficiency of the executive attention network is related to academic outcomes, particularly in mathematics, as well as to some aspects of social adjustment such as control of aggression in the classroom. In addition, effortful control, the more temperamental dimension of self-regulation, appears to be a significant predictor of all dimensions of school competence examined in the study. Moreover, results indicate that the relationship between social adjustment and poor schooling outcomes is mediated by temperamental effortful control. These data suggest that individual differences in systems of self-regulation are central to understanding processes of learning and social adjustment in the school context.

INTRODUCTION

Individual differences in attentional control and temperamental characteristics largely contribute to the ability to regulate one's own desires and impulses, important for accomplishing goals, following instructions and complying with social norms. In Psychology, the concept of self-regulation refers to those processes by which people exercise control over their emotional and behavioral responses in order to accomplish their own goals and/or to adapt to the cognitive and social demands of specific situations (Thompson, 1994; Kopp, 1992). It involves controlling reactions to stress, maintaining focused attention, and interpreting mental states in themselves and others (Fonagy & Target, 2002). The emergence of self-regulation during early childhood seems to provide the basis for developing competencies leading to successful socio-emotional adjustment. For example, individual differences in self-regulation have been related to social competence, emotionality, compliance, moral development, empathy and adjustment as well as cognitive and academic performance (Eisenberg, Smith, Sadovsky, & Spinrad, 2004). Therefore, individual differences influencing the ability to self-regulate seem central to understanding the processes involved in both social adaptation and the deployment of skills necessary for achieving success at the school context. Examining the influence of cognitive as well as temperamental variables contributing to self-regulation and school competencies during the transition between childhood and adolescence is the goal of the current study.

Attentional and temperamental contributions to self-regulation

Attention is viewed by many authors as an important part of the larger construct of self-regulation (Posner & Rothbart, 1998; Posner & Rothbart, 2000; Ruff & Rothbart, 1996). Selecting information and controlling thoughts and actions have been a major function of attention from the earliest theoretical models (James, 1890). Orienting attention and selecting the object or location to attend to is necessary for carrying out desired actions. Likewise, attention can be directed internally to allow coordination of memories, thoughts, emotions and actions.

Within the approach of Cognitive Neuroscience, data have supported the presence of three brain networks related to different aspects of attention. These networks carry out the functions of alerting, orienting and executive control (Posner, Rueda & Kanske, 2007). Alerting is defined as achieving and maintaining a state of high sensitivity to incoming stimuli, and has been associated with frontal and parietal regions of the right hemisphere. Orienting refers to the selection of information from sensory input. The orienting system for visual events has been associated with posterior brain areas, including the superior parietal lobe, the temporal parietal junction and the frontal eye fields. Finally, executive attention involves the mechanisms for consciously monitoring and resolving conflict among thoughts, feelings, and responses. It is related to action coordination in novel or dangerous situations, detecting and correcting errors and overcoming habitual (or automatic) responses (Posner & DiGirolamo, 1998). The brain network associated with this function includes areas of the frontal midline, the anterior cingulate cortex, and lateral prefrontal cortex.

The executive attention network is the network most directly involved in cognitive and affective regulation (Bush, et al., 2000). One of the main nodes of the executive attention network, the anterior cingulate gyrus, is consistently activated by situations requiring the regulation of induced emotions. For example, a study using functional Magnetic Resonance Imaging (fMRI) found anterior cingulate activity to be related to the instruction to regulate arousal resulting from exposure to erotic films (Beauregard, Levesque & Bourgoulin, 2001). In a different study, cognitive reappraisal of photographs producing negative affect showed a correlation between extent of cingulate activity and the reduction in negative affect (Ochsner, Bunge, Gross & Gabrieli, 2002). Moreover, the extent of activation of the executive network has been related to regulation of cognitive processes involved in memory (Anderson & Green, 2001; Anderson, et al., 2004) and other cognitive demands such as perception, response selection, working memory and problem solving (Duncan & Owen, 2000). Tasks used to measure the function of this network usually involve resolving conflict between incompatible responses or inhibiting a dominant response in favor of a less salient one. For example, in the flanker task, individuals are asked to respond to a stimulus surrounded by other stimuli that suggest a response that is either compatible or incompatible with the correct response (Eriksen & Eriksen, 1974). The degree of interference experienced by incompatible information, as measured by reaction time and/or response accuracy, is used as an index of the efficiency of the executive attention network.

Understanding individual differences in the efficiency of these regulatory systems from infancy to adulthood has been undertaken in studies of temperament. Temperament is defined as constitutionally-based individual differences in reactivity and regulation in emotion, activity, and attention (Rothbart & Bates, 2006). Research in the past years has come to identify three broad dimensions that characterize temperament during childhood and adolescence (Rothbart, 2007; Rothbart & Bates, 2006), namely, Extraversion/Surgency (E/S), Negative Affect (NA) and Effortful Control

(EC). The first two dimensions describe individual differences in approach/avoidance reactivity and are related to the personality factors of Extraversion and Neuroticism, respectively. The third dimension, EC, is related to the personality trait of Conscientiousness and describes individual differences in attentional control and the flexible regulation of behavior, such as choosing a particular action under conflicting conditions, detecting errors and planning (Rothbart & Rueda, 2005). Several studies have established connections between activation of brain networks and temperamental characteristics related to reactivity and regulation. Reactive temperament has been related to functioning of the amygdala and dopamine systems, respectively for NA and E/S (Rothbart & Posner, 2006), whereas the executive attention network is viewed as the neural substrate supporting EC (Rothbart & Rueda, 2005; Rueda, Posner, & Rothbart, 2005).

Both reactive and regulative aspects of temperament, as well as the interactions between them, are involved in socialization and socio-emotional regulation. For instance, during childhood, EC appear to be negatively associated with the incidence of externalizing behavioral problems, which are characterized by high levels of aggression and impulsivity, after controlling for other cognitive and social risk factors (Olson, et al., 2005; Valiente, et al., 2003). In a recent study, Oldehinkel et al examined the temperamental profiles of preadolescents with and without behavioral problems. They found that individuals exhibiting externalizing problems showed higher scores on E/S and frustration, and lower rates of EC, while individuals showing internalizing problems were high on fear and shyness and moderately low on EC (Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004). Other studies have also shown that both mother and self-reported low EC together with poor efficiency of executive attention, appear to be consistent predictors of behavior problems during adolescence (Ellis, Rothbart, & Posner, 2004). In addition, research by Kochanska and collaborators has shown that two temperamental systems, one affective (fear) and one attentional (EC), influence the development of conscience (Grazyna Kochanska, Aksan, & Joy, 2007; Grazyna Kochanska, Murray, & Harlan, 2000). In turn, conscience is seen as an internally driven system supporting efforts to self-regulate emotions and actions (Grazyna Kochanska & Aksan, 2006). Fear might provide the reactive inhibitory component of regulation through emotions such as guilt, whereas EC would provide the cognitive flexibility needed to detect those feelings of distress and link them to moral values and actions.

Self-regulation and school competence

Differences among individuals positively contribute to society in general and this can be extended to the micro-society of the classroom. The ways in which children differ from one another affect their willingness to explore and learn as well as their discouragement, frustration, and avoidance of potential sources of knowledge (Rothbart & Jones, 1998). Hence, due to variations in reactivity and attentional control, children may differ in their adjustment to the requirements and challenges of the educational setting. In turn, this adjustment process seems to influence more specific aspects of social development such as self-esteem and relationships with peers, parents and teachers (Sanson, Hemphill, & Smart, 2004).

Negative emotionality and low EC have been consistently linked to problems with adjustment at school from a relatively young age (Nelson, et al., 1999). Teacher-rated higher levels of aggression and anxiety in kindergarten appear to be related to poorer achievement through a relation with lack of cognitive self-control in school tasks (Normandeau & Guay, 1998). Moreover, measures of EC in children show a positive association with academic outcomes, especially mathematics (Blair & Razza, 2007), although this relationship seems to be mediated by school liking (Valiente, Lemery-Chalfant, & Castro, 2007).

The role of attention in cognitive and affective regulation suggests that this function would also be a relevant contributor to school competence. In line with this, measures tapping the executive attention network, such as Stroop-like interference and performance on inhibitory control tasks, also show a consistent relationship with arithmetic competency after controlling for age, intelligence and maternal education (Blair & Razza, 2007; Bull & Scerif, 2001; Espy, et al., 2004). In addition, there is some evidence indicating that children's attention is associated with adjustment to the school context. Raver and colleagues showed that preschoolers who use more attentional strategies during a delay task are rated by their teachers as higher in social competence, and peers tended to rate them as popular rather than rejected or neglected (Raver, et al., 1999). Eisenberg, Guthrie, and colleagues (1997) also found an association between teachers' and parents' reports of elementary school children attentional control and peer nominations for social status.

Aim of the study

The current study aims at examining the interrelations between efficiency of attentional networks and temperament in early adolescents, and to determine the contribution of the different cognitive and temperamental systems to social and academic aspects of school competence during that age period. We view school competence as an aggregate of social adjustment to the educational context and academic achievement. Therefore, in the present study, we will be considering measures assessing these two aspects of school competence.

To examine attention, we follow Posner's neurocognitive approach as previously described. Posner and collaborators have recently developed a computer task aimed to measure the functions of alerting, orienting and executive control, the Attention Network Task (Fan, et al., 2002). This task provides scores related to the efficiency of each of the attentional networks. Probing the validity of this task, imaging of brain activation during performance of the ANT has shown that performance of this task differentially activates the three anatomical networks related to the components of attention in Posner's model (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). In light of the theoretical and empirical link between EC and executive attention (Rueda, Posner, & Rothbart, 2004), we expected that questionnaire-reported measures of EC would be chiefly related to efficiency of the executive component of attention.

Based on prior work showing a consistent association between temperamental systems of negative affectivity and regulation and school adjustment during childhood, we anticipated that this association would continue to be present during early adolescence. However, given the central role of systems of EC and executive attention on self-regulation, we expected these two measures to be the strongest predictors of social adjustment and academic performance.

Finally, we aimed at exploring the interrelation between social adjustment at the school and academic outcomes. Adolescence has long been characterized as a time of heightened emotional reactivity and poor self-control. In the transition between childhood and adolescence, relationships with peers acquire a central role in the process of socio-emotional development. Considering prior evidence suggesting that processes of peer rejection lead to decreases in classroom participation and to lower rates of achievement in childhood (Buhs, Ladd, & Herald, 2006), we expected peer reported evaluations of social status to be related to academic competence in our study. However, we also anticipated individual differences in self-regulation to play an important role in the association between maladjustment and competence at school.

METHOD

PARTICIPANTS

A total of 69 children (mean age: 12.7 years; 34 boys and 35 girls) enrolled at "Padre Manjón" High School in Granada (Spain) and their parents participated in the study. Participants were recruited through a mailed letter addressed to their families informing them about the general purpose of the study. The caregivers of all participants gave written consent to be involved in the study. All participants were Caucasian-European except one girl and one boy who were Hispanic, and one girl who was African.

PROCEDURE

Children completed three different questionnaires in two separate 50-minutes sessions. Participants responded to the questionnaires individually while in class with their usual classmates (approximately 30 students). During the first session, children completed the Early Adolescence Temperament Questionnaire and a questionnaire measuring schooling skills, the Health Resources Inventory. In the second session, they completed a questionnaire regarding the social interactions they experience with their classmates, the Peer-reported Social Status measure. In a third session, children performed a modified version of the ANT. This task was administered in a computer room at the school simultaneously for groups of 10 to 12 children. The standardized instructions to complete the task were given collectively for each group, and then the task was completed individually by each child in a computer assigned to him/her. Sufficient separation between participants was allowed to avoid children interfering with each other's completion of the task. The parent-report version of the EATQ was send to the parents of all children participating in the study with instructions for completing it and returning it to the school with their child in a sealed envelope. Finally, the high school board provided information on grades obtained at the end of the academic year by the students involved in the study.

MEASURES

Attention Network Task (ANT)

A modified version of the Fan et al. (2002) adult ANT was used. In this task, each trial starts with the presentation of a fixation point; its duration is randomly selected ranging between 400 and 1600 ms. After completion of fixation, a 50 ms duration slide is presented accompanied by an auditory tone of 2000 Hz (alerting cue) in half the trials (no tone was presented in the other half). After a blank interval of 400 ms, an orienting cue consisting of an asterisk is presented on 2/3 of the trials for 50 ms (in the other 1/3 of the trials no cue was presented). Finally, a target stimulus is presented consisting of an arrow pointing either right or left. The target is flanked by four other arrows, two on each side. In half of the trials, the flanking arrows point in the same direction as the target arrow (congruent trials), or in the other half, in the opposite direction (incongruent trials). The target could appear either above or below the fixation point (which remain on display through the entire trial). When presented, the orienting cue appears with equal probability either at the same location as the target (cued trials) or at the opposite location (uncued trials). Participants are instructed to discriminate the direction of the target arrow by pressing a corresponding key, left or right, in the computer's keyboard as rapidly and accurately as possible. The alerting score is obtained by subtracting the average reaction time (RT) of trials in which the alerting tone is presented from that of trials in which there was no alerting tone. This provides a measure of the benefit in performance by having information about the immediate upcoming target, using this information to get ready to respond. The orienting score is calculated by subtracting the average RT of cued trials from the average RT of uncued trials. This subtraction provides a measure of how much benefit is obtained in responding when information is given about the location of the target, allowing orienting of attention to that location prior to the presentation of the target. Finally, the executive attention score is calculated by subtracting the RT averaged across congruent trials from the average RT for incongruent trials. This score indicates of the amount of interference experienced in performing the task when stimulation conflicting with the target is presented in the display. Larger interference scores indicate less efficiency of conflict resolution mechanisms (executive attention).

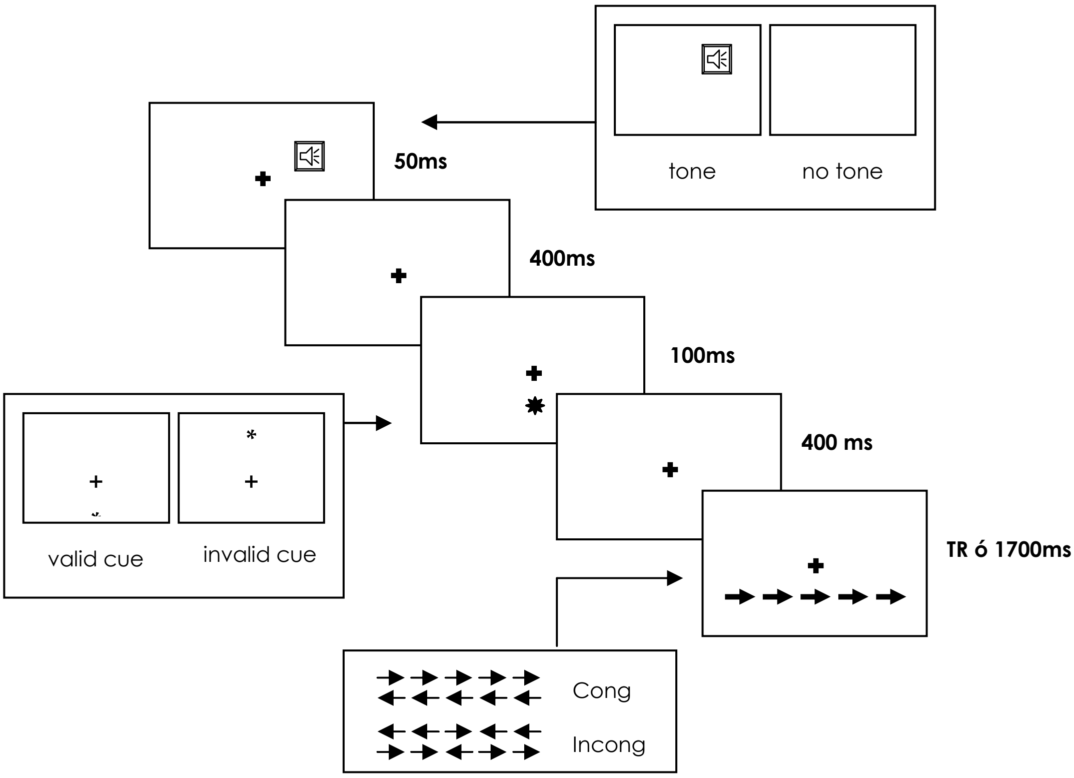

Figure 9. Schematics representation of the Attention Network Test (ANT) modified by Callejas et al. (2004). The modified ANT was structurally similar to the original ANT, except that it presents the alerting and orienting cues in separate displays in order to be able to assess interactions between these two networks

Temperament Questionnaires

Self-report and parent-report versions of the Early Adolescence Temperament Questionnaire – Revised (EATQ–R; Ellis & Rothbarth, 2001) translated into Spanish were used to measure children's temperament. These questionnaires contain 65 items (self-report) or 62 items (parent-report) describing adolescents behavior in a variety of everyday life situations related to different temperamental dimensions or scales. Participants' answers indicated the extent to which a given list of behaviors applied either to them (self-report) or their child (parent-report). The EATQ-R collects information about four broad factors of children's temperament: Effortful Control (EC), Extraversion/Surgency (E/S), Negative Affect (NA) and Affiliation (AF). The scales loading on the factor EC are Activation Control, Attention and Inhibitory Control. The scales loading on the E/S factor are High-intensity Pleasure, Fear and Shyness. Aggression, Depressive Mood, and Frustration, load on the NA factor. Finally, the AF factor is equivalent to the Affiliation scale in the parent-report version. Affiliation, Perceptual sensitivity and Pleasure sensitivity load on the AF factor in the self-report version. The definitions of the temperament scales and sample items for each are presented in the Appendix. The internal reliability (measured by Cronbach's alpha) of the EATQ-R factors calculated in our sample were the following: EC, α = .84; AF, α = .73; E/S, α = .42: NA, α = .63, for the parent-report questionnaire; and EC, α = .71; AF, α = .41; E/S, α = 52.; NA, α = .51, for the self-report measures.

Schooling skills

Information on schooling skills was obtained from each participant using the student-report version of the Health Resources Inventory (HRI; Juvonen and Keogh, 1992). The HRI consists of 31 items which group onto four factors: Rules Following (RF, Cronbach's α = .80), Student-role Understanding (SrU, α = .76), Sociability (SO, α = .64) and Tolerance to Frustration (TF, α = .60). The RF factor reflects the student ability to function within the constraints of the school environment. Sample items for this factor are "I am well-behaved in school" and "I am considerate and polite with others ". The SrU factor describes behavior associated with effective learning such as individuals' understanding of the duties and responsibilities of students (e.g. "I am interested in school work" and "My homework is original"). The SO factor consists of items reflecting effective interpersonal functioning (e.g. "I have many friends" or "My classmates are fond of me"). The factor TF measures the individual ability to cope with failure and other social pressures (e.g. "I can accept things not going my way" and "I face my mistakes"). All items in the self-report HRI questionnaire are responded on a 5- point Likert scale ranging from never to always each particular sentence is true of me.

Peer-reported Social Status

Information about Social Status was obtained for each participant using a peer-report questionnaire containing 6 questions. The first 4 questions are about naming 3 classmates who are 1) Good to work with, 2) Not good to work with, 3) Good to spend free time with, and 4) Not good to spend free time with. In question 5, students are asked to name classmates (one nomination per statement) who are characterized by a series of statements including a) having a lot of friends; b) not having a lot of friends; c) having a good relationship with teachers; d) not having a good relationship with teachers; e) being a nice classmate; f) not being a nice classmate; g) being able to pay attention and listen to others; h) often calling others attention; i) having skills to solve social conflicts; j) being aggressive; k) having communication skills; l) having troubles in communicating with others; m) sharing his/her success with others; and n) being an envious person (see Appendix 2). The factorial analysis of question 5 provided

3 different factors. The first factor which explained the 29.5% of the variance, was called "Appreciated" because all the items loading on it (a, c, e, g, i and k; α = .85) were about peers positive social evaluations. A second factor that explained 16% of the variance was labeled "Rejected" because the items loading on it (b,f, and n; α = .75) implied a lack of social acceptation from peers. The factor analysis showed a third factor which explained the 19% of the variance. The third factor was called "Unsocial" because it involved items related to behaviors that were not socially valued (d, j, h and l; α = .94). Finally, in the last question of the Social Status Questionnaire children rated how they got along with each one of their classmates scoring each of them from 1 (very well) to 5 (very bad).

Academic outcomes

The high school board provided information on grades obtained at the end of the academic year by each student involved in the study. Grades range from 0 to 10 points. The subjects included are shown in Table 4.

Missing data

Data on all measures included in the study were not available for the entire sample. The valid n for each measure is provided in Table 4. Sixteen parents refused to complete the temperament questionnaire. Two children did not complete the HRI questionnaire because they were absent during the testing session. Finally, only 46 families consented to their child completing the Peer-reported Social Status questionnaire.

RESULTS

Descriptive statistics on all measures are presented in Table 4.

Table 4. Descriptive statistics on all measures

		Valid n	Mean	Min	Max	SD
ATTENTION (ANT scores)	Alerting (ALRT)	67	14.5	-.41	78	22
	Orienting (ORRT)	67	63.7	-3.5	157	27
	Executive Attention (EXRT)	67	107	20	3175	46
	Executive Attention (% errors; EXER)	67	4.8	-1	48	7
TEMPERAMENT (EATQ Self-report)	Effortful Control (EC_S)	69	3.6	2.5	4.9	0.6
	Extraversion/Surgency (E/S_S)	69	3.6	1.97	4.8	0.6
	Negative Affect (NA_S)	69	2.7	1.4	3.6	0.5
TEMPERAMENT (EATQ Parent-report)	Effortful Control (EC_P)	53	3.3	1.7	4.8	0.67
	Affiliation (AF_P)	53	2.75	1.8	3.9	0.46
	Negative Affect (NA_P)	53	2.98	2.3	3.6	0.34
SCHOOLING SKILLS (HRI Self-report)	Rule Following (RF)	67	3.9	2.2	4.9	0.61
	Student-role Understanding (SrU)	67	4.1	2.4	5	0.59
	Sociability (SO)	67	4.3	2.4	5	0.61
	Tolerance to Frustration (TF)	67	3.8	2.2	5	0.68
ACADEMIC ACHIEVEMENT (Grades)	Nature Science (NS)	69	5.8	1.5	10	2.3
	Social Science (SS)	69	5.8	1	10	2.3
	Physical Education (PE)	69	5.7	2.5	9.5	1.6
	Native Language (NL)	69	6.1	2	9.5	1.8
	Foreign Language (FL)	69	5.9	1	10	2.1
	Mathematic (MA)	69	5.7	1.5	9	1.9
	Music (MU)	69	5.8	1	10	2.3
	Technology/Mechanical Science: (TM)	69	5.7	0.5	9.5	2.1
SOCIAL STATUS (Peer-reported)	Good to work with (GW)	46	3	0	8	2.2
	Not good to work with (NGW)	46	3.1	0	21	3.7
	Good to spend free time with (GFT)	46	2.6	0	10	2
	Not Good to spend free time with (NGFT)	46	2.5	0	20	3.7
	Appreciated (AP)	46	0.77	0	7.3	1.1
	Rejected (RJ)	46	0.60	0	10.3	1.8
	Unsocial (US)	46	0.60	0	8.7	1.3
	Mean score of social appreciation (mSA)	45	4.23	1.57	3.26	0.66

Note: ANT scores are expressed in milliseconds. Between parentheses appear the abbreviations of the variables names that will be used in subsequent tables and figures

ANALYSIS OF THE ANT

Data from two children were not included in the analysis of this task due to technical problems during task completion. With the rest of the data, separate 2 (Alerting tone vs no tone) x 2 (Orienting valid cued vs invalid cued) x 2 (Executive Attention congruent vs incongruent) repeated measures ANOVA were conducted with the mean of median RTs and percentage of errors per condition. For the RT analysis, the three main effects were statistically significant: Alerting ($F(1,66)=6.2$; $p<.01$), indicating faster responses for trials with tone compared to no-tone; Orienting ($F(1,66)=355$; $p<.001$), indicating faster responses in cued trials than in uncued trials; and Executive Attention ($F(1,66)=342$; $p<.001$), indicating faster responses in congruent trials than incongruent trials. A significant interaction was found between Alerting and Orienting ($F(1,66)= 5.2$; $p<.05$), indicating that the orienting effect (difference between uncued and cue trials) was larger for tone trials than no tone trials. A significant interaction was also found between Orienting and Executive Attention ($F(1,66)=18.8$; $p<.001$) indicating that the congruency effect (difference between congruent and incongruent trials) was larger for uncued trials compared to cued trials. None of the other possible interactions were found to be significant ($F<1$). For the ANOVA with error percentage as the dependent variable, the only statistically significant main effect was that of Executive Attention ($F(1,66)= 26.7$; $p<.001$), indicating fewer percent errors in congruent trials compared to incongruent trials. None of the interactions were found significant in this analysis. Scores for each of the attention networks were calculated for each participant according to the subtractions described in the previous section using median RTs. Since the main effect of Executive Attention was significant in the accuracy ANOVA, we also calculated the score for this network using the percentage of errors.

CORRELATION ANALYSIS

Correlations between attention and temperament measures

Pearson's unilateral correlations were calculated between the ANT scores and measures of the EATQ-R factors (see Table 5). Statistically significant correlations were found between the Executive Attention score as measured with reaction time (EX_{RT}) and parent-reported Effortful Control (EC), and between the Executive Attention score as measured by percentage of errors (EX_{ER}) and self-reported E/S. The alerting score correlated positively with self-reported EC and negatively with self-reported NA. Finally, the orienting score correlated negatively with self-reported NA.

Table 5. Correlations between attention and temperament measures

		Parent-reported EATQ-r			Self-reported EATQ-r		
		EC_P	AF_P	NA_P	EC_S	E/S_S	NA_S
ANT scores	Executive Attention	-.25*	-.06	.09	-.01	.004	-.14
	Executive Attention	-.21	.07	.17	-.12	-.24*	.002
	Alerting TR	-.06	-.08	-.01	.32*	.16	-.28*
	Orienting TR	.002	-.027	-.006	.04	-.18	-.18

EC: Effortful Control; AF: Affiliation; E/S: Extraversion/Surgency; NA: Negative affect; Suffix p indicates parent-reported; Suffix s indicates self-reported* p<.05

Correlations between attention and temperament and school competence measures

Pearson's correlations indicated significant correlations between RT and accuracy EX scores and grades in mathematics, and also with peer reports of not being good to spend free time with. The EX_{ER} score was also correlated with the mean of all grades. The alerting scores were correlated with the Sociability factor of the Schooling Skills assessment. In addition, significant correlations were found between parent and self-reported EC and grades as well as all Schooling Skills factors. Parent-reported EC was also positively related to peer reports of Appreciated and mean scores of social appreciation. A significant correlation was found between parent and self-reported Negative Affect (NA) and all measures of Schooling Skills except Tolerance to Frustration (TF). In addition, parent-reported NA was negatively correlated with mathematics as well as with the mean of all grades. We also found statistically significant correlations between parent-reported NA and the social measures of rejection (+) and mean of social appreciation (-) as well as peer nomination of being "good to work with" (-) and "not good to spend free time with" (+). Parent-reported Affiliation (AF) was correlated with grades in mathematics, and with peer nomination of being "good to work with" and the general measure of social appreciation. Finally, peer-reported Unsocial behavior was correlated positively with self-reported E/S and the EX score, as measured by reaction time, and negatively with parent-reported EC. These correlations are shown in Table 6.

Table 6. Correlations between attention and temperament measures and measures of school competence

		Grades		Schooling Skills					Social Status							
		Math	All	RF	SrU	SO	TF	All	GW	NGW	GFT	NGFT	AP	US	RJ	mSA
ATTENTION (ANT scores)	EXTR	-.28*	-.17	-.07	.07	.16	-.06	.03	-.09	.18	.10	.25*	-.04	.30*	.19	-.04
	EXER	-.23*	-.28*	.13	-.04	-.13	-.02	-.02	-.14	.02	.001	.07	-.05	-.10	.06	.02
	ALTR	-.07	-.05	.03	.03	.25*	.15	.15	.14	.04	.03	-.04	.01	-.09	.04	-.13
	ORTR	.13	.09	-.09	-.22*	-.05	-.16	-.17	.02	.04	.08	.07	.03	-.12	.10	.06
EATQ-r Self report	ECs	.30**	.32**	.37**	.84**	.29**	.34**	.45**	.14	-.09	-.14	-.18	.20	-.12	-.10	-.03
	E/Ss	-.09	-.18	-.15	.03	.10	-.04	-.02	-.11	-.004	.07	.05	-.10	.26*	-.04	-.17
	NAs	-.14	-.16	-.32**	-.33**	-.27*	-.29**	-.39**	.08	-.06	.12	-.07	-.05	.23	-.12	.29*
EATQ-r Parent-report	ECp	.58**	.65**	.39**	.44**	.32*	.29*	.45**	.23	-.01	-.30	-.21	.45**	-.37*	-.06	.33*
	AFp	.32*	.21	.06	.21	.15	.04	.15	.37*	-.15	.03	-.15	.38*	-.12	.05	.03
	NAp	-.28*	-.30*	-.24*	-.23*	-.29*	-.09	-.27*	-.35*	.29	.15	.50**	-.26	.26	.33*	-.40*

EX: Executive attention; AL: Alerting; OR: Orienting; EC: Effortful Control; AF: Affiliation; E/S: Extraversion/Surgency; NA: Negative affect; Suffix p indicates parent-reported; Suffix s indicates self-reported. RF: Rule following; SrU: Student-role Understanding; SO: Sociability; TF: Tolerance to Frustration; GW: Good to work with; NGW: Not good to work with; GFT: Good to spend free time; NGFT: Not good to spend free time; AP: Appreciated; US: Unsocial; RJ: Rejected; mSA: mean scores of Social Appreciation.
** $p<.01$; * $p<.05$

Correlations among school competence and social status measures

As can be observed in Table 7, academic achievement in general and grades in mathematics were positively correlated with all Schooling Skills factors, except for the correlation between mathematics and sociability, which was not significant. Grades were also positively correlated with peer-reported appreciation and peer nominations of being "good to work with", but negatively correlated with nominations of being "not good to spend the free time with" and the aggressiveness score. Moreover, significant correlations were found between several measures of Schooling skills and Social Status measures. Peer nominations of being "good to work with" and "not good to spend free time with" were correlated with rule following. We also found a correlation between peer-reported levels of appreciation and scores of Student-role Understanding and Sociability. Finally, peer-reported Unsocial behavior was negatively correlated with the HRI scores of the Rule Following and Tolerance to Frustration factors.

Table 7. Correlations among measures of school competence

		Grades		Schooling Skills					Social Status						
		Math	All	RF	SrU	SO	TF	All	GW	NGW	GFT	NGFT	AP	US	RJ
Grades	Math	--													
	All grades	.87**	--												
Schooling Skills	RF	.38**	.48**	--											
	SrU	.24*	.38**	.71**	--										
	SO	.004	.20*	.37**	.57**	--									
	TF	.29*	.28*	.49**	.40**	.34**	--								
	All skills	.29*	.43*	.82**	.85**	.72**	.73**	--							
Social Status	GW	.48**	.50**	.29*	.21	.19	-.02	.21	--						
	NGW	-.17	-.15	-.05	-.05	-.03	-.01	-.05	-.24	--					
	GFT	.18	.03	-.11	-.15	-.01	.02	-.08	.35**	-.21	--				
	NGFT	-.33*	-.37**	-.28*	-.21	-.20	-.12	-.26*	-.55**	.79**	-.02	--			
	AP	.39**	.46**	.19	.30*	.35*	.17	.32*	.53**	-.13	.28*	-.23	--		
	US	-.27*	-.28*	-.44**	-.19	-.07	-.30*	-.33*	-.25*	.10	.04	.26*	-.12	--	
	RJ	-.16	-.20	-.01	.01	-.05	-.10	-.04	-.32*	.72**	-.14	.79**	-.07	-.04	--
	mSA	.20	.29*	.08	.11	.08	-.08	.06	.38**	-.29*	.18	-.36**	.09	.07	-.37**

RF: Rule following; SrU: Student-role Understanding; SO: Sociability; TF: Tolerance to Frustration; GW: Good to work with; NGW: Not good to work with; GFT: Good to spend free time; NGFT: Not good to spend free time; AP: Appreciated; US: Unsocial; RJ: Rejected; mSA: mean scores of Social Appreciation.
** $p<.01$; * $p<.05$

REGRESSIONS

As discussed in the introduction, executive attention and temperamental effortful control are both theoretically and empirically linked. In our data, three dependent measures showed significant correlation with both executive attention and effortful control, grades in math, mean of all grades and the measure of aggressiveness in the Social Status questionnaire. To examine the unique contribution of these two aspects of self-regulation on the variance of these dependent measures we conducted stepwise multiple regression analysis, controlling for covariance between independent measures. These analyses indicated that both parent-reported EC ($\beta = .47$; $p < .01$) and the EX score as measured by RT ($\beta = -.24$; $p = .05$) were significant predictors of the grade in mathematics (R^2 of the model: 0.34). However, the parent-reported EC ($\beta = .62$; $p < .05$) was uniquely related to the mean grade of all subjects included in the curricula (R^2 of the model: 0.47). Likewise, parent-reported EC was the unique significant predictor ($\beta = -.39$; $p < .05$) of aggressiveness in the regression model (R^2 of the model: 0.15).

MEDIATIONAL ANALYSIS

Our data showed a significant correlation between aspects of social adjustment and schooling skills and academic outcomes. We argued that aspects of self-regulation (i.e. EC and/or EX) might mediate this relationship. To test this hypothesis, we carried out mediational analysis following the procedure proposed by Baron and Kenny (1986) for those social and self-regulation variables that were inter-correlated with the average of grades and the average of schooling skills. For instance, both measures of Unsocial and Appreciated as well as parent-reported EC showed significant correlations with the average of grades and schooling skills. Therefore we intended to examine whether (a) social measures of Unsocial and Appreciated reliably predict EC reported by parents, (b) these two measures of social adjustment reliably predict schooling skills and academic achievement, and whether (c) when EC reported by the parents is controlled for, the prediction of academic achievement and schooling skills decreases reliably.

The first mediational analysis showed that Unsocial behavior significantly predicted EC ($\beta = -.37$; $p < .05$), as well as the average of grades ($\beta = -.28$; $p = .06$). EC also significantly predicted the average of grades ($\beta = .6$; $p < .001$). However, when EC was entered in the regression equation together with Unsocial, EC still significantly predicted the average of grades ($\beta = .7$; $p < .001$), whereas Unsocial no longer significantly predicted the average of grades (β = -.08;p > .05). This indicates that parent-reported EC mediates the relationship between higher levels of unsocial behavior and poor academic achievement at school (see figure 10a). The second mediational analysis (Figure 10b) tested whether the relation between Unsocial and the average of all Schooling Skills was also mediated by parent-reported EC. Results showed that Unsocial significantly predicted parent reports of EC (β = -.37; p < .05), and also the average of all Schooling Skills (β = -.33; p < .05). EC also significantly predicted the average of all Schooling Skills (β = .46; p < .01). However, when both EC and Unsocial were entered in the regression equation only EC significantly predicted the average of all Schooling Skills (β = .42; p < .05; for Unsocial: β = - .01; p > .05).

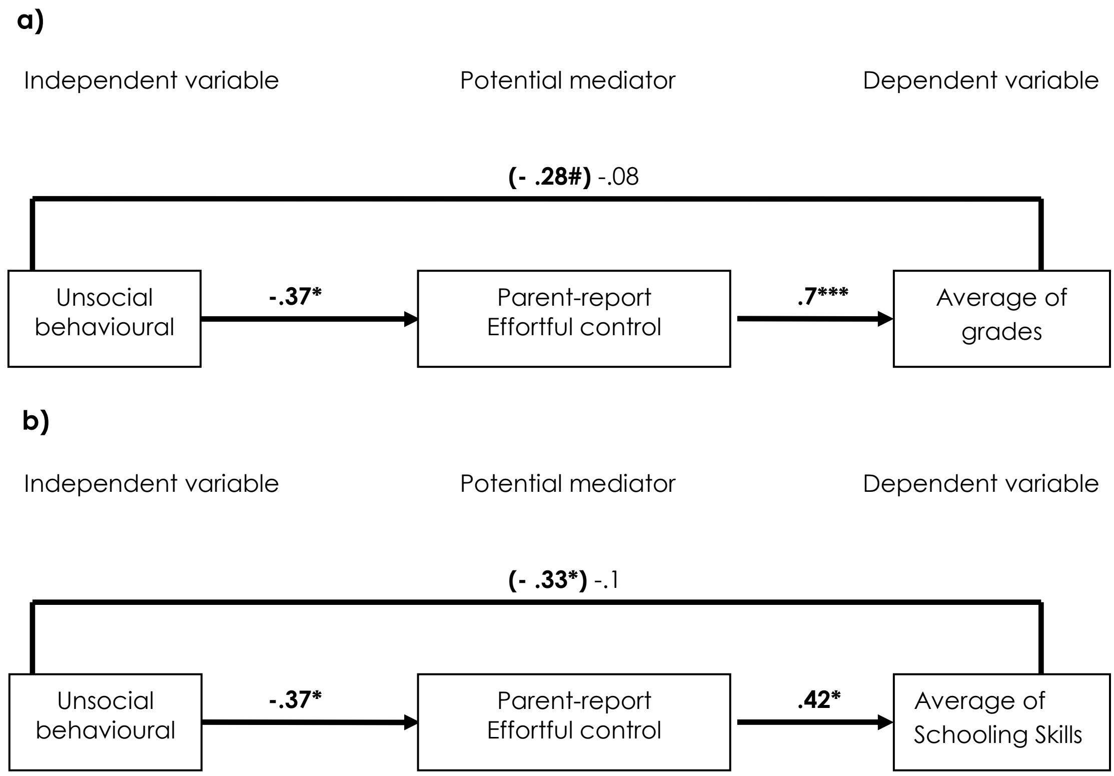

Figure 10. Effortful Control as mediator of the effect of unsocial behavior on school competence. a) Model predicting average of grades. b) Model predicting average scores of Schooling Skills. Numbers are ß values. Values in parenthesis show ßs when the independent variable is regressed alone on the dependent variable. These values are followed by ßs when both the independent variable and the potential mediator are regressed on the dependent variable
*Significance levels: *** p < .001; ** p<.01; * p<.05; # p < .06*

We also conducted this type of analysis to test the mediational role of EC in the relationship between social appreciation and schooling outcomes. As shown in Figure 11, EC was found to be a significant mediator of both the average of Schooling Skills and the average of all grades.

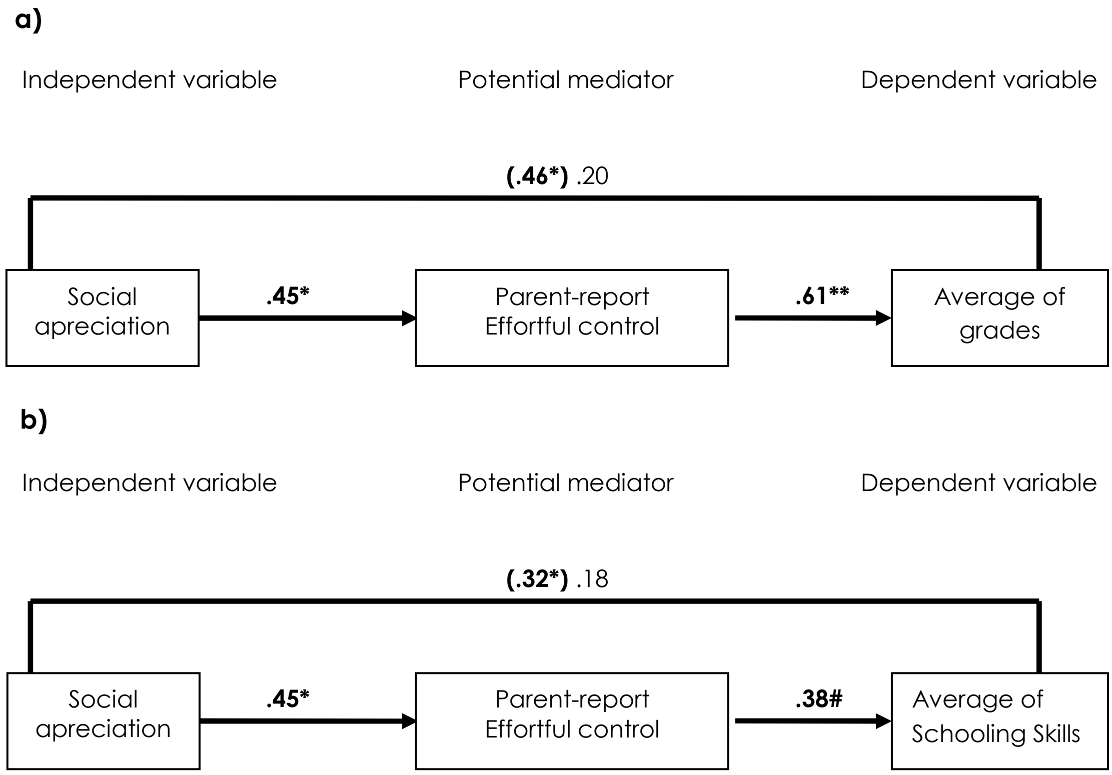

Figure 11. Effortful Control as mediator of the effect of social appreciation behavior on school competence. a) Model predicting average of grades. b) Model predicting average scores of Schooling Skills. Values in parenthesis show ßs when the independent variable is regressed alone on the dependent variable. These values are followed by ßs when both the independent variable and the potential mediator are regressed on the dependent variable
*Significance levels: *** p < .001; ** p<.01; * p<.05; # p < .06*

Other mediational analysis were conducted with executive attention as the potential mediator between social measures and grades in mathematics, average of all grades and average of schooling skills; these analyses yielded no significant mediational effects.

All together, these results show that measures of social adjustment such as Aggression and Appreciation are significant predictors of the average of grades, and the average of all Schooling Skills, but this relationship appears to be mediated by individual differences in Effortful Control.

DISCUSSION

This study examined whether early adolescents academic outcomes and social adjustment at the school were associated with individual differences in attentional efficiency and temperamental reactivity and self-regulation.

Attention and schooling outcomes

Efficiency of the different attentional functions included in Posner's model was tested with the ANT. Results obtained with this task were consistent with the literature. Participants responded slower and less accurately to trials in which stimuli surrounding the target induced conflict (incongruent trials) than to no-conflict (congruent) trials. This interference effect is indicative of the efficiency of brain mechanisms involved in conflict resolution and cognitive control (Posner & DiGirolamo, 1998). On average, the size of the interference effect was 107 ms for response time, and 4.8 percentage points as measured on response accuracy. Individual variations in this interference effect, assessed by the executive attention score, were related to academic achievement in general and more consistently to grades on mathematic. Larger interference scores, and hence poorer executive attention efficiency, was also related to peer-reports of aggressive behaviour as well as to nominations for being someone not good to spend free time with. Both of these findings are consistent with the literature.

Other studies with preschoolers and first-graders have shown that various measures of executive function predict competence in arithmetic tasks (Blair & Razza, 2007; Bull & Scerif, 2001; Espy, et al., 2004). Additionally, lateral frontal regions of the brain considered part of the executive attention network are activated by marker tasks of general intelligence (Duncan, et al., 2000). In our view, efficiency of this brain system results in more successful acquisition and application of knowledge taught at the school, especially in those subjects involving complex reasoning such mathematics.

The relationship between attentional interference and greater aggression and social rejection is also consistent with the role given to the executive attention network in Posner's model. One of the main nodes of this network, the anterior cingulate cortex (ACC), is involved in controlling cognitive as well as affectively-relevant information. The strong connections between the ventral division of the ACC and subcortical limbic structures such as the amigdala is likely to implement a circuitry for the control of emotion (Posner, et al., 2006). Larger rates of unsocial behavior together with larger interference scores in the ANT indicate less efficiency of this circuitry in exercising control over negative emotionality, likely leading to social maladjustment and rejection by peers.

As predicted, the other two aspects of attention measured by the ANT show a much less clear pattern of associations with schooling outcomes than the executive attention network. The correlation between the alerting score and the HRI measure of socialization might indicate that greater levels of responsiveness to stimulation (preparation from cues) leads to better processing of socially-relevant cues from others, thereby enhancing responsiveness to such cues. However, the observed correlation between orienting and the Student-role Understanding scale of the HRI is more puzzling. Understanding this association would require replication and further investigation.

Temperamental contributions to social and academic outcomes

Temperamental researchers have pointed to the fact that children's differences in their experience and expression of negative and positive emotions as well as their capacities for attentional self-regulation (EC) influence both their own adaptation to the classroom and how they are viewed by peers and teachers (Rothbart & Jones, 1998). In agreement with this, our data with early adolescents show that there is a relationship between school competence and both reactive and self-regulative aspects of temperament. Temperamental systems of negative emotionality show a strong association with poorer schooling skills that is consistent across self and parent reports. Moreover, parent-reported negative affectivity is associated with low academic performance and increased social rejection in school. On the other hand, both self and parent–reported temperamental EC is positively related to all measures of schooling skills and academic achievement, and parent-reported EC is also positively associated with social appreciation and negatively with aggressiveness (see Table 3).

The variety of measures used in our study allows for a deeper understanding of how temperament may influence school outcomes. Thus, our data show that those children with higher reactive negative emotionality have more trouble following rules, understanding their role as students, socializing with peers and tolerating frustration, and therefore might be experiencing greater difficulties adapting to the classroom setting. In turn, failure to use these skills likely results in behavior disruptive to the classroom routine, thus affecting both achievement and social acceptance, and potentially leading to increased discouragement, frustration and avoidance of potential sources of learning. On the other hand, the positive association between individual differences in self-regulatory systems such EC and social and academic outcomes likely represent the influence of attentional control, persistence and motivation in the learning context (

Martin, et al., 1988; Rothbart & Hwang, 2005; Rothbart & Jones, 1998). Children with higher EC scores are also more able to use their self-regulatory capabilities to comply with the demands of teachers and peers in the classroom, thus increasing their social acceptance and their opportunities to learn (Rothbart &Jones 1998).

Additionally, correlations among the measures of school competence assessed in our study show a consistent association between social adjustment and both academic achievement and display of schooling skills (see Table 4). Better adjusted children, those with higher rates of social appreciation and lower rates of aggression, are the ones obtaining better grades in school subjects and showing better scores in skills important for positive schooling. This pattern of associations is consistent with prior studies establishing that socio-emotional competence contributes to adequate academic progress during childhood (Ladd, Herald, & Kochel, 2006). However, mediational analyses conducted with our data indicate that the relationship between social maladjustment and poorer schooling outcomes is mediated by EC (see Figures 10 & 11). While other studies have proposed that the development of positive social relationships in the school is the primary factor promoting school competence (Mashburn & Pianta, 2006), our data suggest that individual differences in temperamental systems of attention regulation are central to understanding the relation between social adjustment in the school and students' performance. Nonetheless, although we propose a major role for temperamental self-regulation in both learning and the acquisition of school-related competencies, we also acknowledge the importance of other individual variables such as children's reports of school liking (Valiente, et al., 2007) and emotional intelligence (Marquez, Martin, & Brackett, 2006), as well as environmental and family variables such as parenting or socio-economic status (Hill, 2001; Kessler, 2002; Ryan, Fauth, & Brooks-Gunn, 2006) that were not taken into account in the current study.

Unique contributions of neurocognitive and temperamental systems of self-regulation to school competence

As we pointed out at the introduction, there is a conceptual link between the functions of the cognitive system of executive attention and the temperamental dimension of effortful control. The executive attention network is in fact considered part of the brain system supporting effortful control (Rothbart & Rueda, 2005; Rueda, Posner, & Rothbart, 2004). As prior studies have shown (Gonzalez, et al., 2001; Rothbart, et al., 2003), we found a significant correlation between a measure of the efficiency of the executive attention network, the interference score obtained with the ANT, and parent-reported effortful control. Despite their conceptual and empirical overlap, these two concepts represent different, although interconnected, levels of analysis of the ability to exercise control over one's behavior. The executive attention measure taps the efficiency of neurocognitive mechanisms important for resolving conflict among incongruent stimuli. This involves processes such as the detection of conflict and the inhibition of both processing and responding to the non-relevant stimulation. Effortful control refers to the efficiency with which self-regulatory abilities are used in both personal and interpersonal situations that require overcoming dominant but inappropriate responses.

In our study, we were able to examine the separate contributions of these two levels of analysis of self-regulation to schooling outcomes. Multiple regression analysis in which colinearity among executive attention and EC was controlled showed that executive attention accounted for unique variance only when predicting grades in mathematics. This results is consistent with data from prior studies in which cognitive measures of inhibitory control accounted for unique variance, independent from teacher's reports of effortful control, in predicting math abilities in kindergarten (Blair & Razza, 2007).

Conclusions and implications for education

The current study aimed at increasing our understanding of the role of neuro-cognitive and temperamental systems of self-regulation in several dimensions of early adolescents' school competence. The main conclusion that can be drawn from our results is that while efficiency of the executive attention network seems to relate mainly to academic achievement and to some aspects of social adjustment, the temperamental dimension of self-regulation, a broader concept that also includes aspects of socio-emotional and behavioral regulation, appears to be a significant predictor of all dimensions of school competence examined in the study: achievement, social adjustment and employment of appropriate schooling skills.

The central role that temperamental systems of self-regulation appear to play in early adolescents' schooling outcomes points to the importance of understanding students' temperament by parents and educators in order to promote their adaptation to the classroom setting. Other studies have reported that children with poorer attentional self-control receive more criticism from their teachers (Martin, 1989). Increased teacher's awareness of how students' temperament relates to their responses to the social and academic challenges is likely to reduce teacher's negative reactions and promote feelings of support, which in turn have the potential to reduce conflict and encourage the use of more appropriate coping strategies by the students (Pullis, 1985).

This perspective on school competence, emphasizing the mediating role of self-regulatory processes, also offers guidance for designing interventions to improve school readiness by enhancing cognitive and temperamental control systems. In the recent years, there have been several efforts to design programs aimed to promote executive control abilities in preschoolers and first graders. In one of these studies, a set of child-friendly computer-based exercises were used to train 4-6 year-olds' attention, emphasizing aspects of executive control (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Several training sessions with this program have produced significant improvements in measures of IQ and brain responses during performance of a conflict task in normally-developing children. Other training programs aimed to improve executive functions have also reported positive results in enhancing cognitive efficiency of children suffering from attention-related pathologies (Klingberg, et al., 2005). In addition to these computer-based interventions, a study by Diamond et al has also shown beneficial effects of a curriculum implemented by teachers in the regular classroom setting with the aim of improving cognitive control in preschool (Diamond, Barnett, Thomas, & Munro, 2007). Although these efforts to train aspects of self-regulation show very promising results, they have mainly focused in the training and testing effects at the neurocognitive level. Further research would be needed in order to examine whether the beneficial effects of these training programs also affect temperament and academic performance and transfer to abilities relevant for schooling competence such socio-emotional regulation.

CHAPTER IV

BEHAVIORAL AND BRAIN MEASURES OF ATTENTION CONTROL PREDICT SCHOOLING COMPETENCE IN LATE CHILDHOOD

ABSTRACT

The present study examines the role of executive attention on school competence in early adolescence. A group (n=37) of 12 year olds children performed a combined Flanker - Go/Nogo task while their brain activation was registered using a high-density electroencephalography system. Additionally, we obtained parent-reported measures of children regulation, self-reported measures of schooling skills, and teacher-reported achievement. We observed that individual differences in self-regulation predict most dimensions of school competence. Also, individual differences in the amplitude of event-related potentials components related to interference suppression, but not in response inhibition, predict school achievement as well as some skills important for school. Thus, connections are established between brain responses in a laboratory task and school performance. The results are consistent with the role attributed to executive attention in the control of cognition and regulation of behavior.

INTRODUCTION

A wide variety of everyday situations call for effortful control of behavior in order to adjust actions to goals. This is particularly important in the classroom where students have to regulate behavior or focus on what is being discussed in the classroom despite the presence of potential distracting events. The regulation of cognition and action has been considered an important function of attention (Posner & Rothbart, 1998). Attentional control or executive attention is particularly required in situations that involve overcoming well-learned or dominant responses, facing novel and/or dangerous situations, detecting and correcting errors and planning actions (Posner & DiGirolamo, 1998). Within Posner's neurocognitive model, executive attention is related to the function of a neural network involving the anterior cingulate cortex and prefrontal regions, called the executive attention network (Posner & DiGirolamo, 1998; Posner & Rothbart, 1998).

A basic measure of executive attention in the laboratory is provided by tasks involving conflict among possible responses. An example of these is the Flanker task. In this task, participants are required to respond to a central target and ignore flanking stimuli. The target may consist of an arrow pointing either right or left and the required response is to indicate the direction of the central arrow by pressing a key. Then, flanking arrows point to either the same (congruent trials) or the opposite (incongruent trials) direction than the central arrow. In the incongruent condition, processing of the flankers suggests a response that conflicts with that of the relevant central stimulus. It is thought that resolving conflict requires the selection of the appropriate response and the suppression of competing and interfering incongruent responses which results in slower reaction time and lower accuracy in incongruent compared to congruent conditions (Eriksen & Eriksen, 1974).

A different task commonly used to study inhibitory control is the so-called Go/No-Go task. It involves presentation of a series of stimuli that require a fast response ("Go" trials), usually pressing a key. Frequent "Go" trials are intermixed with infrequent "No-Go" trials to which participants must hold their response. The frequency of "Go" trials creates a tendency to respond that must be inhibited in No-Go trials, thereby providing a measure of the ability to inhibit a response tendency.

Both tasks involve executive attention because optimal performance requires either suppression of interfering information or inhibition of preponderant responses. Multiple studies have examined the neural bases of both interference suppression (IS) and response inhibition (RI) processes. Using event-related potentials (ERPs) it has been found that the N200 component, a negative deflection registered at frontal channels around 200 ms post-target, is larger for trials that involved IS and RI (Incongruent and No-Go trials, respectively) than for Congruent and Go trials, respectively. Brain imaging studies have shown that IS and RI processes are supported by a network of cortical areas involving the dorsal division of the anterior cingulate cortex (dACC), and regions of the dorsolateral prefrontal cortex (DLPFC), ventro lateral prefrontal cortex (VLPFC), and parietal cortex (Corbetta & Shulman, 2002; Fan, et al., 2005). However, regions within this network appear to be activated differently by IS and IR processes. A study using fMRI showed that RI involves greater recruitment of DLPFC, VLPFC and parietal structures than IS, while IS is associated with greater dACC recruitment relative to RI (Blasi, et al., 2006). Other studies indicate that the VLPFC is implicated in both IS and IR, while additional posterior structures such as anterior and posterior cingulate cortex and superior and inferior parietal lobe are involved in RI (Bunge, et al., 2002).

It is evident to parents and teachers that attention is an important ability in the classroom (Rothbart & Jones, 1998). Attention allows students to focus on school tasks and suppress irrelevant stimulation in the environment, abilities that are important for learning (Blair, 2002). Moreover, attention appears to be a relevant contributor to academic outcomes, particularly in school subjects such as mathematics and literacy, given its central role on cognitive flexibility and regulation (Blair & Razza, 2007; Bull & Scerif, 2001; Checa, Rodriguez-Bailon, & Rueda, 2008; Fuchs, et al., 2005; Russell & Ginsburg, 1984). For instance, Passolunghi et al (1999) have shown that children exhibiting poorer performance when solving arithmetic tasks have greater difficulty inhibiting irrelevant information than better performers. Although these studies have considered attention as a key factor to school success, any of them have examined separately the contribution of interference suppression and response inhibition to school competence.

Behavioral regulation is necessary in the classroom in order to comply with the demands of teachers and peers, and with the demands related to school tasks (Myers & Sheffield Morris, 2009; Rothbart & Jones, 1998). Understanding individual differences in the efficiency of self-regulation have been undertaken in studies of temperament. In temperament studies, individual differences in reactivity and regulation are commonly measured using questionnaires. Factor analyses of mostly parent-reported questionnaires have provided evidence for three broad temperament factors in childhood: Surgency/Extraversion, Negative Affect and Effortful Control. Effortful Control (EC) is the temperamental factor related to self-regulatory abilities. EC captures individual differences in the ability to regulate behavior in relation to current and future needs, and reflect individuals' efforts to control impulses according to instructions, goals or social norms (Rothbart & Derryberry, 1981). It has been argued that the executive attention network in Posner's model constitutes the neural system underlying EC (Rothbart & Rueda, 2005). Supporting this idea, many studies have shown a correlation between performance in conflict tasks tapping executive attention and measures of EC (Checa, et al., 2008; Ellis, et al., 2004; Gerardi-Caulton, 2000; Gonzalez, et al., 2001).

The role of EC in school competence has been examined in various studies. Individual differences in EC are shown to be positively related to academic outcomes (Devinsky, Morrell, & Vogt, 1995; Ellis, et al., 2004), and appear to be a key mediator of the relationship between children's social adjustment to school and academic achievement (Checa, et al., 2008).

While a considerable amount of data suggest that systems of self-regulation such as temperamental effortful control and executive attention are important for school competence, to our knowledge, only one study has examined the relationship between brain measures tapping the functioning of the executive attention network and school competence. Hirsh and Inzlicht (2009) have recently shown that the amplitude of the Error-related Negativity (ERN), a post-response ERP component associated with action-monitoring, is related to academic achievement in undergraduate students. They have interpreted this result as indicative of the importance of efficiently engaging cognitive control processes, such as error-detection, when needed in order to monitor learning processes central to academic success.

The main goal of the present study was to test the relationship between brain processes engaged during performance of executive attention tasks in the laboratory and various measures of school competence, including academic achievement and skills important for school performance. To evaluate school competence we collected information about children's schooling skills and academic achievement at completion of the academic year. Brain processes underlying attentional control can be examined during performance of cognitive tasks using electroencephalography. By using a task that combined Flanker and Go/No-Go conditions we aimed at examining the specific contribution of response inhibition and interference suppression processes to school competence. Effects of distracters' suppression and response inhibition on the amplitude and latency of ERPs will be taken as indexes of efficiency of underlying brain mechanisms. Prior studies have shown that the ability to suppress irrelevant internal (thoughts) as well as external information is related to school achievement, thus we expect to find an association between the ERPs effects, particularly those related to interference suppression, and measures of school competence. We also predict that EC, a concept capturing self-regulatory skills in a broad range of behaviors (Rothbart & Rueda, 2005; Rueda, Posner, & Rothbart, 2004) would also be an important predictor of most aspects of school competence.

METHOD

PARTICIPANTS

A total of 37 children (mean age: 12.6 years, SD: 0.60; 19 girls) from Granada (Spain) and their parents participated in the study. Participants were recruited at the school by sending a letter to their caregivers with information about the general purpose of the study. The caregivers of all participants gave written consent to participate in the study. All participants were Caucasian-Europeans except one girl who was African and one girl and one boy who were Hispanic.

PROCEDURE

The study involved two sessions. In the first session which was conducted at the school and took approximately 50 minutes, participants filled-up a questionnaire about their schooling skills. Also, the parent-report version of the Early Adolescence Temperament Questionnaire – Revised (EATQ-R; Ellis & Rothbart, 2001) was given to caregivers with instructions for completing it and returning it to the school with their child in a sealed envelope. In the second session, children were tested individually at the Cognitive Neuroscience laboratory of the University of Granada. At arrival, participants were informed of the general procedure of the session and were given a few minutes to get comfortable with the lab setting before starting. Putting the net on and checking impedances took about 10 minutes. Once wearing the net, children were verbally informed of the instructions to complete the experimental task (described below). Completing the task took about 15-20 minutes. Once the task was completed and the net was taken-off, participants completed the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 2000), which took about 15 minutes. A T-shirt of the lab and other small presents were offered to the children at the end of the experimental session in appreciation for their collaboration. Finally, the board of the school in which children were enrolled provided information on grades obtained at the end of the academic year by the students involved in the study.

MEASURES

Experimental task

We used a combination of the Flanker and Go/Nogo tasks in order to measure processes of interference inhibition and response inhibition (see Figure 12). Each trial started with a fixation point of variable duration randomly selected between 600 and 1200 ms. Subsequently, a target was presented until a response was made or as long as 2000 ms. The target display consisted of an arrow pointing either right or left that was flanked by two arrows on each side. For half of the trials the flanking arrows pointed to the same (congruent) direction as the central arrow, and they pointed to the opposite (incongruent) direction for the other half of the trials. The row of arrows could either appear above or below the fixation cross (50% of the trials on each location). Participants were instructed to indicate the direction of the central arrow by pressing a response button (left button for leftward pointing central arrows and right button for central arrows pointing right) as fast as possible only when the arrows were presented in black color (Go condition, 75% of the trials) and withhold their response when the arrows were presented in red color (No-Go condition, 25% of the trials). Finally, an error-feedback tone was provided only when a response was made in No-Go trials. Each participant performed a total of 192 trials divided in three blocks, with a brief break between blocks. The type of trial (whether it was congruent or incongruent and Go or No-Go) was randomly assigned in each trial.

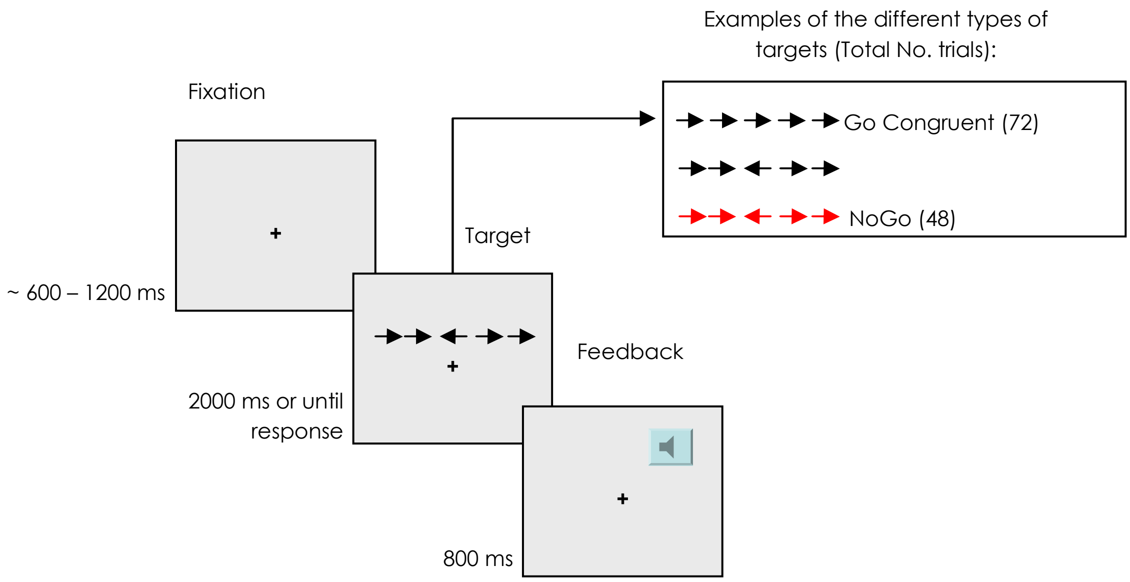

Figure 12. Schematic presentation of the attentional task used in this study

Measure of temperamental Effortful Control

The Spanish parent-report version of the Early Adolescence Temperament Questionnaire – Revised (EATQ–R; Ellis and Rothbart, 2001) was used to measure children's effortful control. Only items from the scales loading on the EC factor (Activation Control, Attention and Inhibitory Control) were taken into account. The internal reliability (measured by Cronbach's alpha) of the EC calculated in our sample was α = .80. Three parents did not return the temperament questionnaire.

Measure of Schooling Skills

Information on schooling skills was obtained through the self-report version of the Health Resources Inventory (HRI; Juvonen and Keogh, 1992). This questionnaire consists of 31 items that group onto four factors: Rule following (RF, Cronbach's α = .79 in our sample), Student-role Understanding (SrU, α = .80), Sociability (SO, α = .50) and Tolerance to Frustration (TF, α = .55). The RF factor reflects the student's ability to function within the constraints of the school environment. Sample items for this factor are "I behave well at school" and "I am considerate and polite with others". The SrU factor describes behaviors associated with effective learning such as students' understanding of their duties and responsibilities. Samples items are: "I am interested in the work we do at school" and "I try to complete home-work assignments". The SO factor consists of items reflecting effective interpersonal functioning (e.g., "I have many friends" or "My classmates are fond of me"). Finally, the TF factor measures the individual ability to cope with failure and other social pressures. Sample items are "I can accept things not going my way" and "I face my mistakes". Items are responded in a 5-point Likert scale ranging from never to always each particular item is true of oneself.

Measure of Intelligence

We used the Kaufman Brief Intelligence Test (K-BIT; Kaufman and Kaufman, 2000) to measure intelligence. The K-BIT is an individually administered test that consists of two subscales, vocabulary and matrices. The vocabulary scale is a measure of language and experience-related knowledge, and the matrices scale assesses abstract reasoning or fluid intelligence skills. The test provides scores for the two subscales as well as a composite IQ score.

EEG DATA ACQUISITION AND ERPS PROCESSING

EEG was recorded using the 128- channel Geodesic Sensor Net (www.egi.com). The EEG signal was digitized at 250 Hz. Impedances for each channel were measured prior to recording and kept below 80 kΩ before testing. Recording was vertex referenced and the time constant value was 0.01 Hz. Data from 4 children were not included in the analysis due to technical problems during task completion.

To build target-locked ERPs, individual files were filtered using a 0.3-12 Hz band-pass. Subsequently, continuous data were segmented into 1.2 seconds-long epochs (from -200 ms pre-target to 1000 ms post-target). Segmented files were scanned for artifacts with the Net Station artifact detection tool using a threshold of 80 mVolts for eye blinks and eye movement's detection. Segments containing eye blinks or movements as well as segments with more than 25 channels with noisy signal (containing abrupt amplitude changes) were discarded for further processing. Data were also visually inspected to ensure the parameters of the artifact detection tool were appropriate for each child. In addition, we used a criterion of a minimum of 15 clean segments per condition among the correctly responded trials for processing individual data. Six children were excluded because they did not reach this criterion. Thus, data from a total of 27 children were used for ERPs analyses.

RESULTS

BEHAVIORAL RESULTS

Mean (across subjects) of median (per subject) reaction times and percentage of errors were obtained for congruent and incongruent conditions. The difference in reaction time between congruent (574 ms) and incongruent (648 ms) trials was significant (t (64) = -3.5; p<. 001). A similar result was obtained for percentage of errors, with less percentage of errors in congruent trials (1.4%) compared to incongruent trials (4.3%), t (64) = -.2.5; p< .05. Also, the percentage of errors for the Go condition (omission errors) was 0.98 %, and 0.84 % for the No-Go condition (commission errors).

ERPs RESULTS

ERPs for the four experimental conditions included in the task are presented in Figure 13. As expected, we observed a larger negativity for incongruent compared to congruent trials (IS contrast) as well as for No-Go compared to Go trials (RI contrast) in frontal leads. However, the differences appeared at different time-windows. To examine interference suppression (IS) we computed mean amplitudes within a time-window of 460 to 760 ms post target for incongruent and congruent trials. To examine response inhibition (RI) we computed mean amplitudes in a time-window of 330 to 630 ms post-target for Go and No-Go trials. In order to test whether these amplitude differences were larger at midline or lateral sites, mean amplitude of several channels on the left-frontal (F3), midline (Fz) and right-frontal (F4) sites was calculated. The latency was computed as the time elapsing between presentation of the target and the maximum negative peak within the 330-630 ms post-target window for response inhibition, and between presentation of the target and the maximum negative peak within the 460-760 ms post-target for interference suppression.

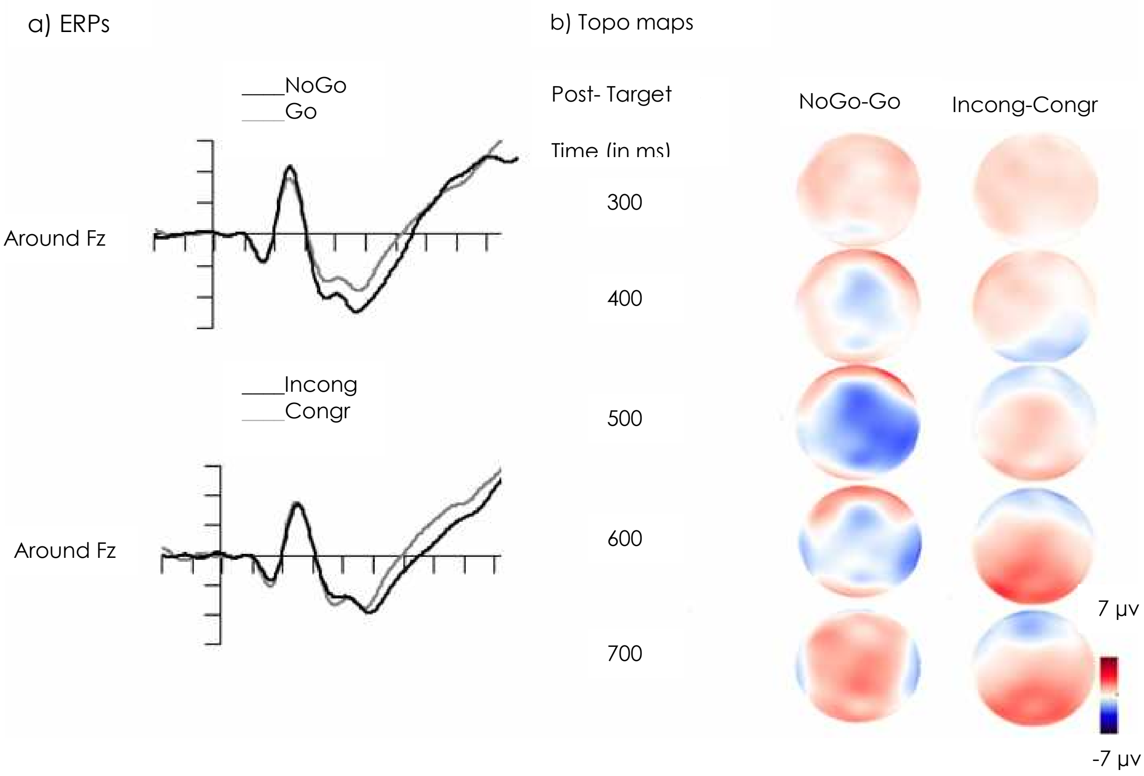

Figure 13. a) ERPs. Response Inhibition effect: Go vs No-Go condition (top of the figure) and Interferference Supression effect: congruent (Congr) vs. incongruent (Incong) trials (bottom of the figure). b) Topographic maps. Scalp distributions of the difference between Go and Nogo trials (left panel) and the difference between Congruent and Incongruent trials (right panel) at various time points after presentation of the target

Separate 2 (Flanker Type: congruent vs. incongruent) x 3 (Electrode Position: left, midline and right) ANOVAs with mean amplitude and latency as dependent measures were conducted. For amplitude, the main effect of Flanker Type was significant (F (1, 26) = 13.68; $p < .001$), indicating larger negative amplitude for incongruent (-.8µV) compared to congruent (.23 µV) trials. The main effect of Electrode Position was also significant (F (2, 52) = 3.9; $p < .05$) with larger negative amplitude for midline leads compared to right (F (1, 26) = 9.5; $p < .001$), or left F (1, 26) = 3.3; $p = .08$), sites. The Flanker Type x Electrode Position interaction was not significant ($F > 1$). Also, no significant effects were obtained using latency as dependent measure (all $F > 1$).

Additionally, separate 2 (Trial Condition: Go vs No-Go) x 3 (Electrode Position: left, midline and right) ANOVAs were conducted with mean amplitude and latency as dependent measures. Using amplitude, the main effect of Trial Condition was significant (F (1, 26) = 5.6; $p < .05$) showing larger negative amplitudes for No-Go (-3.4 µV) compared to Go (-2 µV) trials. The main effect of Electrode Position was also significant ($F(2, 52) = 6.5$; $p<.01$) with larger negative amplitude for midline, compared to left ($F(1, 26) = 9.4$; $p<.01$) and right ($F(1, 26) = 11.9$; $p<.01$) sites. The Condition x Electrode Position interaction was not significant. Finally, using peak latency as dependent variable, only the main effect of Electrode Position was significant ($F(1,52)=3.7$; $p<.05$) with longer latency of the peak in midline channels compared to leads located on the right ($F(1,26)= 5.4$;$p<.05$) or left sides ($F(1,26)=7.5$; $p<.05$). The Condition x Electrode Position interaction was not significant ($F>1$).

CORRELATIONS

Two scores were obtained as measures of individual efficiency for processes of interference suppression (IS) and response inhibition (RI) for each participant. The interference suppression score was calculated by subtracting the median RT (or % of errors) for congruent trials from the median RT (or % of errors) for incongruent trials. The response inhibition score (RI) was computed as the percentage of errors in No-Go trials.

Pearson's correlations between these scores and the rest of measures taken in the study were then calculated. These are presented in Table 8 and 9. We found a positive correlation between the RI score (RI_{ER}) and the IS score calculated with the percentage of errors (IS_{ER}). Also, scores of the intelligence subscales of Vocabulary and Matrices and IQ composite were negatively related to the IS score calculated with RT (IS_{TR}) and positively related to Effortful control (EC) (see Table 8). Additionally, the average of all grades and grades on mathematics were positively related to EC as well as measures of intelligence (Table 9). Also, the average of school grades and grades on mathematics were negatively correlated with ISRT. Finally, EC showed a positive correlation with most measures of schooling skills except for Tolerance to Frustration.

<u>Table 8.</u> Correlation among different levels of analysis of efficiency of executive attention

		EXPERIMENTAL TASK			EFFORTFULL CONTROL	INTELLIGENCE TEST (K-BIT)	
		IS RT	IS ER	RI ER	EC	VO	MA
EXPERIMENTAL TASK	IS RT	--					
	IS ER	.15	--				
	RI ER	-.12	.35*				
EFFORTFULL CONTROL	EC	-.18	.02	.06			
INTELLIGENCE TEST (K-BIT)	VO	-.35*	-.22	-.06	.35*		
	MA	-.55**	-.25	-.02	.33*	.64**	
	IQ	-.50**	-.27	-.05	.38*	.89**	.91**

IS: Interference suppression; IR: Response inhibition RT: Reaction time; ER: Errors EC: Effortful Control; VO: vocabulary; MA: Matrices
***p<.001, **p<.01, *p<.05

<u>Table 9</u>. Correlation among attention, temperament and intelligence measures and school competence measures

		Grades		Schooling Skills				
		Math	AllG	RF	SrU	SO	TF	AllS
EXPERIMENTAL TASK	IS RT	-.37*	-.39*	.08	.08	.21	.27	.20
	IS ER	-.07	-.07	.13	-.03	.19	.09	.12
	RI ER	-.09	.09	.16	.22	.26	-.01	.19
EFFORTFULL CONTROL	EC	.38*	.56**	.31	.44**	.40*	.18	.42*
INTELLIGENCE TEST (K-BIT)	VO	.53**	.61***	.36*	.28	.04	.18	.27
	MA	.67***	.68***	.30	.25	.06	.06	.23
	IQ	.66***	.71***	.36*	.25	.05	.06	.23

IS: Interference supression; IR: Response inhibition RT: Reaction time; ER: Errores; EC= Effortful Control; VO: vocabulary; MA: Matrices; IQ: toral scores of intelligence
Math: grades in mathematics; AllS: average of grades
RF: Rule Following; SrU: Student role Understanding; SO: sociability; TF: Tolerance of Frustration; AllG: average of schooling skills
***p<.001, **p<.01, *p<.05

We also calculated electrophysiological effects of interference suppression (ERP-IS) and response inhibition (ERP-RI) for each participant. The ERP-IS score was calculated by subtracting the mean amplitude for congruent trials from the mean amplitude for incongruent trials within the 460 to 760 ms time window. The ERP-RI score was calculated by subtracting the mean amplitude for Go trials from the mean amplitude for No-Go trials in a time window of 330 to 630 ms post-target.

As shown Table 10, the ERP-IS score was negatively correlated with grades in mathematics, as well as Rule Following, Student-role Understanding scores, and the average of all schooling skills. No significant correlations were obtained between the ERP-RI score and any other measure taken in the study.

Table 10. Correlations among ERPs components and temperament, attention, intelligence and school competence measures

	EC	EXPERIMENTAL TASK			IQ		GRADES		SCHOOLING SKILLS				
	EC	IS RT	IS ER	RI ER	VO	MA	Math	AllG	RF	SrU	SO	TF	AllS
ERP-IS	-.19	-.06	-.21	.17	-.14	-.11	-.42*	-.18	-.39*	-.47*	-.36	-.1	-.39*
ERP-RI	.29	-.09	.03	-.18	.27	.24	.37	.30	.14	.21	-.04	.21	.17

ERP-IS = mean of peak amplitude for ERP from incongruent minus mean of peak amplitude for ERP from congruent trials.
ERP-IR = mean of peak amplitude for ERP from Nogo trials minus mean of peak amplitude for ERP from go trials.
Smaller difference means better efficiency of the executive attention network.
EC: Effortful Control; IS: Interference supression; IR: Response inhibition RT: Reaction time; ER: Errores; VO: vocabulary; MA: Matrices; Math: grades in mathematics; AllG: average of grades; RF: Rule Following; SrU: Student role Understanding; SO: sociability; TF: Tolerance of Frustration; AllS: average of schooling skills
*p<.05

REGRESSIONS

To examine the unique contribution of those dependent measures that showed significant correlations with academic outcomes and schooling skills we conducted stepwise multiple regression analysis. We conducted two sets of regression analyses separately for measures of school achievement (average of grades and grades in maths) and the various measures of schooling skills as dependent variables. For the first sets of analysis, (see Tables 11 & 13), scores of intelligence subscales of vocabulary (VO) and matrices (MA) were entered first, followed by Effortful Control (EC) scores, then the reaction time measure of IS (ISRT) and the electrophysiological measure of IS (ERP-IS). For the second set of analysis the order of variables was the same except for not including the VO and MA scores (see Tables 12 & 14). Results showed that EC and ISRT were significant predictors of the average of all grades (see Table 11) and the EC remained significant after controlling by intelligence (see Table 12). Also, the brain measure of interference suppression (ERP-IS) was a significant predictor of grades in mathematics even after controlling by intelligence (see Tables 11& 12).

Table 11. Multiple regression analysis showing change in variance in academic achievement without controlling IQ

Average of grades	ΔR² of the model .37		
	β	F	p
EC	.51	3.6	.001
IS RT	-.30	-.2.1	.05
Grades in Mathematics	ΔR² of the model .16		
	β	F	p
EC	.20	1.01	.32
IS RT	-.31	-.1.6	.11
ERP-IS	-.44	-2.3	.05

EC: Effortful Control
IS: Interference supression
ERP-IS = mean of peak amplitude for ERP from incongruent minus mean of peak amplitude for ERP from congruent trials.

Table 12. Multiple regression analysis showing change in variance in academic achievement controlling by IQ

Average of grades	ΔR² of the model .57		
	β	F	p
VO	.28	1.89	.07
MA	.56	4.5	.001
EC	.38	3.12	.01
IS RT	-.02	-.11	.91
Grades in Mathematics	ΔR² of the model .55		
	β	F	p
VO	.14	.75	.46
MA	.64	4.4	.001
EC	-.07	-.47	.64
IS RT	.14	.74	.47
ERP-IS	-.35	-2.4	.05

VO: vocabulary; MA: Matrices
EC: Effortful Control
IS: Interference supression
ERP-IS = mean of peak amplitude for ERP from incongruent minus mean of peak amplitude for ERP from congruent trials.

In addition, we foun that EC and marginally the ERP-IS score were significant predictors of the skill of Student-role Understanding and the average of all schooling skills (see Table 13 & 14) in both sets of analyses, controlling and not controlling by measures of intelligence. Finally, only the ERP-IS accounted for unique variance when predicting Rule Following.

<u>Table 13</u>. *Multiple regression analysis showing change in variance in school skill without controlling IQ*

Average of schooling skill	ΔR² of the model .17		
	β	F	p
EC	.45	2.4	.05
ERPs- IS	*-.33*	*-.1.8*	*.09*
Student role Understanding	ΔR² of the model .36		
	β	F	p
EC	.40	2.3	.05
ERP-IS	-.43	-.2.5	.05

EC: Effortful Control
ERP-IS = mean of peak amplitude for ERP from incongruent minus mean of peak amplitude for ERP from congruent trials.

<u>Table 14</u>. *Multiple regression analysis showing change in variance in school skills controlling by IQ*

Average of schooling skill	ΔR² of the model .24		
	β	F	p
VO	.06	.30	.76
MA	-.29	-1.5	.15
EC	.38	2.1	.05
ERP-IS	*-.33*	*-.1.8*	*.08*
Student role Understanding	ΔR² of the model .36		
	β	F	p
Vo	.04	.21	.83
MA	-.01	-.03	.97
EC	.40	2.3	.05
ERP-IS	-.43	-.2.5	.05
Rule Following	ΔR² of the model .12		
	β	F	P
VO	*.34*	*1.9*	*.07*
MA	.14	.76	.45
ERP-IS	-.39	-2.1	.05

VO: vocabulary; MA: Matrices
EC: Effortful Control
ERP-IS = mean of peak amplitude for ERP from incongruent minus mean of peak amplitude for ERP from congruent trials.

DISCUSSION

In the current study, we have measured processes of response inhibition (Go vs. No-Go) and interference suppression (Flanker interference) at the behavioural and electrophysiological levels of analysis. We have found a positive correlation between the behavioral indexes of performance associated to flanker interference suppression (IS_{ER}) and inhibition of response (RI_{ER}), which in accordance with the literature indicates that both processes are related to a frontally distributed system involved in inhibitory control (Bunge, et al., 2002). However, despite being related processes, their underlying neural mechanisms may be to some extent different as has been observed in prior neuroimaging studies (Blasi, et al., 2006; Bunge, et al., 2002). Figure 13 shows the scalp distribution of the electrophysiological effects of response inhibition (ERP-RI) and interference suppression (ERP-IS) registered in our study. Both effects have a frontally distributed topography, although several differences are observed. First, the response inhibition effect (i.e. amplitude difference between Go and No-Go conditions) emerges around 400 ms post-target and is sustained for about 300 ms, while the interference suppression effect (i.e. amplitude difference between Congruent and Incongruent flanking conditions) appears later, being observed in a time window between 500 and 800 ms post-target. The observed difference in latency may be related to the amount of processing that is necessary in order to determine the appropriate response in each condition. Performing the flanker task requires participants to visually process the display and decide which of the two possible responses, either pressing the right or left key, is to be made. In our task, No-Go trials were signalled by a salient aspect of the display such as the color of the arrows, and once the color is processed it is not necessary to decide between the two response alternatives, therefore the ERP-RI effect appears about 100 ms earlier than the ERP-IS effect. The second difference involves the distribution of the effects. The ERP-RI effect appears primarily at frontal midline leads, around Fz and Fcz channels, and at about 500 ms post-target it is also observed at parietal leads on the right side. On the other hand, the ERP-IS effect has a more prefrontal distribution, being mostly observed around Fz and AFz channels (see Figure 13). We interpret these topographic differences as indicative of distinct frontal structures underlying RI and IS processes. In fact, prior imaging studies have shown that the VLPFC cortex is recruited by the two types of processes whereas additional posterior structures, such as anterior and posterior cingulate cortices and superior and inferior parietal lobe, are required when response inhibition is required (Bunge, et al., 2002).

In addition to the dissociation between RI and IS processes at the electrophysiological level of analysis, we observed different patterns of correlations between these processes and measures of intelligence and schooling competence. The reaction time measure of IS (IS_{RT}) is correlated with intelligence scores in both the vocabulary and matrices subscales. Likewise, IS_{RT} shows a significant correlation with school achievement as measured with grades obtained in school subjects. Both of these correlations indicate that larger interference scores, and thus poorer ability to suppress distracting information, are related to poorer achievement at school and smaller intelligence scores. Nonetheless, we did not obtain significant correlations between the RI measure and neither intelligence nor any of the variables related to school competence (see Table 8 & 9). The pattern of results is similar when RI and IS are assessed at the electrophysiological level. The ERP-IS index shows a significant correlation with grades in math and some schooling skills, whereas the ERP-RI index does not correlate with any of the schooling variables taken into account in our study (see Table 10). These data show an interesting dissociation between two types of inhibitory processes and measures relevant for school success. Our data suggest that the ability to inhibit processing of irrelevant or distracting information, but not the more peripheral form of inhibition necessary to stop a motor response, is important for aspects of schooling that involve both fluid and crystallized intelligence, learning of school material and displaying skills that promote school success. Prior studies have shown that performance of inhibitory tasks is related to a variety of aspects of schooling competence (Blair & Razza, 2007; Bull & Scerif, 2001; Checa, et al., 2008; Fuchs, et al., 2005; Russell & Ginsburg, 1984). RI processes may be more important for stopping motor responses and controlling impulses which are necessary for schooling skills such as sitting still or taking turns to talk, and perhaps not so central to skills involving reasoning and cognitive flexibility. However, some studies have found that performance of RI tasks is an important predictor of academic achievement (McClelland, Acock, & Morrison, 2006). Further research is needed in order to clarify the relation between processes of RI and school competence.

We have also observed that individual differences in temperamental Effortful Control (EC) show a similar pattern of correlations with intelligence, schooling skills and academic achievement as measures of IS. This was expected given the fact that EC and behavioral measures of IS are usually correlated (Checa, et al., 2008; Ellis, et al., 2004; Rothbart & Rueda, 2005). The correlation between IS and EC did not reach significance in the current study probably due to lack of power caused by the limited size of our sample. However, numerous empirical data (Checa, et al., 2008; Ellis, et al., 2004; Gerardi-Caulton, 2000; Gonzalez, et al., 2001) have supported the relationship between temperamental EC and the functional efficiency of the executive attention network mostly measured thru performance of IS tasks. The executive attention network is in fact considered the neural circuit supporting EC (Rothbart & Rueda, 2005).

Regression analyses show that EC and IS measured at both behavioural and electrophysiological levels are significant predictors of grades at school (see Tables 11 & 12). When predicting the average of all grades, the effect of IS_{RT} is not significant after controlling for fluid intelligence (Matrices subscale). We believe that fluid intelligence and IS share a considerable amount of variance provided that those tasks requiring interference suppression and those involving fluid intelligence have been shown to activate quite overlapping neural structures (Crone, et al., 2009; Duncan, et al., 2000). Besides, we consider that attentional control is particularly important when it comes to solving tasks with a high load of reasoning. Temperamental EC is nonetheless a significant predictor of the average of school grades either controlling or not for intelligence. We consider that this is because EC is a broader measurement of self-regulatory abilities than IS. EC scores capture individual differences in a larger range of behaviors including patterns of responses that children display at home and other social settings and that are observed and reported by their parents.

Interestingly, the ERP-IS amplitude effect is a significant predictor of grades in math even after controlling for fluid intelligence (see Tables 11 & 12). This is also true when it comes to predicting schooling skills related to following rules and understanding school duties (see Tables 13 & 14). This result complies evidence of a direct connection between two separate levels of analysis related with attentional control and, more broadly, with self-regulation. On the one hand, the assessment of neural mechanisms through the recording of electrical activity coming from cortical neurons while a task requiring attentional control is being performed. On the other hand, the measurement of individual differences in particular behavioral aspects important for adjustment and accomplishment at the school as reported by teachers (grades) or self-reported (schooling skills). Prior developmental studies using the flanker task with ERPs have shown that larger ERP-IS effects are related to immature frontal function. Compared to adults, children appear to show larger amplitude differences between congruent and incongruent conditions in the flanker task. Besides, the effect is sustained longer for children than adults (Rueda, Posner, Rothbart, et al., 2004). This has been interpreted as children's need of greater engagement of frontal structures in order to solve conflict produced by incongruent flankers. Data of the current study indicate that children with more adult-like patterns of brain activation during performance of an interference suppression task are the ones showing greater accomplishment at school.

Conclusions and implication for education

Results in the present study show a link between two levels of analysis related to executive attention, behavioral and electrophysiological, and school competence. Particularly, individual differences in the efficiency with which students suppress the interference created by irrelevant information appear to be an important skill for school success. Electrophysiological data indicate that the students who show more mature patterns of brain activation during suppression of irrelevant information appear to use more appropriate strategies for dealing with school demands. Data obtained in this study provide evidence about the importance of executive attention for education. This type of evidence has the potential to guide the design of intervention programs aiming at enhancing school readiness. Our data point the importance of helping children develop their ability to suppress irrelevant information.

In the past years, there have been some efforts to improve children attention abilities through training. It has been shown that training of attention (Rueda, et al., 2005) and other forms of executive functions, such as working memory (Klingberg, et al., 2005) produces beneficial effects during development. Compared to untrained controls, children who underwent training of attention improved reasoning abilities and showed a more adult-like pattern of activation of the executive attention network (Rueda, et al., 2005) Although this type of research has provided encouraging evidence on the effectiveness of interventions, future research will be needed in order to test whether attention training results in better academic performance and schooling competence.

CAPÍTULO V

Discusión general

Las diferencias individuales que los niños presentan a la hora de controlar su comportamiento pueden afectar al correcto desarrollo del niño a nivel socio-emocional, así como, interferir con el rendimiento escolar. Estudiar cómo funciona el sistema de control y qué implicaciones tiene en el desarrollo del niño, tiene un gran valor, si atendemos a las consecuencias que puede conllevar un desarrollo inapropiado. El rendimiento académico y el comportamiento de los alumnos en clase preocupa tanto a profesores y padres como a las instituciones educativas. Esta es una preocupación que lleva a numerosas personas relacionadas con la educación a preguntarse cómo afrontar los problemas a los que diariamente se enfrentan en los centros escolares, preocupación que como máxima tiene el bienestar y el futuro de los niños. Aunandonos a esta preocupación, el objetivo principal de este estudio ha sido profundizar en el curso de desarrollo de la capacidad de control atencional y su relación con la autorregulación, y a su vez, conocer cómo esa capacidad de control podría afectar al ajuste del niño en contexto escolar y al rendimiento académico.

La gran variedad de medidas, cognitivas, temperamentales y electrofisiológicas, que se han utilizado en este trabajo permiten conocer con mayor profundidad cómo el sistema de control puede influir en la autorregulación y en última instancia en la competencia escolar.

RESUMEN DE LA EVIDENCIA APORTADA EN LA TESIS.

El objetivo del primero estudio era analizar el curso evolutivo del sistema de atención ejecutiva (AE) y su relación con la autorregulación. Para analizar el sistema de AE en el curso del desarrollo se tomaron medidas comportamentales y electrofisiológicas relacionadas con el procesamiento del error y la resolución de interferencia. Dado que la AE parece sufrir un desarrollo considerable en la niñez, se evaluaron ambos procesos en niños de edades comprendidas entre los 4 y los 13 años y en un grupo de adultos. Como se ha indicado, el interés era conocer la relación entre el funcionamiento cerebral relacionado con la AE y la ejecución de tareas en las que se requiere regular deseos inmediatos en pos de metas más a largo plazo. En general, se evidencia que el curso evolutivo de las capacidades atencionales está estrechamente relacionado con el desarrollo de los mecanismos cerebrales en los que estas capacidades se sustentan, y que este desarrollo se evidencia en una mayor eficacia en el sistema para controlar la conducta y para controlar los afectos.

En el segundo y tercer estudio, el objetivo principal fue determinar el papel que ejerce el sistema de control en la competencia escolar. Se optó por tomar medidas de diversa índole, relacionadas con el sistema de control, con la regulación emocional y social, el rendimiento académico y habilidades escolares que favorecen el aprendizaje.

Del segundo estudio se desprende que tener un sistema de control cognitivo más eficaz se relaciona con el éxito escolar y social de los alumnos de 1° de la ESO. Además, el sistema de control, medido a través del factor temperamental de control voluntario, parece ejercer un papel mediador entre el ajuste social en el aula y la competencia escolar.

Por otra parte, aunque el sistema de control parece ser un factor relevante para la competencia escolar pocas investigaciones han estudiado la relación entre la actividad cerebral relacionada con este sistema y el rendimiento escolar. Por ello, en el tercer estudio además de medidas temperamentales de control voluntario y medidas de inteligencia, se tomaron medidas electrofisiológicas relacionadas con la eficacia de la AE durante la realización de tareas que requieren la inhibición de respuestas y la supresión de interferencia producida por distractores. Posteriormente se analizó la relación de estas medidas con la competencia escolar. Nuevamente, los datos señalan que el factor temperamental de CV así como los mecanismos cerebrales subyacentes a la supresión de la interferencia, relacionados con estructuras de la red de atención ejecutiva, son predictores significativos de la competencia escolar.

En el siguiente esquema hemos tratado de resumir la evidencia encontrada a lo largo de los estudios presentados en la tesis que apoyan la relación del sistema de control atencional y temperamental con la regulación socio-emocional y con la competencia escolar. En él también se muestra la evidencia que apoya la relación entre la competencia escolar y el regulación socio-emocional.

En la figura 14a se especifican las variables que se han tenido en cuanta para evaluar el sistema de control atencional. En ella se especifican aquellas variables que se han utilizado para medir la Atención Ejecutiva y el Control Voluntario. Entre las medidas de Atención Ejecutiva se muestra, a nivel comportamental la supresión de la interferencia y a nivel cerebral los índices electrofisiológicos, ERP_{i-c}, ERN y Pe. Y por último, se muestra el factor temperamental de control voluntario. Las relaciones que se han mostrado entre estos dos niveles de análisis se señalan con el símbolo ⟷ y con la signo (+) indicando una relación positiva.

En la figura 14 b se especifican las variables que se han evaluado relaciondas conla competencia escolar: rendimiento académico, habilidades escolares e inteligencia. El signo "+" o "-" indica la dirección de la relación. Del mismo modo, en la figura 14 c se especifican las variables relacionadas con la regulación: regulación emocional, social y comportamental. Los símbolos a la derecha de cada variable señalan la relación con las demás variables que evalúan el sistema de control y el signo "+" o "-" indica la dirección de la relación.

Entre la figura 14b y 14c aparece el símbolo ⇔ que especifica la relación que se establece entre la competencia escolar y la regulación. Esta relación se pormenoriza más abajo. El símbolo → representa las relaciones entre el rendimiento escolar y la regulación emocional y social. El símbolo → representa las relaciones entre las habilidades escolares y la regulación emocional. De nuevo, en todas estas relaciones el signo "+" o "-" indica la dirección de la relación.

Estas relaciones se discuten a continuación.

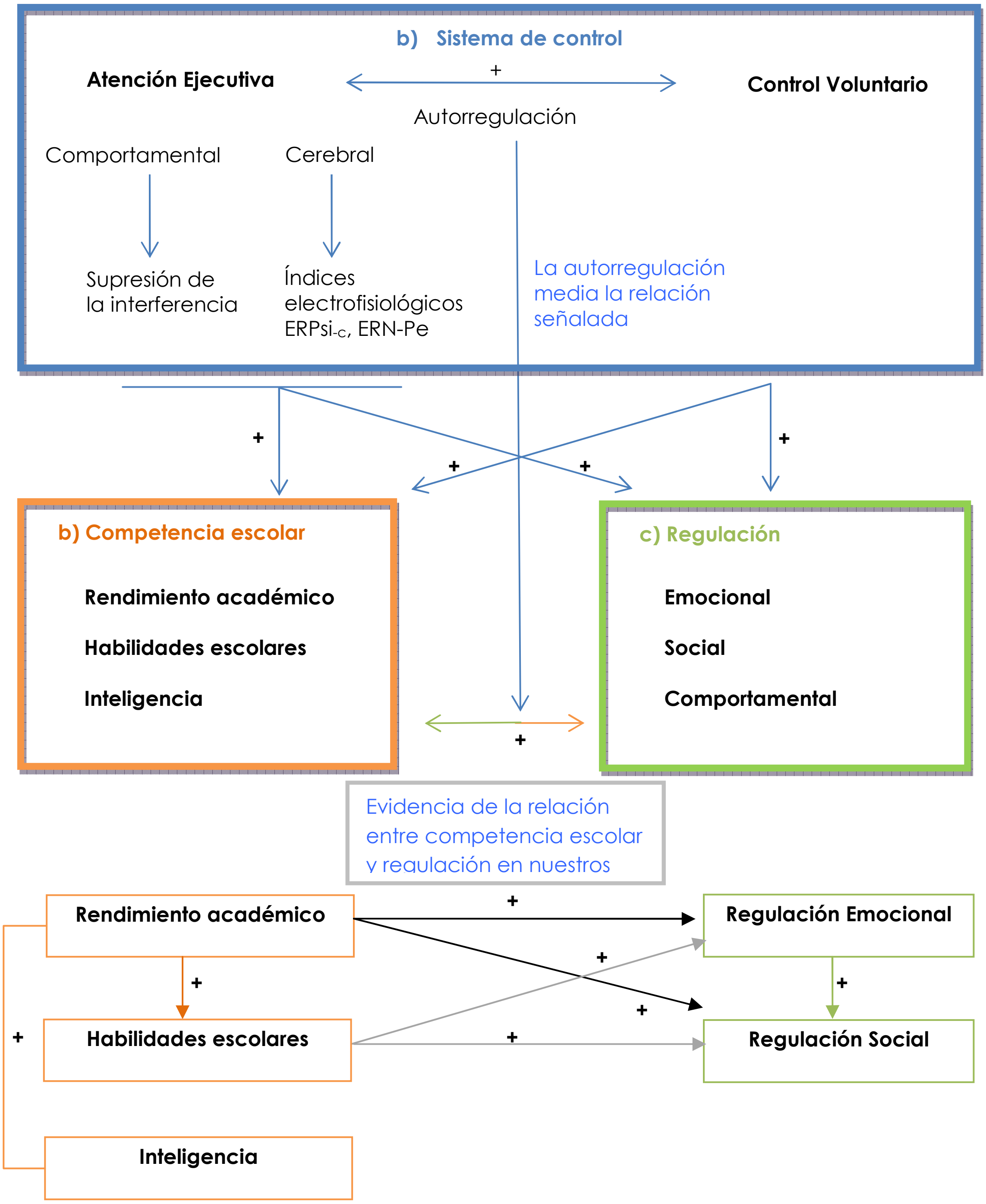

Figura 14. Representación de los datos que apoyan las hipótesis relacionales

RELACIÓN ENTRE LOS DIFERENTES NIVELES DE ANÁLISIS DEL SISTEMA DE CONTROL

A lo largo del trabajo de tesis se ha analizado el funcionamiento del sistema de control a distintos niveles: 1) a nivel temperamental a través de cuestionarios, 2) a nivel cognitivo a través de tareas de conflicto, y 3) a nivel cerebral a través de índices electrofisiológicos. Por una parte, se ha observado que una buena eficacia atencional medida a nivel cognitivo con tareas de conflicto, se relaciona positivamente con una disminución de la amplitud en el componente electrofisiológico relacionado con la resolución del conflicto ($ERPs_{I-C}$), disminución que se ha interpretado como evidencia de un mejor funcionamiento del mecanismo cerebral en la que la Atención Ejecutiva se sustenta Aunque no se encontró una relación significativa entre la funcionalidad cerebral relacionada con la Atención Ejecutiva y el Control Voluntario, si se observó que la eficacia atencional medida con las tareas de conflicto se relaciona positivamente con el CV. Esta relación se ha observado en diferentes estudios de desarrollo (Gerardi-Caulton, 2000; Gonzalez, y cols., 2001; Rothbart, y cols., 2003), interpretándose que la red cerebral de Atención Ejecutiva se encuentra a la base del CV. Esta interpretación, además, se ve apoyada por datos recientes que muestran que el altos niveles de CV se relaciona con un volumen más amplio en ciertas zonas cerebrales como el cortex frontal orbital (CFO) (Whittle, y cols., 2008). La relación entre el CV y el CFO es consistente con estudios de lesiones y de neuroimagen que muestran que esta región es importante para los procesos atencionales y la inhbición de la conducta en dominios afectivos y conductuales (Bechara, Tranel, y Damasio, 2000; Krigelbach y Rolls, 2004).

DESARROLLO DE LA ATENCIÓN EJECUTIVA

En la introducción hicimos una revisión de la literatura sobre desarrollo, en los cuales se evidenciaba que la AE experimenta un gran desarrollo durante la niñez (Clohessy, y cols., 2001; Diamond, 2001; Gerardi-Caulton, 2000; Rueda, Posner, Rothbart, y cols., 2004). Esta etapa en el desarrollo del niño se ha señalado como la etapa donde los niños comienzan a manifestar mayor capacidad de control y con un carácter más voluntario (Rothbart y Bates, 2006), con menor dependencia de señales externas para ejercer la regulación (Clarkins y Hill, 2006).

Ciertos datos en nuestro primer estudio muestran que el control puede ser ejercido a edades tempranas. Encontramos que el P300, un componente electrofisiológico relacionado con la evaluación de estímulos, se manifiesta en todos los grupos de edad. Este componente en nuestro caso está relacionado con la evaluación de un estímulo inesperado (feedback a respuestas correctas pero que han sido dadas fuera de tiempo) pero relevante para la tarea. Según los análisis de localización de la fuente de nuestros datos con adultos, este componente parece generarse en las áreas BA11, 6 y 24. Estos datos están en consonancia con otros hallazgos que muestran que el P300 ante estímulos inesperados se genera en áreas cerebrales implicadas en la regulación, como las zonas fronto-mediales (Luu, y cols., 2009; Tenke, y cols., 2010). El hecho de que el P300 no sufra modulación por la maduración y que su generación se asocie con áreas implicadas en la regulación, puede estar indicando que el sistema de AE es al menos parcialmente funcional a edades tempranas.

Por su parte, y aunque existen señales tempranas de control, como las anteriormente señaladas, el sistema de control parece seguir su proceso de maduración a lo largo de la infancia hasta la adolescencia (Davidson, y cols., 2006). Tal y como planteamos en nuestras hipótesis, el desarrollo del control voluntario debe reflejarse en la disminución de la impulsividad (Wiersema, y cols., 2007), en el aumento de la habilidad para procesar los errores (Jones, y cols., 2003) y para inhibir respuestas automáticas (Diamond, 1991), así como en la mayor eficacia para suprimir la interferencia creada por estimulación irrelevante e incompatible con la respuesta correcta (Gerardi-Caulton, 2000; Rueda, Posner, Rothbart, y cols., 2004). Nuestros datos apoyan estas mejoras en eficacia cognitiva relacionada con las capacidades atencionales, que a su vez van acompañados por una mejora en los mecanismos cerebrales en los que éstas capacidades se sustenta. Dicha mejora se evidencia en una disminución del tiempo necesario para movilizar al sistema para que actúe en situaciones de conflicto, mostrándose que los adultos necesitan menos tiempo para enfrentarse a las situaciones conflictivas, lo que se refleja en la aparción de la diferencia en entre el ERPs relacionado con situaciones conflictivas y no conflictivas (ERPs$_{i-c}$) aproximadamente a los 350 ms después de la aparición del estímulo, mientras que los niños necesitan alrededor de unos 450 ms para hacerlo. La mejora en el sistema atencional también se evidencia en una disminución en el tiempo que necesita para resolver el conflicto, manteniéndose la diferencia en amplitud del ERPs$_{i-c}$ por más tiempo en niños que en adultos. En cuanto al papel funcional atribuido al efecto de conflicto medido en amplitud de los portenciales evocados,a lo que hemos denomindo ERP$_{i-c}$ existen datos contradictorios. Mientras unos autores asumen que la disminución en amplitud del ERP$_{i-c}$ refleja una mejora del sistema de control (Johnstone, Pleffer, Barry, Clarke, y Smith, 2005; Rueda, Posner, Rothbart, y cols., 2004) otro autores afirman que el aumento de dicho amplitud es el reflejo de la mejora (Ladouceur, y cols., 2007). Nuestros datos apoyan que la disminución es el reflejo de una mejora en el sistema de control ya que una menor amplitud en el ERP$_{i-c}$ se ha relacionado con bajos niveles de impulsividad, disminución en el tiempo necesario para resolver el conflicto entre información competitiva, así como, con una conducta más regulada en situaciones afectivas.

Otro dato que apoya el desarrollo progresivo del sistema de control a nivel cerebral son los datos relacionados con el procesamiento del error. Parece claro que los niños pequeños realizan un procesamiento consciente del error, pero no será hasta la adolescencia cuando este procesamiento se complete. Cómo hemos indicado en la introducción, el Pe es un componente electrofisiológico relacionado con el procesamiento tardío del error, que se relaciona con la evaluación consciente y emocional del mismo. Datos de estudios previos y los aportados por nuestro estudio, muestran que el Pe no se modula con la maduración (Davies, y cols., 2004a; Wiersema, y cols., 2007). Esto podría indicar que el sistema de control en los niños de corta edad, 4 años en nuestro caso, puede llevar a cabo cierto procesamiento relacionado con el error, aunque hasta la edad de 10 a 13 años no aparecerá el componente más temprano relacionado con el procesamiento del error (ERN). Por otro lado, conocemos que el Pe y el ERN se generan en zonas cerebrales diferentes (Herrmann, y cols., 2004). Nuestros datos de localización de la fuente así lo demuestran señalando que el ERN parece generarse en el CCA dorsal (BA 24) y el cortex orbito-frontal y medial, mientras que el Pe parece generarse en el CCA dorsal (BA32) y el giro frontal medial.

En su conjunto, los datos de desarrollo y de análisis de localización de la fuente de activación sugieren que el sistema de control en los niños pequeños tarda más tiempo en procesar el error, sin llevar a cabo un procesamiento temprano del mismo, lo que en todo caso podría estar indicando que los niños pequeños no utilizan los mismos mecanismos de control ni las mismas zonas cerebrales, que los adultos y los niños más mayores, para hacer frente a una misma acción o información errónea.

REGULACIÓN SOCIO-EMOCIONAL

Numerosas investigaciones señalan la importancia de la AE y el CV en la regulación socio-emocional. Estudios previos han mostrado que desde la niñez se aprecia que una mayor eficacia de funcionamiento de la red de Atención Ejecutiva, medida a través de tareas de conflicto, se relaciona con una mejora en las expresiones emocionales de ira, frustración, malestar y tristeza (Gerardi, 1997; González, y cols., 2001). El factor temperamental de CV, como parte del mismo sistema control, también parece ejercer su influencia reguladora en la emoción. En virtud de ello, las investigaciones señalan que niños cuyos padres les atribuyen mayores puntuaciones de CV son niños menos reactivos y más regulados tanto ante situaciones emocionales positivas como negativas (Rothbart, y cols., 1994). Tener un sistema de control más eficaz, no sólo parece favorecer la regulación a nivel emocional, sino que también parece favorecer el ajuste social, disminuyendo la probabilidad de conductas socialmente indeseadas como la agresión (Ellis, y cols., 2004; Olson, y cols., 2005) y favoreciendo aquellas socialmente apropiadas, como la empatía (Rothbart, y cols., 1994; Valiente, y cols., 2004).

En nuestro estudio, por un lado, comprobamos que una buena eficacia de la red de Atención Ejecutiva se relaciona con una mejora en la regulación de la emoción negativa (afecto negativo), así como de tendencias reactivas de aproximación (extraversión). Por otra parte, apreciamos que efectivamente, un buen sistema de control tanto atencional como temperamental parece ser que se relaciona con la regulación que los niños muestran en contextos sociales, utilizando métodos socialmente aceptados y evitando conductas agresivas. Esto quizá favorezca la apreciación que sus compañeros muestran hacia ellos, eligiéndoles con mayor probabilidad para pasar el tiempo libre.

La relación entre el sistema de control cognitivo y temperamental y la regulación socio-emocional no es sorprendente, dado el papel que dentro del modelo neuro-cognitivo atencional de Posner se le atribuye a la red de Atención Ejecutiva. Se conoce que una de la áreas que forma parte de esta red, el cíngulo anterior, está implicado en el control de la información tanto cognitiva como afectiva (Botvinick, Nystrom, Fissell, Carter, y Cohen, 1999; Fan, Flombaum, McCandliss, Thomas, y Posner, 2003). En consonancia con la idea que el CCA se encarga de controlar la información emocional, encontramos que los índices electrofisiológicos medidos en nuestro estudio se relacionaban con la regulación de la emoción positiva, cuando los niños han de demorar en situaciones afectivas, y con la regulación del afecto negativo. Aunque en nuestro estudio no se analizó la relación entre dichos índices electrofisiológicos y la ajuste-socioemocional, otros datos sugieren que una hipo-activación del CCA (disminución en la amplitud del ERN) se relaciona con problemas de socialización en niños de 10 años (Santesso, y cols., 2005) y adultos (Munro, y cols., 2007).

RENDIMIENTO ACADÉMICO

En general, las funciones relacionadas con la red de Atención Ejecutiva, como la inhibición de la respuesta y la supresión de la interferencia, se consideran como parte fundamental de la arquitectura neurocognitiva que permite desarrollar actividades intelectuales de alto nivel. La importancia del sistema de control atencional y temperamental se pone de manifiesto en nuestro estudio al encontrar que el rendimiento escolar y el ajuste socio-emocional se relacionan con la capacidad de atención en general. En particular, en el proceso de aprendizaje que tiene lugar en el colegio, la regulación es necesaria para dirigir la atención a las explicaciones de clase y a las tareas escolares que se llevan a cabo, ignorando las estimulaciones que puedan interferir. Dicho control sobre la cognición se refleja en la perseverancia ante las tareas de clase, en la aplicación del conocimiento aprendido, en la expresión de las ideas ante la clase, en el afrontamiento de los fallos cometidos y en el seguimiento de las normas establecidas en clase. Todas estas habilidades son habilidades necesarias para que el proceso de aprendizaje se complete con éxito y para que el niño experimente su capacidad para enfrentarse a los desafíos que se presentan en el colegio. La regulación que el sistema de control ejerce no sólo se refleja en estas habilidades escolares, sino que última instancia se reflejan en el éxito académico de los alumnos. Nuestros datos señalan que cuando el alumno regula su atención ante la información relevante, y controla de un modo voluntario su actuación en el colegio, se obtienen mejores resultados académicos, es decir, calificaciones más altas. En concreto encontramos que aquellos niños con menor interferencia en una tarea de flancos y/o aquellos que eran definidos por sus padres con un mayor CV, fueron aquellos que obtenían mejores notas en general, particularmente en la asignatura de matemáticas. Que la regulación cognitiva se refleje en un mayor rendimiento académico es un dato particularmente interesante, teniendo en cuenta los requisitos cognitivos de las tareas de clase. Muchas de las tareas escolares, y especialmente las que implican razonamientos matemáticos, requieren representar los conceptos de forma abstracta, mantenerlos en la memoria de trabajabo para poder razonar sobre ellos y relacionarlos con otros conceptos, distinguiendo entre la información que es relevante para el resultado y la que no lo es. Una buena capacidad atencional confiere al alumno la habilidad para concentrarse en la información relevante de la tarea en cuestión, ignorando información irrelevante y distractora. Nuestro estudio, además, es uno de los pocos que examina la relación entre la función atencional a nivel cerebral y el rendimiento académico. Los datos electrofisiológicos corroboran los datos comportamentales, señalando que una mayor eficacia del sistema de atención ejecutiva a la hora de suprimir información irrelevante reflejada en una menor amplitud en el $ERPs_{i-c}$ predice mejores resultados académicos.

En cuanto a la inteligencia, algunos trabajos previos han mostrado relaciones positivas entre el factor “g” y las funciones ejecutivas, así como con el rendimiento académico (Engle, Tuholski, Laughlin, y Conway, 1999). Nosotros hemos encontrado que junto a la capacidad de control, la inteligencia, es un factor importante en la predicción del rendimiento académico. Este dato está en consonancia con la idea de que las habilidades que se ponen en marcha cuando se resuelven los test de inteligencia requieren de control atencional, compartiendo para ello el mismo sistema cerebral. En apoyo a esta idea ciertos estudios muestran que se aprecian similitudes comportamentales entre personas con un baja inteligencia y personas con lesiones en el lóbulo frontal (Duncan, 2005). Además, un estudio reciente con resonancia magnética funcional muestra que tanto adultos como niños activan el cortex pre-frontal dorso-lateral y el cortex pre-frontal rostro-lateral para resolver las matrices progresivas del test de inteligencia de Raven (Crone, y cols., 2009). Esta anatomía coincide mayoritariamente con las áreas de la red de AE, propuestas en el modelo neurocognitivo de Posner.

En el colegio, los alumnos no sólo han de regular su comportamiento para desempeñar las tareas académicas, sino también para convivir en el contexto social del colegio. La capacidad de autorregulación a nivel emocional y social es necesaria para establecer un clima que favorezca el aprendizaje en el colegio, y en último término, que promueva que se alcancen los resultados académicos deseados. Diversos estudios han mostrado como la socialización del niño, así como su regulación emocional afectan al rendimiento escolar (Mashburn y Pianta, 2006; Risi, y cols., 2003). Nuevamente, en apoyo a la evidencia previa, y tal y como planteábamos en nuestras hipótesis, nuestros datos muestran que una buena regulación de la emoción negativa favorece el éxito a nivel académico y el despliegue de habilidades escolares. Además, son los niños que muestran una regulación social mayor los que rinden a niveles más altos en el colegio, mostrando una mayor tolerancia a la frustración y un mejor seguimiento de las normas en clase. Así mismo, entre sus iguales estos alumnos son considerados como niños poco conflictivos y mantienen un estatus social favorable, siendo considerados como buenos compañeros tanto para realizar trabjos académicos como para pasar el tiempo libre.

Por tanto, en la medida que los alumnos pueden controlar con más eficacia su atención, estos parecen mostrar una mayor capacidad para regular su comportamiento en el colegio. Esto se evidencia en una mejora en la eficacia para procesar la información relevante, así como en un mejor control de las tendencias automáticas de actuación, siguiendo las normas sociales, y mostrando conductas adecuadas tanto a las demandas de sus compañeros, como a las demandas propias de las actividades escolares.

Dado que el sistema de regulación atencional y temperamental parece influir no solo en la regulación socio-emocional sino también en la competencia escolar, nosotros quisimos conocer qué papel específico juega el sistema de regulación en la competencia escolar. Los análisis mediacionales realizados parecen señalar que el control voluntario es la clave para entender la relación entre la regulación social y el rendimiento académico. Esta variable se establece como una variable mediadora entre la regulación social y el rendimiento académico. Este dato es de gran valor dentro del campo educativo, ya que el desarrollo de programas de entrenamiento de la capacidad de control atencional puede constituir un método eficaz de fomento de la competencia escolar y el desarrollo socio-emocional de los escolares.

IMPLICACIONES PARA LA EDUCACIÓN

Las relaciones que se establecen entre las distintas variables relacionadas con el control atencional y la auto-regulación expuestas en este trabajo, nos ayuda a comprender la importancia que el sistema de regulación tiene para la competencia escolar. Por un lado, el sistema de control se relaciona con la regulación a nivel cognitivo, social y emocional. A su vez, tener una buena regulación en todos estos niveles se relaciona con la competencia escolar. Por tanto, el tener un sistema atencional flexible capaz de adaptarse a las demandas situacionales en cada momento, hace que los alumnos se desarrollen con normalidad en un sistema escolar donde hay que enfrentarse no sólo a las demandas académicas, sino a las exigencias del sistema escolar a nivel social.

Además, los datos apuntan que esta regulación es un factor mediador entre la conducta social y el rendimiento académico de los alumnos, por lo que entrenar en esta habilidad tiene potencial para solventar algunos de los problemas que los niños presentan en su proceso de adaptación a los centros escolares, promoviendo la mejora social y el éxito académico.

Este estudio pone de manifiesto que quizá el entrenamiento de estas habilidades puede ser una vía de intervención para mejorar el rendimiento escolar, implementando dentro de los programas curriculares en los centros escolares, una línea educativa a nivel transversal, basada en el fomento de las capacidades atencionales del alumno. Dado que se conoce que el sistema neural tiene una plasticidad particularmente importante en los primeros años de vida (Neville y Bavelier, 1999) esto abre la puerta a la posibilidad de que el sistema de control pueda modularse con la experiencia. Por ello, en los primeros años escolares, el aprendizaje en control atencional podría establecerse como una habilidad más a educar, desarrollandose programas específicos, para la enseñanza de esta habilidad, y quizá confiriéndole la misma importancia que se le otorga a otras habilidades que se adquirieren en el periodo de preescolar como la lectura. Recientemente, Diamond et al (Diamond, y cols., 2007) en Estados Unidos, han mostrado que métodos educativos que enfatizan los aspectos de control de la atención durante las interacciones sociales en el colegio mejoran la capacidad de control cognitivo, más que los métodos tradicionales.

FUTURAS LÍNEAS DE INVESTIGACIÓN

Teniendo en cuenta los datos aportados por este estudio, los esfuerzos podrían dirigirse a implentar dentro de las líneas curriculares de los centros escolares, una línea de intervención educativa basada en la mejora del control atencional y temperamental. Dado que es en los años preescolares cuando se produce un mayor desarrollo de la habilidad de control atencional, esta etapa podría ser la etapa idónea donde iniciar dicha intervención. En esta línea, se han realizado varios estudios. Rueda y cols (Rueda, y cols., 2005) diseñaron un programa de entrenamiento en atención que recientemente ha sido modificado y aplicado a población española (Rueda, Checa, & Santonja, 2008). En el estudio original, Rueda y cols (2005) entrenaron a un grupo de niños de entre 4 y 6 en la función atencional mostrando mayores beneficios en el curso temporal de los mecanismos cerebrales subyacentes al control atencional en niños entrenados comparados con niños no entrenados. Además, dicha mejora se evidenció en mejores puntuaciones en inteligencia. En el estudio realizado en España, se replicaron los resultados encontrados previamente, mostrando además que el beneficio del entrenamiento se mantenía a lo largo del tiempo y se extendía a la regulación emocional. Dado que este entrenamiento parece mejorar no sólo el funcionamiento del control atencional sino también las habilidades de razonamiento (inteligencia) y la regulación emocional, parece lógico pensar que este entrenamiento pueda tener una repercusión en el rendimiento académico y el ajuste socio-emocional al colegio, por lo que una de las líneas de investigación futuras que sugieren los datos del presente estudio podrían dirigirse a evaluar dicha repercusión.

Aunque efectivamente, nuestros datos señalan la importancia del sistema neurocognitivo atencional en el desarrollo socio-emocional y académico, otros estudios ponen de manifiesto la importancia de variables tales como las familiares y ambientales (ej. estatus socio-económico; (Hill, 2001; Kessler, 2002; Ryan, y cols., 2006) sería interesante explorar si estas variables modulan el funcionamiento del sistema de control atencional, y si por otra parte, el entrenamiento puede mejorar la eficacia de la Atencion Ejecutiva de los niños de modo diferente en función de estas variables.

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Neurocognitive and Temperamental Systems of Self-Regulation and Early Adolescents' Social and Academic Outcomes

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ABSTRACT—The aim of the current study was to examine the role of individual differences in neurocognitive and temperamental systems of self-regulation in early adolescents' social and academic competence. Measures used in the study included the Attention Network Test, the Early Adolescence Temperament Questionnaire, a peer-reported Social Status Questionnaire, a self-reported measure of Schooling Skills, and information on grades obtained by the students in a variety of school subjects (n = 69 12-year olds). Results showed that efficiency of the neurocognitive network of executive attention is related to academic outcomes, particularly in mathematics, as well as to aspects of social adjustment. Temperamental effortful control appears to be a significant predictor of all dimensions of school competence assessed in this study and mediates the relationship between social adjustment and poor schooling outcomes. These data suggest that individual differences in systems of self-regulation are central to understanding processes of learning and social adjustment in the school.

Selecting information and controlling thoughts and actions have been a major function of attention from the earliest theoretical models (James, 1890). Individual differences in attentional control and temperamental characteristics related to volitional regulation of feelings and actions largely contribute to the ability to accomplishing goals, following instructions, and complying with social norms.

Data have supported the presence of three brain networks related to different aspects of attention. These networks carry out the functions of alerting, orienting, and executive control (Posner, Rueda, & Kanske, 2007). Alerting is defined as achieving and maintaining a state of high sensitivity to incoming stimuli and has been associated with frontal and parietal regions of the right hemisphere. Orienting refers to the selection of information from sensory input. The orienting system for visual events has been associated with posterior brain areas, including the superior parietal lobe, the temporal parietal junction, and the frontal eye fields. Finally, executive attention involves the mechanisms for consciously monitoring and resolving conflict among thoughts, feelings, and responses. It is related to action coordination in novel or dangerous situations, detecting and correcting errors, and overcoming habitual (or automatic) responses (Posner & DiGirolamo, 1998). The brain network associated with this function includes the anterior cingulate cortex (ACC) and lateral prefrontal cortex.

The executive attention network is the most directly involved in cognitive and affective regulation (Bush, Luu, & Posner, 2000). One of the main nodes of the executive attention network, the anterior cingulate gyrus, is consistently activated by situations requiring the regulation of induced emotions (Beauregard, Levesque, & Bourgoulin, 2001; Ochsner, Bunge, Gross, & Gabrieli, 2002). Moreover, the extent of activation of the executive network has been related to regulation of memory processes (Anderson et al., 2004) and other cognitive demands such as perception, response

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selection, working memory, and problem solving (Duncan & Owen, 2000).

Understanding individual differences in the efficiency of self-regulation from infancy to adulthood has been undertaken in studies of temperament. Temperament is defined as constitutionally based individual differences in reactivity and regulation in emotion, activity, and attention (Rothbart & Bates, 2006). Research in the past years has come to identify three broad dimensions that characterize temperament during childhood and adolescence (Rothbart, 2007; Rothbart & Bates, 2006), namely, Extraversion/Surgency (E/S), Negative Affect (NA), and Effortful Control (EC). The first two dimensions describe individual differences in approach/avoidance reactivity, respectively. The third dimension describes individual differences in attentional control and the flexible regulation of behavior, such as choosing a particular action under conflicting conditions, detecting errors, and planning (Rothbart & Rueda, 2005). Reactive temperament has been related to functioning of the amygdala and dopamine systems, respectively, for NA and E/S (Rothbart & Posner, 2006), whereas the executive attention network is viewed as the neural substrate supporting EC (Rothbart & Rueda, 2005; Rueda, Posner, & Rothbart, 2005).

The concepts of executive attention and EC represent different levels of analysis of the ability to exercise control over one's behavior (Rothbart & Rueda, 2005; Rueda, Posner, & Rothbart, 2004). Executive attention is a concept emerging from the neurocognitive literature and is linked to the control of cognition and cognitive flexibility; whereas EC is a concept developed within the literature on temperament and it is related to the regulation of reactivity systems associated with positive/approaching and negative/avoiding responses. Several studies have consistently shown a correlation between performance in conflict tasks tapping executive attention, such as Stroop-like and flanker tasks, and parent- and self-reported measures of EC (Rueda, Posner et al., 2004). Thus, together with their conceptual overlap, the empirical correlation supports the idea of these two concepts as representing different dimensions of a system involved in self-regulation.

Both reactive and regulative systems, as well as the interactions between them, are involved in socialization and socioemotional regulation. For instance, during childhood, EC appears to be negatively associated with the incidence of externalizing behavioral problems, which are characterized by high levels of aggression and impulsivity, after controlling for other cognitive and social risk factors (Olson, Sameroff, Kerr, Lopez, & Wellman, 2005; Valiente et al., 2003). In addition, preadolescents with and without behavioral problems appear to have different temperamental profiles. Individuals exhibiting externalizing problems show higher scores on E/S and frustration and lower rates of EC, while individuals showing internalizing problems are high on fear and shyness and moderately low on EC (Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004). Other studies have also shown that both mother and self-reported low EC together with poor efficiency of executive attention appear to be consistent predictors of behavior problems during adolescence (Ellis, Rothbart, & Posner, 2004).

The ways in which children differ from one another affect their willingness to explore and learn as well as their discouragement, frustration, and avoidance of potential sources of knowledge (Rothbart & Jones, 1998). Hence, due to variations in reactivity and attentional control, children may differ in their adjustment to the requirements and challenges of the educational setting. In turn, this adjustment process seems to influence more specific aspects of social development such as self-esteem and relationships with peers, parents, and teachers (Sanson, Hemphill, & Smart, 2004).

Negative emotionality and low EC have been consistently linked to problems with adjustment at school from a young age (Nelson, Martin, Hodge, Havill, & Kamphaus, 1999). Teacher-rated higher levels of aggression and anxiety in kindergarten are related to poorer achievement through a relation with lack of cognitive self-control in school tasks (Normandeau & Guay, 1998). Moreover, measures of EC in children show a positive association with academic outcomes, especially mathematics (Blair & Razza, 2007).

The role of attention in cognitive and affective regulation suggests that this function would also be a relevant contributor to school competence. In line with this, measures tapping the executive attention network, such as Stroop-like interference and performance on inhibitory control tasks, also show a consistent relationship with arithmetic competency (Blair & Razza, 2007; Bull & Scerif, 2001; Espy et al., 2004). In addition, there is some evidence indicating that children's attention is associated with adjustment to the school context (Raver, Blackburn, Bancroft, & Torp, 1999). Eisenberg, Guthrie, and colleagues (1997) also found an association between teachers' and parents' reports of elementary school children attentional control and peer nominations for social status.

The current study aims at examining the interrelations between efficiency of attentional networks and temperament in early adolescents, and to determine the contribution of the different cognitive and temperamental systems to social and academic aspects of school competence during that age period. Figure 1 presents an overview of the attentional and temperamental measures taken into account and their hypothesized relationship to the various dimensions of school competence considered in the current study. Given the central role of systems of EC and executive attention on self-regulation, we expected these two measures to be the strongest predictors of social adjustment and academic performance. Moreover, considering prior evidence suggesting that processes of peer rejection lead to decreases in classroom participation and to lower rates of achievement in childhood (Buhs, Ladd, & Herald, 2006), we expected peer reported evaluations of social status to be related to academic competence in our study. However, we also anticipated individual differences

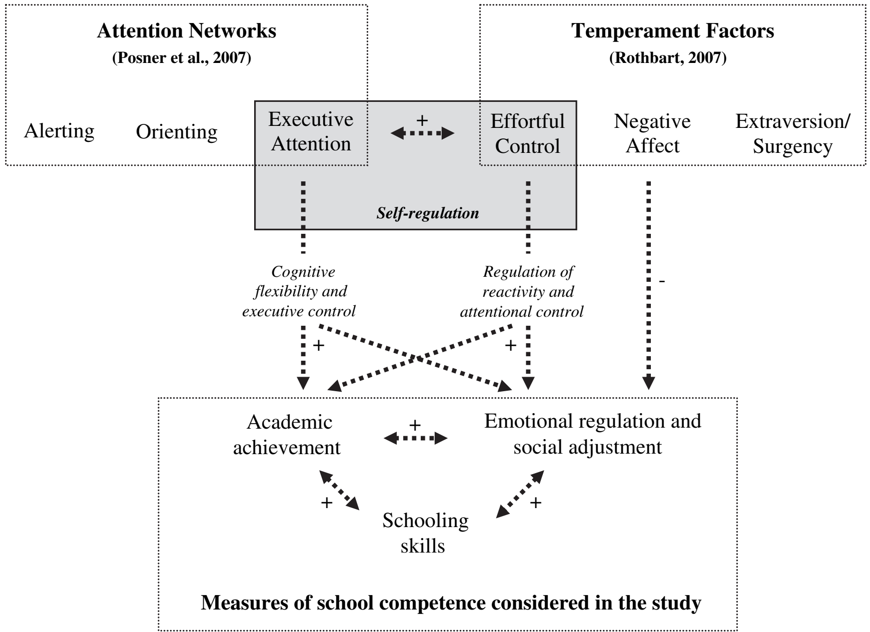

Fig. 1. Overview of the attention and temperament measures assessed in the current study and their hypothesized relationships with academic achievement, socioemotional adjustment at the school, and schooling skills.

in self-regulation to play an important role in the association between maladjustment and competence at school.

METHOD

Participants

Sixty-nine children (mean age: 12.7 years, *SD*: 0.65; 34 boys) enrolled at Padre Manjón High School in Granada (Spain) and their parents participated in the study. Participants were recruited through a mailed letter addressed to their families. The caregivers of all participants gave written consent to be involved in the study. All participants except three were Caucasian-European.

Procedure

Participants completed questionnaires on temperament, schooling skills, and social status individually while in class in two separate 50-min sessions. In a third session, children performed the Attention Network Test (ANT). This task was administered at the school simultaneously for groups of 10–12 children. The instructions to complete the task were given collectively and then the task was completed individually by each child in a computer assigned to him/her with sufficient separation between participants. The parent-report version of the temperament questionnaire was sent to the parents with instructions for completing it and returning it to the school in a sealed envelope. Finally, the high school board provided information on grades obtained at the end of the academic year.

Measures

Attention Network Task

A modified version of the Fan et al. (2002) adult ANT was used.[1] Information on the procedure of this task is provided in Figure 2. Completion of the task allows calculation of three scores related to the efficiency of the attention networks. The *alerting score* provides a measure of the benefit in performance by having a signal that informs about the immediate upcoming of the target and using this information to get ready to respond. The *orienting score* provides a measure of how much benefit is obtained in responding when information is given about the location of the upcoming target. Finally, the *executive attention score* indicates the amount of interference experienced in performing the task when stimulation conflicting with the target is presented in the display. Larger interference scores indicate less efficiency of conflict resolution mechanisms (executive attention).

Temperament Questionnaires

Self-report and parent-report versions of the Early Adolescence Temperament Questionnaire-Revised (EATQ-R; Ellis and Rothbarth, 2001) translated into Spanish were used to measure children's temperament. These questionnaires contain 65 items (self-report) or 62 items (parent-report) describing adolescents' behavior in a variety of everyday life situations. Participants' answers indicated the extent to which each item applied either to them (self-report) or their child (parent-report). The EATQ-R collects information about four broad factors of children's temperament: EC, E/S, NA and Affiliation

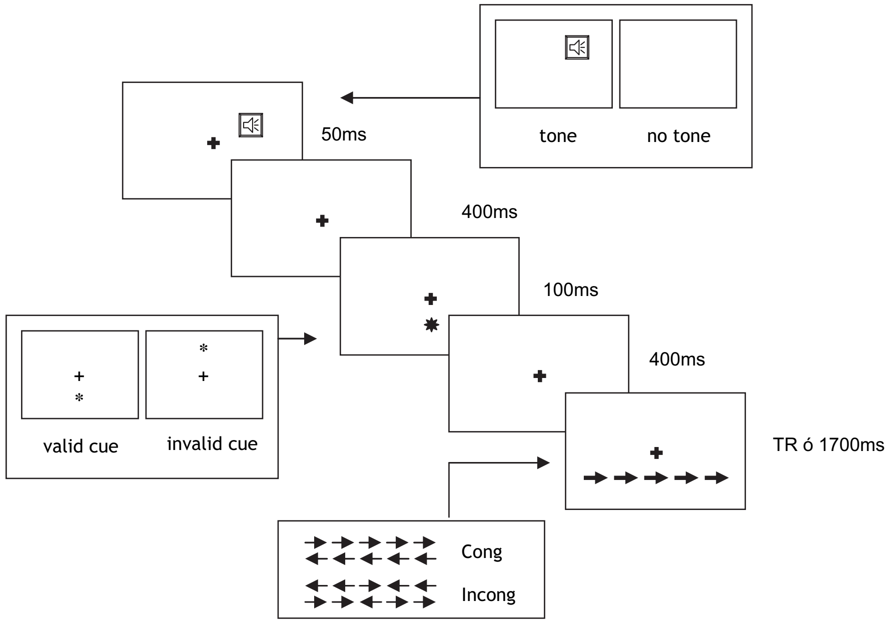

Fig. 2. Schematic representation of the Attention Network Test (ANT). Each trial starts with the presentation of a fixation cross lasting between 400 and 1600 ms. Then, an auditory tone of 2,000 Hz (alerting cue) in half the trials during 50 ms (no tone was presented in the other half). After a blank interval of 400 ms, an orienting cue consisting of an asterisk is presented in two-thirds of the trials for 50 ms (in the other one-third of the trials no cue was presented). Finally, a target stimulus is presented consisting of an arrow pointing either right or left. The target is flanked by two arrows on each side. The flanking arrows may point in the same direction as the target arrow (congruent trials), or in the opposite direction (incongruent trials), equally often. The target appears either above or below the fixation point. When presented, the orienting cue appears with equal probability either at the same location as the target (cued trials) or at the opposite location (uncued trials). Participants are instructed to discriminate the direction of a target arrow by pressing a corresponding key, left or right, in the computer's keyboard as rapidly and accurately as possible, while both reaction time (RT) and accuracy of the response are registered. *Note.* Alerting score = median RT to no tone trials – median RT to tone trials; Orienting score = median RT to trials with invalid cue – median RT to trials with valid cue; Executive Attention score = median RT to incongruent trials – median RT to congruent trials.

(AF). The scales loading on the factor EC are Activation Control, Attention, and Inhibitory Control. The scales loading on the E/S factor are High-intensity Pleasure, Fear and Shyness, the last two loading negatively. Aggression, Depressive Mood, and Frustration, load on the NA factor. Finally, the AF factor is equivalent to the AF scale in the parent-report version. AF, Perceptual Sensitivity and Pleasure Sensitivity load on the AF factor in the self-report version. The internal reliability (measured by Cronbach's alpha) of the EATQ-R factors calculated in our sample were: EC, α = .84; AF, α = .73; E/S, α = .42: NA, α = .63, for the parent-report questionnaire; and EC, α = .71; AF, α = .41; E/S, α = 52.; NA, α = .51, for the self-report measure.

Schooling Skills

Information on schooling skills was obtained from each participant using the student-report version of the Health Resources Inventory (HRI; Juvonen and Keogh, 1992). The HRI consists of 31 items which group onto four factors: Rules Following (RF; Cronbach's α = .80), Student-role Understanding (SrU; α = .76), Sociability (SO; α = .64) and Tolerance to Frustration (TF; α = .60). The RF factor reflects the student ability to function within the constraints of the school environment (e.g., "I am well-behaved in school"). The SrU factor describes behavior associated with effective learning such as individuals' understanding of the duties and responsibilities of students (e.g., "I am interested in school work"). The SO factor consists of items reflecting effective interpersonal functioning (e.g., "My classmates are fond of me"). The factor TF measures the individual ability to cope with failure and other social pressures (e.g., "I can accept things not going my way"). All items are responded on a 5-point Likert scale ranging from *never* to *always*.

Peer-Reported Social Status

Information about social status was obtained for each participant using a peer-report questionnaire containing six questions. The first four questions are about naming three classmates who are (1) good to work with, (2) not good to work with, (3) good to spend free time with, and (4) not good to spend free time with. In question 5, students are asked to name classmates (one nomination per statement) who are characterized by a series of statements including (a) having a lot of friends; (b) not having a lot of friends; (c) having a good relationship with teachers; (d) not having a good relationship with teachers; (e) being a nice classmate; (f) not being a nice classmate; (g) being able to pay attention and listen to others; (h) often calling others attention; (i) having skills to solve social conflicts; (j) being aggressive; (k) having communication skills; (l) having troubles in communicating with others; (m) sharing his/her success with others; and (n) being an envious person. The factorial analysis of question 5 provided three different factors. The first factor, which accounted for 29.5% of the variance, was called "Appreciated" because all the items loading on it (a, c, e, g, i, and k; α = .85) were about positive social evaluations. A second factor that explained 16% of the variance was labeled "Rejected" because the items loading on it (b, f, and n; α = .75) implied a lack of social acceptation from peers. The third factor, which explained the 19% of the variance, was called "Unsocial" because it involved items related to behaviors that were not socially valued (d, j, h, and l; α = .94). Finally, in the last question of the Social Status Questionnaire, children rated how they got along with their classmates scoring each of them from 1 (*very well*) to 5 (*very bad*).

Academic Outcomes

The high school board provided information on grades obtained at the end of the academic year by each student (see Table 1).

Missing Data

The valid *n* for each measure is provided in Table 1. Sixteen parents refused to complete the temperament questionnaire. Two children did not complete the HRI questionnaire because

Table 1

Descriptive Statistics on all Measures

		Valid n	*Mean*	*Min*	*Max*	*SD*
Attention	Alerting (AL_{RT})	67	14.5	−0.41	78	223
(ANT scores)	Orienting (OR_{RT})	67	63.7	−3.5	157.5	27.7
	Executive attention (EX_{RT})	67	107	20	317.5	46
	Executive attention (% errors; EXERR)	67	4.8	−1	48	7.7
Temperament	Effortful control (EC_S)	69	3.6	2.5	4.9	0.6
(EATQ self	Extraversion/Surgency (E/S_S)	69	3.6	1.97	4.8	0.6
report)	Negative Affect (NA_S)	69	2.7	1.4	3.6	0.5
Temperament	Effortful Control (EC_P)	53	3.3	1.7	4.86	0.67
(EATQ parent	Affiliation (AF_P)	53	2.75	1.8	3.9	0.46
report)	Negative Affect (NA_P)	53	2.98	2.3	3.6	0.34
Schooling skills	Rules Following (RF)	67	3.9	2.2	4.9	0.61
(HRI self report)	Student-role Understanding (SrU)	67	4.1	2.4	5	0.59
	Sociability (SO)	67	4.3	2.4	5	0.61
	Tolerance to Frustration (TF)	67	3.8	2.2	5	0.68
Academic achievement	Nature science (NS)	69	5.8	1.5	10	2.3
(grades)	Social science (SS)	69	5.8	1	10	2.3
	Physical education (PE)	69	5.7	2.5	9.5	1.6
	Native language (NL)	69	6.1	2	9.5	1.8
	Foreign language (FL)	69	5.9	1	10	2.1
	Mathematics (MA)	69	5.7	1.5	9	1.9
	Music (MU)	69	5.8	1	10	2.3
	Technology/mechanical science (TM)	69	5.7	0.5	9.5	2.1
Social status	Good to work with (GW)	46	3	0	8	2.2
(peer reported)	Not good to work with (NGW)	46	3.1	0	21	3.7
	Good to spend free time with (GFT)	46	2.6	0	10	2
	Not good to spend free time with (NGFT)	46	2.5	0	20	3.7
	Appreciated (AP)	46	0.77	0	7.3	1.1
	Rejected (RJ)	46	0.60	0	10.3	1.8
	Unsocial (US)	46	0.60	0	8.7	1.3
	Mean score of social appreciation (mSA)	45	4.23	1.57	3.26	0.66

Note. ANT scores are expressed in milliseconds. Between parentheses appear the abbreviations of the variables names that will be used in subsequent tables and figures.

they were absent during the testing session. Finally, only 46 families consented to their child completing the Peer-Reported Social Status questionnaire.

RESULTS

Descriptive statistics on all measures are presented in Table 1.

Analysis of the ANT

Data from two children were not included in the analysis of this task due to technical problems during task completion. Separate 2 (alerting tone vs. no tone) × 2 (orienting valid cued vs. invalid cued) × 2 (executive attention congruent vs. incongruent) repeated measures analysis of variance (ANOVA) were conducted with the mean of median RTs and percentage of errors per condition. The three main effects were statistically significant: Alerting, $F(1, 66) = 6.2$; $p < .01$; partial $\eta^2 = .09$; Orienting, $F(1, 66) = 355$; $p < .001$; partial $\eta^2 = .84$; and Executive Attention, $F(1, 66) = 342$; $p < .001$; partial $\eta^2 = .83$) for the RT analysis. Significant interactions were found between Alerting and Orienting, $F(1, 66) = 5.2$; $p < .05$; partial $\eta^2 = .07$, and Orienting and Executive Attention, $F(1, 66) = 18.8$; $p < .001$; partial $\eta^2 = .22$). For the ANOVA with error percentage, the only statistically significant effect was that of Executive Attention, $F(1, 66) = 26.7$; $p < .001$; partial $\eta^2 = .28$. Scores for each of the attention networks were calculated for each participant according to the subtractions described in Figure 2 using median RTs. Since the main effect of Executive Attention was significant in the accuracy ANOVA, we also calculated the score for this network using the percentage of errors.

Correlation Analysis

Pearson's unilateral correlations between the attention network scores and temperament measures are given in Table 2. Only temperamental factors with $\alpha > 0.50$ were included in the analysis. Correlations between the attention network scores and temperamental factors with all the school competence and social adjustment measures are given in Table 3. Finally, correlations among school competence and social status measures are shown in Table 4.

Regressions

Three dependent measures showed significant correlation with both executive attention and EC: grades in mathematics, mean of all grades, and the measure of Unsocial (see Table 3). To examine the unique contribution of these two aspects of self-regulation on the variance of these dependent measures, we conducted stepwise multiple regression analysis, controlling for covariance between independent measures. These analyses indicated that both parent-reported EC ($\beta = .47$; $p < .01$) and the executive attention score as measured by RT ($\beta = -.24$; $p = .05$) were significant predictors of the grade in mathematics (R^2 of the model: .34). However, the parent-reported EC ($\beta = .62$; $p < .05$) was uniquely related to the average of all grades (R^2 of the model: .47). Likewise, parent-reported EC was the unique significant predictor ($\beta = -.39$; $p < .05$) of Unsocial in the regression model (R^2 of the model: .15).

Mediational Analysis

We argued that aspects of self-regulation might mediate the relationship between social adjustment and schooling outcomes. To test this hypothesis, we carried out mediational analysis for those social and self-regulation variables that were intercorrelated with the average of grades and the average of schooling skills. The first mediational analysis showed that Unsocial behavior significantly predicted EC ($\beta = -.37$), as well as the average of grades ($\beta = -.28$). EC also significantly predicted the average of grades ($\beta = .6$). However, when EC was entered in the regression equation together with Unsocial, EC still significantly predicted the average of grades ($\beta = .7$), whereas Unsocial no longer significantly predicted the average of grades ($\beta = -.08$). This indicates that parent-reported EC mediates the relationship between higher levels of unsocial behavior and poor academic achievement at school (Figure 3a). Subsequent mediational analysis tested whether the relation between Unsocial and the average of all Schooling Skills was

Table 2
Correlations Between Attention and Temperament Measures

		Parent-Reported EATQ-r			*Self-Reported EATQ-r*		
		EC_p	AF_p	NA_p	EC_s	E/S_s	NA_s
ANT scores	Executive Attention RT	.25*	−.06	.09	−.01	.004	−.14
	Executive Attention ERR	−.21	.07	.17	−.12	−.24*	.002
	Alerting RT	−.06	−.08	−.01	.32*	.16	−.28*
	Orienting RT	.002	−.027	−.006	.04	−.18	−.18

Note. Suffix "p" indicates parent-reported, suffix "s" indicates self-reported. AF = Affiliation; EC = Effortful Control; E/S = Extraversion/Surgency; NA = Negative affect. Significance level: *$p < .05$.

Table 3

Correlation Between Attention and Temperament Measures and Measures of School Competence

		Grades		*Schooling Skills*					*Social Status*							
		Math	*Average of All*	*Rule following*	*Student-role understanding*	*Sociability*	*Tolerance to Frustration*	*Average of All*	*Good to work with*	*No good to work with*	*Good for free time*	*No good for free time*	*Appreciated*	*Unsocial*	*Rejected*	*Mean of Social Appreciation*
Attention (ANT scores)	EX_{TR}	-.28*	-.17	-.07	.07	.16	-.06	.03	-.09	.18	.10	.25*	-.04	.30*	.19	-.04
	EX_{ER}	-.23*	-.28*	.13	-.04	-.13	-.02	-.02	-.14	.02	.001	.07	-.05	-.10	.06	.02
	AL_{TR}	-.07	-.05	.03	.03	.25*	.15	.15	.14	.04	.03	-.04	.01	-.09	.04	-.13
	OR_{TR}	.13	.09	-.09	-.22*	-.05	-.16	-.17	.02	.04	.08	.07	.03	-.12	.10	.06
EATQ-r self report	EC_S	.30**	.32**	.37**	.84**	.29**	.34**	.45**	.14	-.09	-.14	-.18	.20	-.12	-.10	-.03
	E/S_S	-.09	-.18	-.15	.03	.10	-.04	-.02	-.11	-.004	.07	.05	-.10	.26*	-.04	-.17
	NA_S	-.14	-.16	-.32**	-.33**	-.27*	-.29**	-.39**	.08	-.06	.12	-.07	-.05	.23	-.12	.29*
EATQ-r parent report	EC_P	.58**	.65**	.39**	.44**	.32*	.29*	.45**	.23	-.01	-.30	-.21	.45**	-.37*	-.06	.33*
	AF_P	.32*	.21	.06	.21	.15	.04	.15	.37*	-.15	.03	-.15	.38*	-.12	.05	.03
	NA_P	-.28*	-.30*	-.24*	-.23*	-.29*	-.09	-.27*	-.35*	.29	.15	.50**	-.26	.26	.33*	-.40*

Note. Suffix "p" indicates parent reported; suffix "s" indicates self reported. AF = Affiliation; AL = Alerting; EC = Effortful Control; E/S = Extraversion/Surgency; EX = Executive attention; OR = Orienting; NA = Negative affect.
Significance levels: $^{**}p < .01$. $^{*}p < .05$.

Table 4

Correlation Among Measures of School Competence

		Grades		*Schooling Skills*					*Social Status*						
		Math	*Average of All*	*Rule Following*	*Student-role Understanding*	*Sociability*	*Tolerance to Frustration*	*Average of All*	*Good to work with*	*No good to work with*	*Good for free time*	*No good for free time*	*Appreciated*	*Unsocial*	*Rejected*
Grades	Math	—													
	All	.87**	—												
Schooling skills	RF	.38**	.48**	—											
	SrU	.24*	.38**	.71**	—										
	SO	.004	.20*	.37**	.57**	—									
	TF	.29*	.28*	.49**	.40**	.34**	—								
	All	.29*	.43*	.82**	.85**	.72**	.73**	—							
Social status	GW	.48**	.50**	.29*	.21	.19	-.02	.21	—						
	NGW	-.17	-.15	-.05	-.05	-.03	-.01	-.05	-.24	—					
	GFT	.18	.03	-.11	-.15	-.01	.02	-.08	.35**	-.21	—				
	NGFT	-.33*	-.37**	-.28*	-.21	-.20	-.12	-.26*	-.55**	.79**	-.02	—			
	AP	.39**	.46**	.19	.30*	.35*	.17	.32*	.53**	-.13	.28*	-.23	—		
	US	-.27*	-.28*	-.44**	-.19	-.07	-.30*	-.33*	-.25*	.10	.04	.26*	-.12	—	
	RJ	-.16	-.20	-.01	.01	-.05	-.10	-.04	-.32*	.72**	-.14	.79**	-.07	-.04	—
	mSA	.20	.29*	.08	.11	.08	-.08	.06	.38**	-.29*	.18	-.36**	.09	.07	-.37**

Significance levels: $^{**}p < .01$. $^{*}p < .05$

also mediated by parent-reported EC (Figure 3b) as well as the mediational role of EC in the relationship between social appreciation and schooling outcomes (Figure 4). EC was found to be a significant mediator of both the average of Schooling Skills and the average of all grades. Other mediational analysis were conducted with executive attention as the potential mediator between social measures and grades in mathematics, average of all grades, and average of schooling skills; these analyses yielded no significant mediational effects.

DISCUSSION

Attention and Schooling Outcomes

The executive attention score is indicative of the efficiency of brain mechanisms involved in conflict resolution and cognitive control (Posner & DiGirolamo, 1998). Individual variations in this score were related to academic achievement in general and more consistently to grades in mathematics. We also found a significant correlation between the executive attention score and parent-reported EC. As discussed earlier, the executive attention measure taps the efficiency of neurocognitive mechanisms important for resolving conflict among incongruent stimuli, such as detection of conflict and inhibition of both processing and responding to nonrelevant stimulation. EC refers to the efficiency with which self-regulatory abilities are used in both personal and interpersonal situations that require overcoming dominant but inappropriate responses. Our data showed that executive attention accounted for unique variance only when predicting grades in mathematics. Prior studies carried out with younger children have shown that various measures of executive function predict competence in arithmetic tasks (Blair & Razza, 2007; Bull & Scerif, 2001; Espy et al., 2004). In a study with kindergarteners, a cognitive measure of inhibitory control accounted for unique variance, independent from teacher's reports of EC, in predicting math abilities (Blair & Razza, 2007). Lateral frontal regions of the brain considered part of the executive attention network are activated by marker tasks of general intelligence (Duncan et al., 2000). In our view, efficiency of this brain system results in more successful acquisition and application of knowledge taught at school, especially in those subjects involving complex reasoning such as mathematics.

Larger interference scores, and hence poorer executive attention efficiency, was also related to peer reports of unsocial behavior as well as to nominations for being someone "not good to spend free time with." This relationship is also consistent with the role given to the executive attention network in Posner's model. One of the main nodes of this network, the ACC, is involved in controlling cognitive as well as affectively relevant information. The strong connections between the ventral division of the ACC and subcortical limbic structures such as the amygdala are likely to implement a circuitry for the control of emotion (Posner, Sheese, Odludas, & Tang, 2006). Larger rates of unsocial behavior together with larger interference scores in the ANT indicate less efficiency of this circuitry in exercising control over negative emotionality, likely leading to social maladjustment and rejection by peers.

The scores of the alerting and orienting networks show a much less clear pattern of associations with schooling outcomes than executive attention. The correlation between the alerting score and socialization might indicate that greater levels of responsiveness to stimulation leads to better processing of socially relevant cues from others, thereby

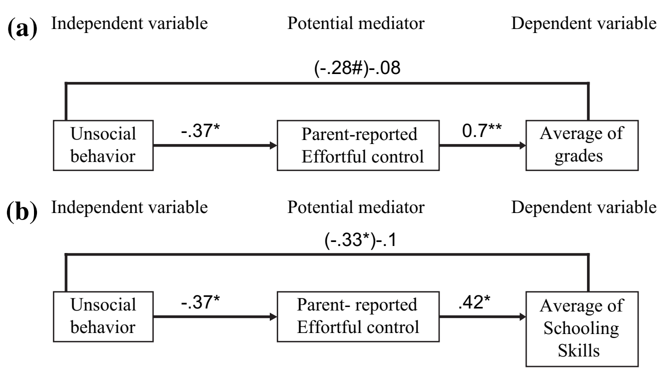

Fig. 3. Effortful Control as mediator of the effect of unsocial behavior on school competence. (a) Model predicting average of grades. (b) Model predicting average scores of Schooling Skills. Numbers are β values. Values in parenthesis show βs when the independent variable is regressed alone on the dependent variable. These values are followed by βs when both the independent variable and the potential mediator are regressed on the dependent variable. Significance levels: *** $p < .001$; ** $p < .01$; * $p < .05$; # $p < .06$.

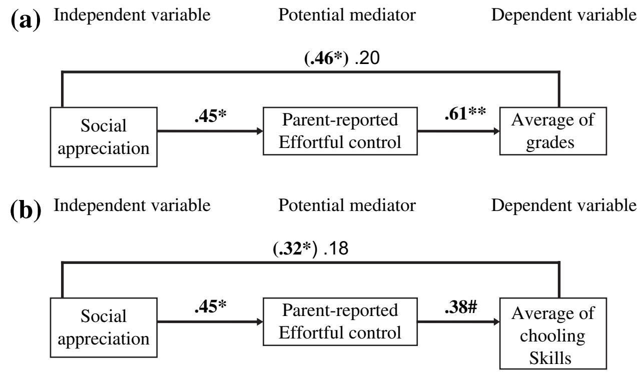

Fig. 4. Effortful Control as mediator of the effect of social appreciation behavior on school competence. (a) Model predicting average of grades. (b) Model predicting average scores of Schooling Skills. Numbers are β values. Values in parenthesis show βs when the independent variable is regressed alone on the dependent variable. These values are followed by βs when both the independent variable and the potential mediator are regressed on the dependent variable. Significance levels: ***$p < .001$; **$p < .01$; *$p < .05$; #$p < .06$.

enhancing responsiveness to such cues. However, the correlation between orienting and the SrU scale is more puzzling. Understanding this association would require replication and further investigation.

Imaging of brain activation during performance of the ANT has shown that performance of this task differentially activates the anatomical networks related to alerting, orienting, and executive attention (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). Moreover, the extent of activation of these networks appears to relate to performance of the task, which in turn relates to individual variation in particular genes involved in brain neurophysiology (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2001). In future studies, it would be desirable to include measures of brain function during performance of cognitive tasks to test the connection between activation of the brain network and behavioral regulation and achievement at school.

Temperamental Contributions to Social and Academic Outcomes

Temperamental systems of negative emotionality show a strong association with poorer schooling skills that is consistent across self and parent reports. Moreover, parent-reported negative affectivity is associated with low academic performance and increased social rejection in school. However, both self- and parent-reported temperamental EC is positively related to all measures of schooling skills and academic achievement, and parent-reported EC is also positively associated with social appreciation and negatively with unsocial behavior (Table 3).

The variety of measures used in our study allows for a deeper understanding of how temperament may influence school outcomes. Those children with higher reactive negative emotionality have more trouble following rules, understanding their role as students, socializing with peers, and tolerating frustration, and therefore might be experiencing greater difficulties adapting to the classroom setting. In turn, failure to use these skills likely results in behavior disruptive to the classroom routine, thus affecting both achievement and social acceptance, and potentially leading to increased discouragement, frustration, and avoidance of potential sources of learning. However, the positive association between individual differences in self-regulatory systems such EC and social and academic outcomes likely represent the influence of attentional control, persistence and motivation in the learning context (Martin, Drew, Gaddis, & Moseley, 1988; Rothbart & Hwang, 2005; Rothbart & Jones, 1998). Moreover, EC might provide the regulatory capacity needed to detect feelings of distress in oneself and others and link them to actions and moral values (Kochanska & Aksan, 2006). Thus, children with higher EC scores are more able to use their self-regulatory capabilities to comply with the demands of teachers and peers in the classroom, thus increasing their social acceptance and their opportunities to learn (Rothbart & Jones, 1998).

Additionally, better adjusted children are the ones obtaining better grades at school and showing better scores in skills important for positive schooling (Table 4). This pattern of associations is consistent with prior studies establishing that socioemotional competence contributes to adequate academic progress during childhood (Ladd, Herald, & Kochel, 2006). However, mediational analyses indicate that the relationship between social maladjustment and poorer schooling outcomes is mediated by EC (Figures 2 and 3). Although other studies have proposed that the development of positive social relationships in the school is the primary factor promoting school competence (Mashburn & Pianta, 2006), our data suggest that individual differences in temperamental systems of self-regulation are central to understanding the relation between social adjustment in the school and students' performance.

Implications for Education

Our results point to the importance of understanding students' temperament by parents and educators to promote their adaptation to the classroom. Increased teacher's awareness of how students' temperament relates to their responses to the social and academic challenges is likely to reduce teacher's negative reactions and promote feelings of support, which in turn have the potential to reduce conflict and encourage the use of more appropriate coping strategies by the students (Pullis, 1985).

Emphasizing the mediating role of self-regulatory processes also offers guidance for designing interventions to improve school readiness by enhancing cognitive and temperamental control systems. In the recent years, there have been several efforts to design programs aimed to promote executive control abilities in normally developing preschoolers and first graders (Diamond, Barnett, Thomas, & Munro, 2007; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005) and children suffering from attention-related pathologies (Klingberg et al., 2005). Although these efforts to train aspects of self-regulation show very promising results, they have mainly focused in the training and testing effects at the neurocognitive level. Further research would be needed to examine whether the beneficial effects of these interventions also affect temperament and academic performance and transfer to abilities relevant for schooling competence such socioemotional regulation.

Several developmental studies have shown a progressive development of self-regulatory functions up to late adolescence, with the greater development occurring during early childhood (Rothbart & Rueda, 2005; Rueda et al., 2004). The association between either performance in cognitive tasks or reports of children's EC and achievement, and socioemotional regulation has been found from early childhood (Blair, 2002; McClelland et al., 2007). However, assessing this relationship in cross-sectional and/or longitudinal studies along the periods of major development of self-regulation would inform about the influence of the maturation of systems of self-regulation on the control of behavior required for school competence, as well as the developmental periods in which interventions to foster regulatory capacities have the greater impact in children's social and academic competence.

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NOTE

1 The modified ANT (Callejas, Lupianez, & Tudela, 2004) is structurally similar to the original ANT, except that it presents the alerting and orienting cues in separate displays in order to be able to assess interactions between these two networks.

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