Doctoral Dissertation

Reasoning skills and Reading
(Habilidades de razonamiento y lectura)

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Contents

Introduction

Research about reasoning and about reading (and reading difficulties) has been developed in parallel. However, both reading and reasoning abilities are associated, especially considering that reading comprehension, which implies inferences, may need other reasoning abilities. Moreover, research has suggested that people with reading difficulties use different strategies from people without reading difficulties when they have to make inferences (Bacon & Handley, 2010; Bacon, Parmentier, & Barr, 2013, Bacon & Handley, 2014).

According to one of the principal theories of reasoning, the Theory of Mental models (Johnson-Laird, 1983; Johnson-Laird, 2006), when people make inferences, they make mental models in order to maintain the information presented in the premises. These mental models can elicit visual images and they can also represent conditions that cannot be visualized (Johnson-Laird & Byrne, 2002). Following Knauff & Johnson-Laird (2002) "the relationships that provoke visual images which contain details irrelevant to an inference could hinder reasoning" (p.364). They called this phenomenon the "Hypothesis of Visual Impedance". Bacon and her colleagues' results (Bacon & Handley, 2010) from university students with dyslexia suggest that they, unlike participants without it, would not show the effect of visual impedance.

These results could indicate that people with reading difficulties are using different deductive processes and an alternative source for those differences could be based on their reading and writing skills/difficulties during reasoning tasks. The problem is that most of the available tasks for testing reasoning are quite demanding of reading and writing skills, which raises an important issue in this research framework.

For all that, the main aim of the research developed in this Doctoral Dissertation was to create a task equivalent to the propositional transitive inference traditional task but decreasing the "propositional" requirements. This research presents some new evidence for the examination and detection of the "visual impedance effect" by using an innovative reasoning task in which pictures are used instead of verbal content. Although inference processing should be the same, the new task based on "pictures" should also show the "visual impedance effect", and could be used in reasoning research by people with difficulties in reading and writing, both adults and children, without the interference of written language.

A task that demands fewer verbal skills would also be suitable for studying reasoning skills at school levels when children have not yet mastered written skills. Therefore, this research shows evidence for the compatibility of a task free of verbal context for evaluating reasoning abilities, suggesting that it could be an appropriate task for studying reasoning in populations with poor verbal skills, such as those with learning disabilities or dyslexia and then expanding the possibilities for the enhancement of research about reasoning and about reading (and reading difficulties).

This Doctoral Dissertation starts with this introductory part in which the relationship of reasoning and reading skills is addressed. Then the Theoretical part (Part I) presents a review of the literature on transitive reasoning, research in transitive reasoning in adult and children population, studies addressing the process of inference making and the use of mental models in transitive reasoning, the relationship of reasoning and reading comprehension and strategies in reasoning and reading comprehension. This part concludes with the description of the aims and hypothesis that will lead the experimental part. In the Experimental Section (Part II), the main studies part of this dissertation are presented (Experiments 1, 2 and 3), describing their methods and main results and specific findings. Finally, the general findings and their relevance in the framework of research in reasoning and reading are discussed, and future directions for research are suggested.

Part I. Theoretical framework

Chapter 1. Reasoning

Early research asserts that reasoning relies on a mental implementation of formal logic (Khemlani & Johnson-Laird, 2013) and that it is also the dominant component of rationality (Johnson-Laird, 2010). Reasoning concerns the cognitive procedures for drawing conclusions from some given information (Khemlani, 2018).

Psychological theories about reasoning propose the idea of rules of inferences. An inference is made when we find any part of information that is not clearly presented in a phrase, a paragraph or a text. There are different types of inferences: complex inferences, elaborative inferences and inferences that imply supplementary ideas in a paragraph or text; normally, this last category of inferences, combines parts in a paragraph or a sentence (McKoon & Ratcliff, 1992). These theories suggest that people at the time of reasoning, link the coherent parts of the premises using pertinent rules (Johnson-Laird, Girotto, Legrenzi, & Legrenzi, 1999; Ragni, Khemlani, & Johnson-Laird, 2014). Following these theories, the conclusion depends on the evidence coming out from the premises (Johnson-Laird et al., 1999).

Reasoning ability can be measured mainly with deductive reasoning tasks, inductive reasoning tasks, and abducting reasoning tasks (Khemlani, 2018; Su¨ß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). The present work focuses on deductive reasoning.

Deductions are inferences that are true in the cases in which the premises are true (Khemlani, 2018). No new knowledge is added in deductive reasoning, but it states necessary consequences of what is already assumed; because of that, it is said that deductive reasoning is tautological (Evans, 2013). Deductive reasoning tasks use syllogistic problems, mathematical text problems and surface development tasks, among others (Su¨ß et al., 2002).

1.1. Transitive reasoning

Transitive reasoning is a very used type of deductive reasoning. In transitivity, there is one relationship between items with one premise pair (for example *A* and *B*), and the relationship between a second pair of items (*B* and *C*). From these two relationships, individuals must conclude the inference between *A* and *C* (Wright, Robertson, & Hadfield, 2011). A well-known example of a transitive inference is: If A is taller than B, and B is taller than C, what we can conclude of the relationship between A and C, is that A is taller than C (Goodwin & Johnson-Laird, 2005).

Transitive reasoning tasks differ in type (different type of relations included in the task) and in the number of items. More frequently, transitive tasks include two, three, four, five or sometimes more items, that may be different in weight, length, size, etc. (Verweij, Sijtsma, & Koops, 1999). The most typical tasks in transitive reasoning include three-term series problems. In this type of problems, the information is provided by two sentences named *premises*; the conclusion is drawn essentially from the premises (Knauff, 2009). For example, if A is taller than B; and B is taller than C; thus A is taller than C (Knauff, Fangmeier, Ruff, & Johnson-Laird, 2003).

Markedness is a crucial reference point in elaborating transitive inferences, and it is defined as the relationship between two adjectives that are opposites. In the example A is taller than B; C is shorter than B, the main adjective is “tall”, because most reasoners rely on this adjective in order to make the deduction. The adjective “short” is the second reference point, because it is the opposite of “tall” (the first reference point); “short” is defined in relation to the first reference point. Likewise, “short” is a “marked” relational adjective, opposite to “tall”, which is described as “unmarked” adjective (Wright & Smailes, 2015).

The difficulty in that type of term series problems, relies on the premises’ integration, because it requires effort and time to unify the prior sentences (premises) with the third one (conclusion). Therefore, the best predictor of the emerging difficulty at the time of elaborating the premises, is the quantity of associating variables that have to be displayed at the same time, in order to proceed to the reasoning process (Goodwin & Johnson-Laird, 2005).

1.2. Studies in transitive reasoning.

In human reasoning, problem solving can be performed in various ways. One of these ways is proposition-based reasoning. Propositions are defined as explicative declarations which express relations (such as, “Juan is taller than Ann”; Moses, Villate, Binns, Davidson, & Ryan, 2008). Some of the studies in transitive reasoning in adults, have utilized this propositional format with paper and pencil tasks (Bacon & Handley, 2010, 2014; Favrel & Barrouillet, 2000).

In Favrel and Barrouillet’s (2000) study, the hypotheses that making deductive inferences form a text is a procedure which implicates either the construction of an integrated mental model or the step-by-step coordination of propositional representations of the sentences, were tested. Notebooks were given to the participants including 16 texts with four different contents (fictitious tribes, cars, skyscrapers, and basketball players). Two texts comprised four set inclusion relations and the other two texts comprised four linear ordering relations. In each notebook, 10 conclusions related to the premises were included. The participants had to learn the information provided in the text so as to be capable to reason about the conclusions associated to the premises in this text. After thinking that all the information was obtained, the texts were removed, and the participants were asked to recall all, and only, that information that was presented in the form *All... are..*, (provided in the set inclusion texts), or in the form *is higher than..*, (provided in the linear ordering texts). After the recall, the participants had to state in writing the logical validity of the conclusions presented in the corresponding notebooks without, at any stage, going back to their answers (Experiment 2). The results suggest that the information included in the text, is stored in memory in an atomic form, and is organized on a step-by-step base in working memory when an inference has to be made or evaluated. Moreover, the results suggest that inferences are made within the retrieval and organization of premises which are stored atomically, apparently in a propositional form.

In Bacon and Handley's (2010) study, the role of visual processes in relational reasoning amongst adults with dyslexia and with typical development, was tested. The participants completed a transitive inference task composed by 16 three-term series problems with terms represented by three capital letters, and they had to judge the relationship between the two last terms in the context of the relational adjectives described. Eight problems included relational adjectives that were easily imaginable (fat–thin; clean–dirty) and (tall–short; rough–smooth). The other eight structurally equal problems included neutral adjectives, (smart–dumb; better–worse) and (kind–

cruel; rich–poor). Participants had to both write down their working out (written protocol) and to describe their reasoning out loud. Problems were provided in a booklet, one per page, with space given beneath each of the written protocol.

The results showed that the participants who used a visual-spatial strategy (participants with dyslexia), described the three capital letters in their written protocols as having specific and relative physical properties. In contrast, participants who used an abstract-spatial strategy (participants with typical development), recounted the placing of the three capital letters in a line or in order. For example, participants in the first case after read the premise "A is dumber than B" drew an "A" with a fool's cap, and in the second they just wrote the letter "A" on the left of "B".

Moreover, participants who used a visual-spatial strategy (participants with dyslexia), stated a need to clarify the relative properties of the objects in order to reason, by using vivid pictorial representations of the specific properties described by the problems.

Additionally, regarding the response times, in Experiment 2, the results of between groups analysis showed that participants with dyslexia were slower than participants with typical development in all the types of problems presented. Moreover, comparing each group apart, it was confirmed that participants with typical development were slower in evaluating visual problems than neutral or visuospatial problems, but neutral problems took longer than visuospatial problems in this group. In contrast, participants con dyslexia showed no differences in response times according to problem types. In Experiment 3, regarding the time measure (response times), between groups analysis showed that participants with dyslexia were later in reading premises than participants with typical development in all types of problems, but the difference was significant only in visuospatial problems. In neutral and visual problems there was no difference in the response times between groups. Comparing each group apart, participants with typical development were later in visual problems than in neutral and visuospatial problems. Participants with dyslexia showed no effect of problem type with similar latencies on all three types of problems.

For reasoning accuracy, in Experiment 2, the results of analyzing each group apart, showed that participants with dyslexia were less accurate on visual problems in comparison to neutral and visuospatial problems. In the case of participants with typical development, a significant difference in accuracy was observed between visual and neutral problems. Comparing both groups of participants (with dyslexia and with typical development), both groups were comparably accurate on neutral and visuospatial problems. Moreover, participants with dyslexia were less accurate on visual problems than the participants with typical development. These results are in line with the results in Knauff and Johnson-Laird's (2002) study, in which it is suggested that visual but not spatial imagery, can hinder reasoning.

It was also suggested that the reasoning process of people with typical development, presents little involvement of visual procedures. They elicit an essential linear ordering of objects from the initial representation, and then utilize it in order to make a transitive inference. In contrast, people with dyslexia lean on visual information, utilizing it to get help in order to compare the physical characteristics that they add to the objects.

Other tasks that were used in studies of transitive reasoning in adults are: tasks which include *three-four-terms series problems* presented visually on a computer screen, in order to restudy the assumption that visual images help people to reason (Knauff & Johnson-Laird, 2002). The premises on the screen were presented in black letters and the conclusions in red letters. The participants had to evaluate whether the conclusion followed necessarily from the premises. They responded by pressing either a ‘‘yes’’ or a ‘‘no’’ key on the keyboard. All the problems included three sorts of relations (visuospatial, visual, and control) and used the same nouns (‘‘dog,’’ ‘‘cat,’’ ‘‘ape,’’ and for the four-term inferences: ‘‘bird’’). Half the problems had valid conclusions and half had invalid conclusions. The results showed that the nature of the relations influenced reasoning responses time. Inferences that included visual relations impeded reasoning in comparison with the other three type of relations and they also took more time, in comparison with control relations that were difficult to visualize. The visuospatial relations did not accelerate the process of inference, but the participants did read the visuospatial premises more quickly (Knauff & Johnson-Laird, 2002).

Other tasks included *three-four-term series problems* presented visually on a computer screen or acoustically via pneumatic headphones, in order to study the issue of mental representations in reasoning, especially focusing on visual images. The participants were sighted and blind university students. The problems and the procedure was equal to the previous study mentioned in the paragraph above. The results showed that all type of the four relations, lead to the construction of models that underlie the inferential process. They also showed that, the visual relations which are hard to envisage spatially, head to a mental picture, but the vivid details in this picture impede the process of reasoning (Knauff & May, 2006).

Problems with more terms were used in various studies, increasing in that way the difficulty of the task, like for example, *five term-series problems* presented on a computer screen, including believable and unbelievable premises (Andrews, 2010). The aim of the study was to study belief-based processing versus analytic processing in transitive inferences. Each of the transitive inference problems included four premises that, when unified, elicited an ordered five-term sequence of the form a > b > c > d > e. The elements in each problem were taken from the same category (e.g., animals, vehicles, household items). Transitive relations (e.g., taller–shorter, heavier–

lighter, faster–slower) connected the elements in the premises and the conclusions. Unmarked (e.g., taller) and marked (e.g., shorter) forms were each utilized twice in every premise set. Valid conclusions were stated in the form b > d. Invalid conclusions were stated in the form d > b and were always defined as invalid. There were 16 test problems, four of every type (Valid Believable-VB, Valid Unbelievable-VU, Invalid Believable-IB, Invalid Unbelievable-IU), and two practice problems with the same form as the test problems but including neutral content. The problems were provided on a laptop computer screen. The participants had to read the premises carefully and to think about how every premise connected to the others. When the conclusion aroused, they had to read and evaluate it in terms of the premises, then record their yes/no response and their confidence in their decision on the sheet provided (Experiment 1). The results showed that reasoning was affected by premises-encoding time, indicating in that way the integration of the premises is the most demanding element of transitive inferences. The results also suggested that belief-based and analytic procedures are used when people elaborate transitive inferences (Andrews, 2010).

The results showed that ordered and non-ordered transitive inference tasks aid different patterns of performance. Additionally, the results indicated that transitive responding depended on task awareness for all participants. Precisely, awareness was positively associated with transitive performance in the novel testing pairs; the higher the awareness score was, the higher the accuracy to the testing pairs was observed.

In another study, Brunamonti, Genovesio, Carbè and Ferraina, (2011) tested the role of the mental organization of stimuli during transitive inferences. The experimenters used visual stimuli of pairs of Japanese ideograms, provided on a computer screen. In every trial, the pairs of stimuli were randomly chosen from a rank ordered set of stimuli. The participants had to select the higher in rank of each pair by moving, with their right hand, a joystick bar pointing to the stimulus. Two different acoustic feedbacks informed the participant if they have responded correctly or not. Before starting the learning session, information was given to the participants that ten Japanese characters were arbitrarily rank ordered in a series such as A < B < C < D < E < F < G < H < I < J, and that they had to learn, by trial and error, the reciprocal relationship between all the items of the series. No information was given about the expected form of the sequence. Finishing every learning block of trials, a graphical feedback notified the participants about their performance in the block. The trials finished when the participants achieved in the last performed block, by 80% correct. In testing trials, the participants were asked to judge also non-adjacent items of the series, never paired during the learning phase. Trials with adjacent and non-adjacent items were randomly intermingled within the block. In order to solve the task with non-adjacent items, the participants were permitted to lean on the learned relationship between items and, based on them, conclude the relationship between the items of every pair. The results support the "mental number line" hypothesis, which is defined as a working area utilized by individuals, to mentally depict and relate quantities and their symbolic depiction. The results also showed that participants implicitly position the premises of the transitive inference on a "mental line", and utilize this "mental line" in order to relate the premises, even though other models have been suggested to be used.

The studies with adults participants mentioned in this section have used different tasks in order to evaluate transitive reasoning. In some of these tasks, three-term series problems were used, while in others more complex problems (five-six-seven-series problems) were used. The reason for using these complex problems is to control the possible effect of learning trough the visual association of the stimuli. However, the results of the tasks which include more complicated problems (five-six-seven-series problems) are not different substantially from the results obtained by less complex series problems. Among the obtained results, the effect of awareness was found. Also, it is in manifest the importance of the spatial representations of the organized stimuli in order to explain the process of resolving such tasks. As in the previous transitive reasoning studies, the research with adults seems to be consistent to the advantage of using a spatial strategy for codifying premises in order to make inferences.

1.3. Studies in transitive reasoning in children

Among the existing research in studies of transitive reasoning skills in children, which are less than in adults, reasoning was tested with propositional information utilizing paper and pencil tasks, in which reading and writing skills are required (Ameel, Verschueren, & Schaeken, 2007). Also, some studies used tasks which include two-three-four-five series problems**,** utilizing different elements like length, height or weight, and also, different types of materials like balls, cards with figures, plastic tubes, etc (Andrews & Halford, 1998; Chapman & Lindenberger, 1988; Luo & Beck, 2010; Markovits, Dumas, & Malfait, 1995; Mou, Province, & Luo, 2014; Wright & Smailes, 2015).

For example, Wright and Smailes (2015), tested mental seriation in transitive reasoning. The experimenters used two cards with photo pictures, each one showing the relationships between two of three objects (figures of animals) regarding height or length. Actual toy objects were also used, representing the objects of the photos but in actual size. The two photo-picture cards were allocated on the table in front of the child simultaneously. The participants were children of 6-7-8 years old. Children had to describe each picture, and to say what the objects were and which the relation between them was. In that way, the experimenter did not have to present any premises verbally, and could keep verbalisations for conversational reasons only, meanwhile encouraging the child's own verbalisations. Children had then to affirm the most unmarked item (e.g. which ball bounces highest of all three balls). Here, children responded through a combination of voice, gesturing and touching of the concrete objects or the items in the photographs. Children had also to point the most marked item out (e.g. which ball bounces the lowest) and to say which was the whole series (e.g. from highest to lowest). Children had the two premise pairs continually in view during the whole process of the experiment. The results confirmed that transitive reasoning is demanding in children at the age of six, but it improves at the age between 6 and 8 years (Wright & Smailes, 2015).

Other studies included tasks consisted of three-four-five-term series problems that include spatial relations for length and weight of colored sticks and balls (Chapman & Lindenberger, 1988, 1992; Brainerd & Reyna, 1992). For example, Chapman and Lindenberger's (1988) tested the role of functional reasoning in the content of age between length and weight. The participants were children from 6 to 9 years. Children were provided with both standard and alternate versions of the transitive-reasoning task for length and weight problems. The number of the objects used in the tasks differed from three to five (aside from the standard version for weight, in which only three and four objects were utilized). This study included several tasks that were provided in the following order: three-term standard length task, three-term standard weight task, five-term standard length task, four-term standard weight task, four-term standard length task, alternate length task (three to five terms), and alternate weight task (three to five terms). In the comparisons of the provided premises and in asking about nonadjacent relations, exclusively single comparatives were utilized ("longer" or "heavier"). In *Standard length tasks*, three different colored sticks were utilized (A, B, C). At the starting point of the problem all three sticks were provided with the ends hidden so that their relative lengths could not be noticed. The children had to name the color of the sticks. Then the experimenter took away all the sticks and allocated them in a box under the table. Sticks B and C were presented again and allocated upright on the table next to each other. The children had to point out which stick was longer. After that, both sticks were taken away and the same procedure was followed with sticks A and B. Memory for these "premise comparisons" was examined by replicating the preparatory questions twice. After that, the sticks A and C were provided with the ends hidden hence no difference in length was visible, and children had to indicate which stick was longer. Finally, children had to explain their judgments. The same procedure followed in the standard length task with four and five comparison objects. In *the Standard weight tasks,* all weight tasks were displayed by means of a balance scale manipulated by the experimenter; children were not permitted to touch the scale nor the balls being weighed. Three colored balls were presented to the children (ball A, ball B and ball C). Preparatory questions referred to balls AB and BC, accordingly. After that, the experimenter held the balls A and C in his hands and the children had to say which ball was heavier.

Finally, children had to explain their judgments. The same procedure followed in the standard weight task in which four objects (colored balls) were utilized. In *the Alternate length task*, five sticks (A, B, C, D, and E) colored with the same color were utilized, differing in length. At the starting point of the task, the sticks were allocated in ascending order on the table at a distance of roughly 30 cm between adjacent sticks, hence it was impossible to notice the respective lengths of the sticks at once. Preparatory questions referred to the relative lengths of adjacent sticks in the order AB, BC, CD, and DE. At the time of showing these "premise" comparisons, the experimenter allocated each pair of adjacent sticks next to each other, hence the length difference became visible and the children had to point out the longer stick. After that, the experimenter returned the sticks to their original positions and checked memory for premise comparisons by asking about adjacent sticks twice in the same order as before. Sticks remained spaced apart from each other all along this test phase. After the test questions were answered by the children, the children had to explain their judgment. *In the Alternate weight task*, five balls (A, B, C, D and E) colored with the same color, were utilized. At the beginning of the problem, the balls were allocated on the table in ascending order, with the lightest ball to the left and the heaviest ball to the right. To show the weight relations between adjacent balls, the experimenter allocated each pair of adjacent balls on the balance scale and the children had to point out the heavier ball. Test questions referred to the relative weight of nonadjacent balls and were posed in the following order: BD, AC, BE, AD, CE, and AE. At the end of the task, the children had again to explain their judgments. The results showed that the alternate version of the task was solved by a bigger percentage of children in all grades than the standard version. In Experiment 2, in the case of Alternate vs Standard task, for length tasks, differences in percent correct between three-four-five-term problems were statistically significant for first graders for second graders and for third graders. For weight tasks, these differences were significant for first graders, for second graders and for third graders.

It was also showed that the spatial ordering of comparison objects in the alternate task permitted children to give a correct answer by utilizing preoperational reasoning (length or weight derived as a function of spatial position), but in contrast, the standard version demanded the operational composition of relations for its solution. Moreover, the results indicated that transitive tasks which permit children to infer relative length as a function of spatial relations, can be worked out at a much earlier age than tasks in which operational composition of premise relations is needed.

There are some interesting question regarding whether preschooler can solve transitive reasoning tasks and whether their possible skills allow them to apply transitivity between different domains in the problem. To test it, some studies used tasks consisted of five-term series problems using labels such as length and weight of colored sticks (Andrews & Halford, 1998; Bryant & Trabasso, 1971; Kallio, 1982). Andrews and Halford (1998), evaluated young children's ability to elaborate transitive inferences. Additionally, they examined the flexibility of elaborating transitive inferences in young children by demanding mapping from premises in one element to another (for example, from sticks to ball). Children's age ranged from 4 to 6 years. Two nonmapping tasks were used: a) nonmapping blocks (Bl-Bl) where the premises were blocks and the children ordered blocks, and b) and non-mapping sticks (St-St), where the premises were sticks and children ordered sticks. In the first task, children utilized premise information to predict the relative vertical position of blocks B and D (prediction), and then to construct a 5-block tower with a top-down order A, B, C, D, E (construction). In the second task, the sticks were substituted for blocks, and the left-right relation was substituted for the above-below relation. Children used the premise information to predict the left-right position of sticks B and D (prediction), and to construct a left-right 5-stick array (construction). Also, two mapping tasks were used: a) mapping sticks-to-blocks (St-BI) and b) mapping blocks to sticks (Bl-St), in which the premise materials and relations were different from the materials and relations utilized in the prediction and construction subtasks. In the St-B1 task, premise information consisted of pairs of sticks as in the St-St task. Children predicted the relative vertical positions of two blocks, B and D (prediction), and constructed a 5-block tower with top down order A, B, C, D, E (construction). The left-right relation in the premises had to be mapped into the above-below relation in the prediction and construction subtasks. The *BI-St task* was similar except that mapping was in the contrary direction. The blocks were 15 wooden blocks colored in five different colors. Color names were utilized to refer to the blocks and sticks. The premise pairs were always allocated in random spatial order on the table at which the child was seated. Every time that a prediction question was asked, the relevant blocks or sticks were allocated in view of the participants so that nonverbal replies could be displayed if the children preferred. The experimenter told the children that they would be playing a game with blocks. The game included constructing a tower utilizing five blocks (construction), and answering questions about some of the blocks (prediction). Five blocks were provided to the children, one of each color, and they had to construct a 5block tower consistent with the order of the blocks in the premises. They were told, for example, that if red was above green in the small towers, red must also be above green in the big tower. After the tower was suitably constructed, it was removed and the children's attention was leaded to the premises. They had to answer three questions (for example "When you build the tower, which block will be higher up, B or C?"). After answering the questions, children constructed again the tower. The three prediction questions were asked before children constructed the tower. In the *St-St task,* the experimenter told at the children that they would be playing a game with sticks. The game included placing five sticks in left-to-right order (construction), and answering questions about some of the sticks (prediction). A stuffed toy frog was allocated on the left side of the table and the phrase "closer to Froggie" was utilized instead of "left of' in all instructions and questions. The results showed that in the mapping tasks, unlike 6-year-olds, 4-year-olds participants performed at baseline level on prediction, proposing that they cannot elaborate transitive inferences when they have to map premise information from one display to another. Their performance may reflect leaning on content-specific, imaginable representations.

In another study with school children, another task consisted of three-four-five-term problems was used (Verweij et al., 1999) to test whether presenting the information in the premises one by one (successive) *versus* presenting all together (simultaneously), has some effect on the kind of strategy used by children. The aim of the study was to examine the effects of task format (inequality and equality) together with the presentation procedure (successive and simultaneous) on reasoning performance in young children. Additionally, the strategies that children used while reasoning, were also tested. The participants were children of the 3rd grade of primary education. The problems included labels like length, weight and size by using colored plastic tubes, copper tubes, round wooden sticks, round wooden discs and clay balls. The premises were presented to the children and the experimenter asked them to answer which object is the longest or if the objects are equal. Children had also to explain and judge verbally the relation between the objects. They were not allowed to touch the objects. The objects were allocated down in front of the child. For inequality tasks, length was growing from left to right. The experimenter placed the objects from a premise close together, thus the length relation was visible and could be memorized. Children were permitted to pick up both objects to explore their relation. Then, they were asked to answer which object is the longest or if they are equal. The results showed that the presentation of the premises influenced the judgment and the explanations of the children on the 3-, 4-, and 5-term inequality tasks, but did not influence performance on the equality tasks. The utility of strategies relied on the presentation procedure, task format, and distance between objects (equalities) or length difference between objects (inequalities). The most important results were obtained in the unequal condition, that showed that when the information was presented simultaneously, children used a propositional strategy in order to solve a task while they used more different deductive strategies with the information was presented in the successive condition. More interesting, when there were differences between the objects, more visual strategies were used (Verweij et al., 1999).

Another type of transitive task has been used to test whether preschool and school children make transitive inferences using a spatial strategy. Some example of materials used in this task, are towers of coloured blocks and sticks with relations like “higher than-lower than” (Thayer & Collyer, 1978; Markovits et al., 1995). For example, Markovits et al., (1995) studied the way that children handled conditions in which, the extremities of the towers provided in the premises had relative positions that were in contrast to their position as characterized by a 3-point ordinal scale. A sequence of nine experimental problems with children at the age of 4, 6, and 8 years. The first six problems contained two colored towers, while the last three problems contained three colored towers. In all problems, once the towers had been presented, participants had to make an inference about the relative position of two single blocks in the final tower and after that, construct the final tower. In other words, representations were presented to the children in form A<B, B<C, and then the children had to infer which was the relation between A and C (higher-lower), before constructing a single tower that contains the premises A, B and C. Results suggested that young children have a cognitive strategy which capacitates them to elaborate correct inferences. Additionally, results indicated that 4-year-olds participants showed no evidence that they could make transitive inferences about spatial position. In contrast, 8-year-old participants performed better on the majority of items.

Other studies have tested transitive inferences in toddlers adapting traditional inference tasks to the “visual preference” paradigm, using colored footballs and changing the relative location of the stimuli (such as, on the left-on the right; Luo &

Beck, 2010; Mou et al., 2014). In Mou et al's., (2014) study, the capacity of the children at the age of 16th months to elaborate transitive inferences about other person's preferences, was tested. The object used in the study, was an apparatus that was a white wooden display box, allocated above the room floor. The child sat on the parent's lap and faced an opening in front of the apparatus. A wooden frame covered with white muslin that could be pulled up or lowered in front of the opening during the trials. The three footballs were covered with colored tape. Each football was allocated on a small circular base so that it was standing upright (see Figure 1). The children were provided two pairs of test trials alternating between the expected and unexpected events. The experimenter grasped the red (A) (expected event) or the green (C) (unexpected event) football during the 2-s pre-trial and paused until the trial ended during the main-trial. Each test main-trial was finishing when the infant looked away for two consecutive seconds after having looked at it for at least 5 cumulative seconds, or looked for 60 cumulative seconds. The goal was that, children should predict (based on transitivity) that when the experimenter faced with the red and the green footballs, (s)he should choose the red one (A > C). Consequently, the children should expect the experimenter to grasp the red (A) as adverse to the green football (C) during the test trials and therefore, look longer at the unexpected than at the expected event. The results showed that children with 16 months of age succeed in a three-item transitivity task along the dimension of the experimenter's preferences for different objects (A > B, B > C, and so A > C). Precisely, results indicated that, when the experimenter's premise preferences were presented in the reversed order (BC then AB), children failed to employ transitive inferences. The result shows that although with important limitations, even toddlers have a very basic deductive inference skill in the appropriate conditions.

Linear condition *Reversed condition*

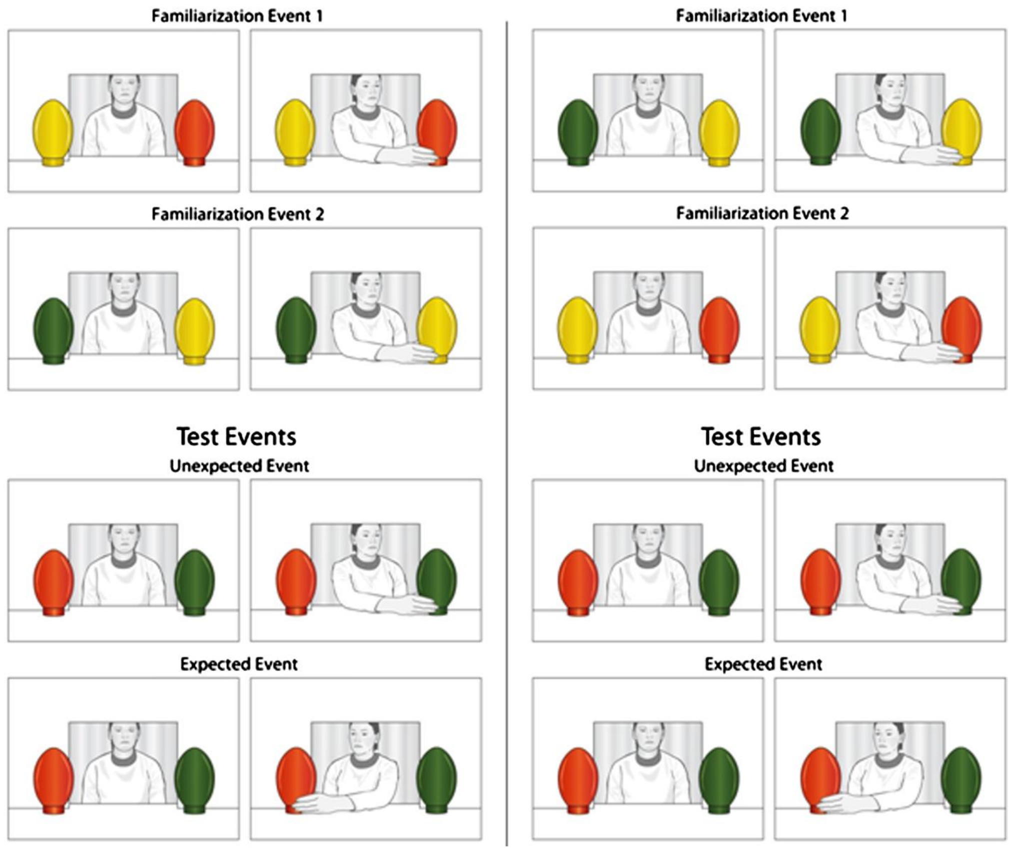

Figure 1. Schematic drawing of the familiarization and test events shown in Experiment 1 (reproduced from Mou's et al., 2014).

As has been shown in the previous studies reviewed, children seem to have very basic ability to make deductive inferences of transitivity, and that older children can make more complex inferences. One important common element in the tasks used in those studies, is that the propositional requirements to process the premises are reduced in comparison with the tasks used by adults. For example, premises are referred to physical objects, figures with distinct types of materials were utilized (colored sticks, balls, wooden cubes), and relationships such as height, length, weight. All of them seem to have an effect on the kind or conclusions generated. However, when tasks are adapted to test children's skills one consequence is that the execution of adults and children cannot be directly compared, because they are using different tasks. In the present study we will create another adapted task that could be used with children but also with adults.

Chapter 2. How people make transitive inferences: the use of mental models.

It has been proposed that people make deduction using two different systems (or different type of processes, see Evans, 2013): System I is rapid and automatic. Given the premises of a logical argument (e.g. a syllogism), the meanings of words in the lexicon are used in order to create an intentional representation that relies upon the grammatical relations between the words. The system allows to construct initial representation from the premises based on the mentioned information. On the contrary, System II is slow and deliberate. It utilizes the intension of the premises in a syllogism to construct an updates the initial representation given by the System I, and allow to look for alternative representations (Khemlani & Johnson-Laird, 2013).

The mental model theory integrates these two systems and explains how people make transitive inferences as well as a wide range of reasoning tasks. It is based on the concept of mental model (Khemlani, Byrne, & Johnson-Laird, 2018).

Mental models are iconic mental representations of state of affairs. They can represent, concrete objects, abstract entities or even different phases of as sequence of events (Khemlani et al., 2018). For example, given the premise “the cat is smaller than the dog”, people represent a mental model, something like a mental image that contains a small cat and a big dog. After reading a second premise “the mouse is smaller than the cat” people can represent a second “mental model” or a kind of image with the cat and a small mouse. People can compare the two mental models and create a third model as a conclusion with the mouse and the dog, being the dog bigger than the mouse which allows them to conclude that the mouse is smaller than the dog, the model theory does not establish that people represent those exact images. However, as we will see bellow, in some conditions, visual information can be used in the construction of the mental models.

The mental model theory suggests that the more models are necessary to make an inference, the more complex the inference should be, and also, it should require more time (Khemlani, Orenes, & Johnson-Laird, 2014). Additionally, a lot of studies have shown that individuals create only one typical model, although the premises permit other various possible models (Nejasmic, Bucher, & Knauff, 2015).

The mental model theory has been re-described in order to clarify how the model theory is a dual system theory (Khemlani et al. 2018). Thus, two different systems for reasoning can be described. The first one employs mental models (or initial representations obtained directly by the premises) and the second one, explicit models entirely. Both together are known as the “dual-system”. Both systems combine distinct uses from the same premises. System 1 is equal to intuitive reasoning: it focuses on inferences producing a unique mental model that can be kept in a memory buffer. The buffer possesses a small limited space. System 2 is equal to deliberation: it is entirely based on explicit models. It uses the working memory capacity, which although it is also limited, permits computations or recursive procedures and to take into account other models to further elaborate the information inside the model. The theory considers that both models are different, but they can interact and they share a lot of components. Differently from other dual process theories, this theory considers the two systems as part of a unique system and not as separated entities (Khemlani et al., 2018). People, and particularly, children, usually tend to use system I because is less cognitive demanding, and therefore, the theory can make predictions about what children and adults tend to conclude in everyday situations.

One interesting prediction from the mental model theory is derived from how people represent the information in the premises and what information is relevant to make the inference. Knauff and Johnson-Laird (2002), suggested the "visual impedance-imagery hypothesis", according to which, needless visual images which can be evoked at the time of processing the inferences, should hinder reasoning, causing in such way prolonged reaction times (Gazzo, Castaneda, & Knauff, 2013). These authors also suggested that mental models are spatial and not visual, and they tested the visual impedance effect with people without difficulties (Knauff & Johnson-Laird, 2002; Gazzo Castaneda, & Knauff, 2013), or some disability (for example, blind people; see Knauff & May, 2006).

Precisely, it is suggested that spatially organized mental models, form the base for all types of relational reasoning, and that these models are not defined as visual images. Moreover, in typical reasoning process, visual images are not included. For example, if you represent that a red hat is on the left of a glass, and a glass is on the left of a pencil, the color red is irrelevant to know that the red hat is on the left of the pencil. In contrast, abstract spatial representations, that is, spatial mental models, are involved. In inferential tasks, visual details are about to be eliminated by the resulting spatial depictions, in order to represent exclusively the information that is pertinent to the inference. Therefore, the resulting spatial representations take the form of a depiction that keeps the spatial connections among objects in a multidimensional array (Knauff, 2009).

Investigating more the imagery theory, some studies have suggested that the premises that include adjectives that they are easy to visualize, evoke visual images, whereas the premises that include adjectives that they are not easy to visualize, do not evoke such images (Knauff, 2009; Knauff & Johnson-Laird, 2002). Their results showed that the relations which included adjectives that they were easy to visualize, impeded reasoning. They also showed that participants needed more time in this type of relations than with the other type pf relations, and that in the spatial relations participants were the quickest, whereas in visual relations were the slowest. So, that is what they defined as *the visual impedance effect* (Knauff & Johnson-Laird, 2002).

2.1. The visual impedance effect.

Apart from Knauff and Johnson-Laird's (2002) study, other studies have investigated the visual impedance effect in transitive reasoning in adults with typical development (Gazzo Castaneda, & Knauff, 2013; Knauff, 2009; Knauff et al., 2003; Sato, Sugimoto, & Ueda, 2017), and also in blind adults (Knauff & May, 2006).

The procedures and the results of Knauff and May's, (2006) study, related to the visual impedance effect, are previously described.

On their part, Gazzo Castaneda and Knauff, (2013) tested the hypothesis that the visual impedance effect, depends on how much individuals use visual mental images at the time of reasoning. The experimenters used 32 relational inferences, which described the same relation (left-right), but the term was either easy (fruits, tools, cutlery or office implements) or hard to visualize (nonsense syllables). Half of the problems had a valid conclusion and half, an invalid conclusion. The premises and the conclusions were presented on separate slides, on a computer screen. The required response was given by pressing two keys: one for “correct”, one for “false”: the premises and the conclusion were presented one at the time by pressing the space bar (Experiment 1).

Results showed that the participants who visualized the terms, were slower than the participants who verbalized the terms, in resolving the problems including the terms that were easy to visualize. In the problems that were hard to visualize, the participants who verbalized the terms were slower than the participants who visualized the terms. The participants who visualized the terms showed no difference in both types of problems. The conclusion was that a visual impedance effect seemed to appear in the participants who visualized the terms, but not in the participants who verbalized the terms.

In the Experiment 2, the experimenters tested also spatial, verbal and visual strategies of the participants by using a transitive reasoning task. In this task the premises included terms that can be imagined either visually or spatially. Thirty-two items were also used, including the same terms (dog, cat, ape). Half of the problems had a valid conclusion and half had an invalid conclusion. The inference task was again presented on a computer screen. The results showed that in the case of reasoners who verbalize the terms, the visual features of the problems do not influence them; thus these participants seem unaffected by the visual impedance effect. In the case of the reasoners who visualize the content of the premises, they do that also in non-visual problems and likewise, they show the visual impedance effect on all problems (Gazzo Castaneda & Knauff, 2013).

In other line of studies, the relationship between visual impedance and the brain structures implicated on visual processing and activated during deductive reasoning, has been studied. In Knauff et al's. (2003) study, the cognitive processes of the imagery and the role of mental representations, involved in deductive reasoning, were studied. They tested both behavioral and neural (fMRI) correlates for these processes. Four types of relations were used in the experiments: a) *visuospatial relations* that are easy to envisage visually and spatially, like ''above'' and ''below'', b) *visual relations* that are easy to envisage visually but hard to envisage spatially, like ''cleaner'' and ''dirtier", c) *spatial relations* that are difficult to envisage visually but easy to envisage spatially, like ''further north'' and ''further south'', and d) *control relations* that are hard to envisage both visually and spatially, like ''better'' and ''worse". The same nouns (dog, cat, and ape) were utilized. In the fMRI experiment, the problems were presented acoustically through pneumatic headphones. In Experiment 1, participants evaluated eight transitive inferences that included each of the three types of relations (visuospatial, visual, and control). Half of the problems were three-term series and half of them were four-term series. Half the problems included a valid conclusion and half, an invalid conclusion. The problems were provided on a computer screen and participants were passing from one problem to another by using the space bar. The premises were provided in black letters and conclusions in red letters. Participants had to choose if the conclusion could emerge from the premises, and answer by pressing the ''yes'' or ''no'' button on the keyboard. In the Experiment 2, participants performed a conditional reasoning task that also included the three sorts of relations (visual, visuospatial, and control). There were valid and invalid problems. The procedure was the same as in the Experiment 1. In Experiment 3, participants worked out 16 three- and 16 four-term series problems, which were the same as those in Experiment 1. The inferences included four kinds of relations: spatial, visuospatial, visual, and control relations. There were two valid and two invalid inferences of each of the four relations in both the three- and four-term series problems. The procedure was the same as in the other experiments.

In the fMRI part of the study, the activation of the parts of the brain while elaborating transitive inferences, was also tested. The materials were based on the previous behavioral studies (Knauff & Johnson-Laird, 2000, 2002). The participants evaluated eight transitive inferences that included the four types of relation: visuospatial, visual, spatial, and control relations. The same nouns (dog, cat, and ape) were utilized in all the premises. Participants had to choose if the conclusion could emerge from the premises, and answer by pressing the ‘‘yes’’ or ‘‘no’’ button on the keyboard, during the response interval after the presentation of each conclusion. Half of the problems included a valid conclusion, and half, an invalid conclusion.

Results showed that there was not difference in accuracy as a function of the four types of relations in any of the experiments. Participants were faster in the visuospatial inferences than in the control inferences, and slower in the visual inferences than in the control inferences. In Experiment 3, visual relations delayed reasoning, in comparison with the other three sorts of relation. In the fMRI experiment, the results showed that the correct responses were slower in the visual problems in comparison with the other sorts of problems. Moreover, an activation in the superior parietal cortex, was showed. In spatial processing, the superior parietal cortex has a key role, and also, in incorporating information into spatial representations (Andersen, Snyder, Bradley, & Xing, 1997).

In the study of Sato et al. (2017), the visual impedance hypothesis was tested in external representations and diagrammatic reasoning. To test this hypothesis, the experimenters utilized at the same time, computer graphic objects and real objects.

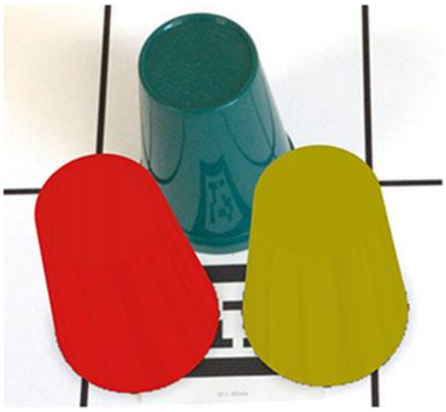

Figure 2. Augmented reality: the red and yellow cups are *computer graphic* objects, and the green cup is a *real object*.

Conditional sentences and conjunctive sentences which included cup locations on a board with a 3 x 3 grid, were also utilized. The participants were divided in three groups: a Linguistic group (L), in which the participants had to carry out common sentential tasks without utilizing any objects; a Reality group (R), in which the participants had to utilize only real objects; and an Augmented Reality (AR) group, in which the participants had to utilize augmented objects as well as real objects. The participants in the L group were provided only with inference tasks, and the participants in R and AR groups were provided with inference tasks using cups as stimuli (see Figure 2). The problems, consisted of three sentences (conditional and conjunctive), were presented on a tablet screen (Figure 3 and 4).

Example for Conjunctive sentences and situations:

(5) The red cup is in the right-upper square, and the yellow cup is in the center-upper square.

Example for Conditional sentences and situations:

(6) If the red cup is in the right-upper square, the yellow cup is to the left of the red cup.

	Y	R

Figure 3. Situation for conjunctive statement (5): "R" refers to the red cup, and "Y" refers to the yellow cup.

	Y	R

	Y	R

	Y	R

Figure 4. Situations for conditional statement (6): Black font indicates that the sentence of the cup location is true, and gray font indicates that the sentence is false.

After the three sentences were presented, participants had to decide if the last sentence could emerge from the other two sentences, and answer with "yes" or "no". Conditionals and conjunctions were included in the sentences. The contents of the sentences described the locations of cups on a 3 x 3 grid. The participants in the R group and the AR group had to move three (red, yellow, and green) cups and reason about the first and the second sentence. Results showed that in the case of conditionals, real objects impeded reasoning, but augmented objects did not, suggesting that this negative effect of real objects may be explained by the visual impedance effect.

Additionally, the visual impedance effect in transitive reasoning was also tested in adults with dyslexia (Bacon & Handley, 2010). The procedure and the results of this study, were mentioned before.

All the previous studies show that visual impedance during reasoning is strongly related to reasoning with visual stimuli but not with the visuo-spatial information. What could be expected is that in people with typical development, visual relationships impede reasoning while visuospatial relationships do not. In contrast, in case of people with dyslexia (see Bacon & Handley, 2010), the visual impedance effect is not presented while they seem to use visual representations of the premises.

Chapter 3. Reasoning and reading.

Reading comprehension is the process through which a reader constructs a coherent mental representation of the information contained in the reading text (word, sentence, text level) in his/her memory (Kendeou, Muis, & Fulton, 2011). Snow (2002) states that is the process of "simultaneously extracting and constructing meaning through interaction and involvement with written language" (p. 11). Reading comprehension entails three main components, namely the reader, the text and the activity in which comprehension is applied. The reader is responsible to build the mental representation of what is contained in the text, considering the activity and other factors like background knowledge, previous experiences, and reading ability, etc. The mental representation that the reader gets, is the principal outcome of the reading process (Kendeou et al., 2011). The comprehensive activity will require to understand and integrate information in this mental representation (Snow, 2002).

As a complex skill, reading comprehension entails several different cognitive processes. Overall, these cognitive processes that can be divided into two categories: (1) *lower level processes* that include decoding, reading fluency, and vocabulary knowledge and, (2) *higher level processes* that include inference making, executive function processes and attention–allocation abilities (Kendeou, van den Broek, Helder, & Karlsson, 2014).

In order to understand and integrate information from a text, phonological recoding skills are essential. There is an unquestionable link between oral skills and reading skills, as oral comprehension development precedes the acquisition of reading comprehension (Morais, 1998). Phonological recoding skills, are defined as the transformation of the visual information to sound (Goswami, 2015) and precedes the development of decoding skills. The equation that combines decoding with oral language skills has reading comprehension as result (Morais, Cary, Alegria, & Bertelson, 1979).

Phonological decoding skills require phonological awareness (Martinelli & Schembri, 2015), which can be defined as: "the ability to recognize, identify, or manipulate any phonological unit within a word, be it phoneme, rime, or syllable." (Ziegler & Goswami, 2005, p. 4). A variety of studies have indicated that poor phonological awareness skills characterize poor readers (Carroll & Snowling, 2004; Ziegler & Goswami, 2005) and ultimately, poor comprehenders. Precisely, Clarke, Snowling, Truelove and Hulme (2010) tested a group of children with specific reading-comprehension difficulties to study their improvements through a suitable remedial teaching program. Their results suggest that deficiencies in oral-language skills provoke reading-comprehension failure. These findings support the mentioned relation between reading comprehension and oral language skills.

Grammatical knowledge and syntactic skills are also connected to reading comprehension, because understanding a sentence is evidently essential in order to understand the higher levels of a text. More specifically, grammatical skills in children can help them to discover and correct reading errors and, in this way, assess their comprehension monitoring (Oakhil, Cain, & Bryant, 2003).

The ability to make the connection between oral language skills and reading comprehension, during the reading acquisition, leads to successful reading performance (Facoetti et al., 2010). That is, if any of the equation components are damaged, it will ultimately affect reading comprehension. In the case of children with dyslexia, although they may not have their oral comprehension impaired a priori, as they show problems in decoding skills and in some oral skills like phonological awareness (Carroll & Snowling, 2004), their reading comprehension skills get affected.

One of the most emphasized findings in this area, is that the realization of the inferences is essential for the comprehension (Anderson & Pearson, 1984). It has to do with the ability to understand a determined aspect of the text from the context of the rest of the text (Cassany, Luna & Sanz, 1994). Several studies have demonstrated that there are distinct types of inferences in function of different factors (Soto et al., 2019), like the type of text, the level of probability or certainty, the moment in which the inferences are taking place, the cognitive resources used, the direction of the inference, the type of the context or the source of information, etc. Moreover, some studies have shown that the type of inference that is made, varies in function of the type of the text (Graesser, Person, & Hu, 2002; León, van den Broek & Escudero, 1998; Millis & Graesser, 1994). This suggests that is it possible to interfere in problems of reading comprehension o in problems of making inferences, through the manipulation of all these variables.

3.1. Relationship between reading comprehension and reasoning

Several studies have mentioned the connection between reasoning and reading comprehension (Cromley, Snyder-Hogan, & Luciw-Dubas, 2010; Cromley & Wills, 2016; Graesser, Singer, & Trabasso, 1994; Osana, Lacroix, Tucker, Idan, & Jabbour, 2007; Rapp, van den Broek, McMaster, Kendeou & Espin, 2007; Swanson, 2012; Tzeng, 2010). Both processes imply the construction of a mental representation, as well as the use of inferences and to integrate information.

In Tzeng's (2010) study, comprehension at the moment of generating interactions between schemata and texts (GIST) and reasoning were tested. Precisely, the study tested if utilizing concept maps could be a useful measure to assess the reader's comprehension and reasoning skills. For that, several tasks including a reading comprehension tasks (two comprehension texts) and tasks assessing the reader´s background knowledge, reflections, memory, reasoning and synthesis skills during reading the texts, were used. The use of concept map helped both reading comprehension skills and GIST reasoning abilities, compared with the no map group.

Osana et al. (2007) tested the connection between exposure to a specific genre of text and deductive reasoning. Specifically, the study assessed the relation between making inferences and reasoning, and how to make explanatory bridging inferences while reading would predict the performance during a syllogistic reasoning task. Exposure to print and cognitive skills (verbal and nonverbal ability) were tested. For evaluating reasoning, 24 problems which included two premises and a conclusion, were used (three categories: consistent, inconsistent and neutral). Half of them included valid conclusions and half invalid conclusions. Participants had to decide if the conclusion could emerge logically from the premises. Explanatory inference ability was tested using a reading comprehension test, which included four short texts. After each text, eight open-ended comprehension questions were presented on a separate page. The texts were divided in low-inference version and one high-inference version. They found that exposure to print correlated with syllogistic reasoning. Moreover, high-inference-load and the low-inference-load measures correlated with the syllogistic reasoning.

3.2. Inference making and comprehension.

Regarding the cognitive higher level processes of reading comprehension, inference making is especially relevant in the framework of reasoning. As mentioned in previous chapter, an inference is any part of information that is not clearly presented in a phrase, a paragraph or a text (McKoon & Ratcliff, 1992). People use inferences in order to understand better the information given on a text and to integrate this information with their background knowledge. There are several types of inferences: complex inferences, elaborative inferences and inferences that imply supplementary ideas in a paragraph or text (bridge inferences); normally, this last category of inferences, combines parts inside a paragraph or a sentence (McKoon & Ratcliff, 1992).

Other classification considers inferences related to local coherence versus global coherence of the text. The first are based on explicit information from the text and are utilized to determine *local coherence* from the text. In contrast, *global coherence* is determined by inferences that relate globally distinct parts of textual information, and that makes them a necessary part of reading comprehension (McKoon & Ratcliff, 1992).

Another classification considered categories of inferences are the *text-connecting* inferences and the *gap-filling* inferences. In *text-connecting* inferences, the reader has to search logical connections between the incidents described in a text. In *gap-filling* inferences, the reader has to complete the information that is missing through his background knowledge about the world (Chikalanga, 1992).

When readers have problems in elaborating inferences, they normally fail to understand simple texts, because they are incapable to give coherence to their text representations (Kendeou et al., 2014) or they fail to fill conceptual gaps between sentences and paragraphs in a text (Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002). Therefore, they show difficulties in reading comprehension.

More precisely, studies in children that were poor comprehenders, had shown that reading comprehension problems have been associated with deficits in a variety of cognitive processing skills, like phonological processing, word-decoding, vocabulary and inference-making (Cain, 2009; Cain & Oakhill, 2004; Cain & Oakhill, 2006; Cain, Oakhill, Barnes, & Bryant, 2001). Following their results, poor comprehenders cannot construct a full representation of the text, because although they can process and integrate information, they cannot make a coherent mental model of the text as a unit. Results also suggest that poor comprehenders are less capable to rely on useful strategies like rereading previous text, in order to find a solution for their comprehension failure (Cain, 2009). This issue about the lack of proper strategies will be discussed later on.

In order to explore reasons of inference failure, Cain et al. (2001), used questions that were based on texts which were presented to children that were poor comprehenders and to children without difficulties. By using this questions, the experimenters evaluated the ability of making two types of inferences: coherence inferences, that are essential to determine the connections between premises in the text, and elaborative inferences, that enhance the text representation. The results showed, that in poor comprehenders, the difficulty of making inferences was emerging from their incapacity to choose the information that was relevant in order to make an inference.

For understanding a sentence or an entire text, people have to process visually and combine separate units, so that they can construct a coherent mental representation of the text in the memory, which leads to a successful comprehension of the text through other processes like semantic processes (Rapp et al., 2007). In this mental representation, textual information and background knowledge about context are involved, as well as some components coming from the comprehender, which also play their role (motivation, overall ability, epistemic beliefs, text properties, the frame where reading occurs, etc.) (Kendeou et al., 2011). That is why inferences are critical to comprehension (Bowyer, Crane & Snowling, 2005; Cain & Oakhill, 1999; Florit, Roch, & Levorato, 2011; Nation & Angell, 2006; Oakhil, et al., 2003).

Cain and Oakhill, (1999) studied causes for which children (poor comprehenders and good comprehenders) fail to make correct inferences, and also, studied the relation between reading comprehension and inference making. The experimenters used the two types of inferences referred previously: *text-connecting* and *gap-filling inferences*. Their results showed that the fact of using distinct reading strategies was the cause of the differences observed in the comparison groups. Precisely, their results suggest that poor comprehenders are less capable to understand how to connect text information and knowledge in order to provide the parts that are absent in the text.

In order to study the contribution of various skills in reading comprehension in children which are poor and good readers, Oakhil, Cain, and Bryant, (2003) used a variety of measures which include inference and integration tasks, comprehension monitoring, story structure understanding, syntactic, and phonological skills, etc. Their general results showed that diversity in reading comprehension skills and in word reading skills, is attributed to distinct abilities. Moreover, the results showed a correlation between comprehension skills and word reading, but there were no correlation between inference and integration tasks.

Moreover, some studies had shown that the improvement of inference-making skills could also lead to the improvement of reading comprehension (Desmarais, Nadeau, Trudeau, Filiatrault-Veilleux, & Maxès-Fournier; 2013; Florit et al., 2011; Rapp et al., 2007). Precisely, Florit et al., (2011), tested how verbal and inferential skills interact with the comprehension of explicit and implicit information in a text, in children with typical development. Their results showed that children are based on inferential procedures in the comprehension of both explicit and implicit information.

As a conclusion, the results of the studies mentioned above, show a relevance between reading comprehension and inferences, suggesting that inferences play an important role in comprehension and also, that bad and good comprehenders could be using different ways of processing information for making inferences during reading.

Chapter 4. Strategies in reasoning.

At the time of reasoning, the task can induce the development of different reasoning strategies. Specifically, different types of tasks and presentation procedures, make different demands on memory capacity and may induce different reasoning strategies. It can thus be hypothesized that the difficulty level of transitive reasoning tasks, depends on use of reasoning strategies, which in turn depends on task format and presentation procedure (Verweij et al., 1999).

In one of their studies, Bacon, Handley, and Newstead (2003) tested the hypothesis of individual differences in the use of reasoning strategies (predominantly spatial and verbal strategies) in a syllogistic reasoning task. The participants were undergraduate university students with typical development. The experimenters replicated the procedure used in Ford's (1995) study, providing the participants with a set of 27 thematic syllogisms generated from the 27 valid forms presented in the studies of Johnson-Laird and Bara (1984) and Johnson-Laird and Byrne (1991). The terms were names given to people with certain hobbies or persuasions (like vegetarians or beekeepers) and also, names of people with given occupations (like lawyers or librarians). In each occasion, the two premises were provided, and the participants had to make a conclusion. The test items were 27 and were provided in a different random order within each booklet, each on a single page, leaving space below for written notes. Verbal protocols that participants had to speak while reasoning, were recorded. Additionally, a brief questionnaire created to identify the types of the participants reasoning processes, was also performed. The 13 items included in this questionnaire were developed in line with the types of reasoning behaviors that Ford linked with verbal and spatial strategies.

Results showed the clear presence of the two types of strategies: verbal and spatial. Verbal reasoners referred to actions like replacing, substituting, and cancelling syllogistic terms, whereas spatial reasoners often described the terms, and the relationships presented in the terms, as groups or subsets by using shapes like ovals or circles.

Expanding their studies to people with reading disabilities, Bacon, Handley, and McDonald (2007), tested the hypothesis that people with reading difficulties and concretely with dyslexia, have a higher proportion to use visuo-spatial strategies in their reasoning than the people without reading disabilities. At that time, the authors did not distinguish between visual strategies and viso-spatial strategies, as in latter articles, and their spatial manipulation included "visual" elements. Therefore, when they classify a strategy as spatial, could be visual as well. The authors tested the hypothesis by using a syllogistic reasoning task that included eight syllogisms presented on a booklet. The booklet at the end of each page had a space in which the participants had to note their written protocol. The authors compared the strategies identified from these written protocols, and reported by two groups of participants, one with and one without dyslexia. The results showed that in both groups of participants, verbal and spatial strategies were markedly detected. A verbal strategy is a substitution type process, in which, the information is operated in its abstract form (swapping words in the premises). Spatial strategies require that the reasoner make a connection between the terms contained in the first premise, that is, to detect their relationship. After that, the second premise helps by adding some information regarding a third term. For representing the relations of the terms presented in the premises, spatial reasoners showed in their written protocols that they used terms within shapes (usually circles), located in differing spatial relationships.

It was found that the participants with dyslexia showed a clear preference in use of (visuo) spatial strategies, while most of the participants without dyslexia preferred to use a verbal strategy. Moreover, results showed that the performance of the participants with dyslexia was hindered on syllogisms which included terms that can be easily visualized, suggesting that the easy of visualization of the premises, or imagery, is that provokes problems in the reasoning of people with dyslexia. In contrast, verbal reasoners (group without dyslexia) seemed to be uninfluenced by the ease of visualization of the premises. These results suggest that the imagery is that provokes problems in the reasoning of people with dyslexia, because it leads to less efficient reasoning.

Additionally, Bacon and Handley (2010), tested the function of visual processes in transitive reasoning of people with dyslexia, and also the visual impedance effect. The authors performed three experiments using written and verbal protocols of the participants. The procedure and the results were previously described. The experimenters did not doubt for the visual impedance hypothesis, neither were in contrary to this hypothesis. Their results agree with Knauff and Johnson-Laird's (2002) hypothesis that visual imagery can hinder reasoning. Expanding this suggestion to people with dyslexia, Bacon and Handley (2010) state that even though these people do use a visual strategy rather than a spatial one, and constantly add vivid pictorial representations to the premises while reasoning, they do not benefit from this visual strategy. In contrast, these strategy leads them to less accuracy and longer latencies. Moreover, Bacon and Handley (2010) propose two new limitations to the visual impedance hypothesis, stating that the visual impedance effect can be improved by changing the problem content, and also, that this effect may not apply similarly to all types of reasoners.

Continuing their investigation for the reasoning strategies that individuals with dyslexia use, Bacon and Handley (2014) tested again a hypothesis of previous studies, which propose that the reasoning strategies that individuals with dyslexia utilize, are based on visual mental representations, while individuals with typical development utilize abstract verbal strategies. The participants were divided in two groups, one with dyslexia and the other with typical development. Two experiments were performed in which two reasoning tasks were used, one syllogistic and one propositional, and also, a visual memory measure (VPT= Visual Patterns Test).

In Experiment 1, the results between the two groups showed that both groups performed equally in all three measures. Moreover, for the group with dyslexia, visual memory (VPT) was firmly correlated to reasoning accuracy in both types of problem. Analyzing each group apart, it was showed that on propositional problems, visual memory was a significant predictor for the participants with dyslexia but not for the participants with typical development. Also, it was showed that equally, on syllogistic problems, visual memory predicted accuracy for the participants with dyslexia but not for the participants with typical development. The authors concluded from Experiment 1, that participants with dyslexia lean on especially visual processes while reasoning. For both syllogistic and propositional reasoning, visual memory capacity (VPT score) significantly predicted reasoning accuracy for the participants with dyslexia, but not for the participants with typical development. This relationship seems to be absent in participants with typical development.

In Experiment 2, the results between the two groups in Reasoning Accuracy, showed that both groups performed better on propositional problems in comparison with syllogisms. Also, participants with dyslexia were generally less accurate overall than participants with typical development. The results between the two groups in Pattern Recall, showed that participants with dyslexia were less accurate under high concurrent visual memory load on both problem types, in comparison with participants with typical development who seemed uninfluenced from the secondary task. These results suggest that participants with dyslexia lean on visual memory while reasoning with both syllogisms and abstract propositional arguments. Also, participants with dyslexia recalled significantly fewer visual patterns on the secondary task. Analyzing each group apart in Reasoning Accuracy, it was showed that participants with typical development tended to perform best on propositional problems. Concluding from both experiments, the authors suggest that like in previous studies it has been showed that individuals with dyslexia manifest a deficit in verbal memory, they adopt a strategy that is compensatory while reasoning, leaning on visual resources to balance out such verbal deficit.

The conclusion of Bacon's studies is that people with dyslexia lean on visual processes while reasoning (Bacon & Handley, 2014), and they add vivid characteristics to the premises, even to the ones that are not easy to visualize (Bacon & Handley, 2010). The problem with these visual processes that they use and the vivid characteristics that they add to the premises, is that they do not get any help from that. In contrast, they present difficulties while reasoning, and thus, they are less accurate and their response times are later than these of people without dyslexia (Bacon & Handley, 2010). So, it is suggested that is the ease of visualization of the premises that hinders the reasoning of people with dyslexia (Bacon et al., 2007), and that the visual impedance effect can be improved by changing the problem content (Bacon & Handley, 2010).

Finally, some studies that explored different types of assessment to enhance reading comprehension in people with reading disabilities (RD) have shown that some types of strategies could help these people; for example, Swanson (2012) showed that reading comprehension could be improved by using key instructional components, like *directed response and questioning*, *modeling by the teacher of steps*, and *strategy cues*. This last ones is a metacognitive strategy allowing for independent practice.

In children, research has showed that the strategies that children use while reasoning, are based on the presentation procedure, task format, and distance between objects (equalities) or length difference between objects (inequalities). Also, it has been showed that children normally use the simplest strategy in order to solve a task (Verweij et al., 1999). Moreover, it is also suggested that children use inductive reasoning when they make a conclusion taken out from their experiences (Schraw, McCrudden, Lehman, & Hoffman, 2011).

4.1. Strategies in reading comprehension.

Strategies not only have been crucial in reasoning. A lot of studies had shown the importance of using strategies while reading a text, in order to integrate better the information provided in it (Ainsworth & Burcham, 2007; Broer, Aarnoutse, Kieviet & Van Leeuwe, 2002; Cromley et al., 2010; Cromley & Wills, 2016; McDaniel, Howard, & Einstein, 2009; Nation & Angell, 2006; O'Reilly, Best, & McNamara, 2004; Perfetti, Yang, & Schmalhofer, 2008). Some strategies that can be used from teachers in order to enhance reading comprehension, are summarisation, concept mapping, self-questioning (Vacca & Vacca, 2005), comprehension monitoring (Cromley et al., 2010), note-taking (Bonner & Holliday, 2006) and making schematics (Broer et al., 2002). These strategies are defined as *cognitive strategies*, *metacognitive strategies*, or *self-regulatory strategies*. The utilization of these strategies is connected with advances in reading comprehension in undergraduate and elementary students. Teaching the students how to use specific reading comprehension strategies can also increment the correct inferences in a narrative text (Cromley et al., 2010).

The strategies that a reader can use while reading a text, are divided in two categories: *high-level and low-level strategies*. The strategies which require the modification of the read context –like summarising by connecting information from the sentences in the text, self-questioning and concept mapping- are defined as *high-level strategies*. The strategies which require few modification of the read context – like rereading, underlining/highlighting or paraphrasing in a singular sentence – are defined as *low level strategies* and frequently, appear not to be directly related with comprehension (Cromley & Wills, 2016).

Cromley et al. (2010), tested a direct and inferential mediation (DIME; Cromley & Azevedo, 2007) model of reading comprehension in university students. The authors also used measures of prior topic knowledge, inference, reading strategy use, reading vocabulary, and word reading fluency. All measures were provided in paper-and pencil format. The results showed medium-sized indirect effects of reading comprehension strategies (via inference) on reading comprehension.

McDaniel et al. (2009), tested the efficiency of the 3R (read-recite-review) strategy for learning from educational texts, by performing two experiments and as sample college students. They compared the 3R strategy with other strategies like rereading and note-taking study strategies, by utilizing free-recall, multiple-choice, and short-answer inference tasks. The 3R strategy requires reading the text, leave it apart and narrate aloud all that can be remembered, and then read the text again (the read-recite-review strategy, called 3R). The results showed that the 3R strategy, in the case of rereading only, gave benefits for multiple-choice performance (on a task which contained inference questions) and for problem solving, suggesting also that, 3R could develop profound learning of the material (maybe for example, the construction of an efficient mental model).

These studies suggest that when a reader develops useful reading strategies, (s)he can enhance reading comprehension and so, good reading comprehension enhances inference making.

Chapter 5. Objectives, hypotheses and methodology of the experimental series.

As shown, the visual impedance effect has been found in adults with typical development, but not in adults with dyslexia. It was explained by the use of visual representation as part of a different strategy applied for reasoning.

It has been suggested that people with RD seem to be unaffected from this effect because they always use visual strategies to represent the premises, regardless of the propositional, spatial, or visual nature of the premises (Bacon & Handley, 2010). They are more used to rely on a visual strategies in order to compensate their problems with written/verbal content and for that they have more practice dealing with irrelevant visual content. Therefore, they will not show the visual impedance effect.

Few is known about how children represent and make inferences, and therefore whether the visual impedance effect is also present in reasoning in children. As far as we know, there is not previous investigation that tests the visual impedance effect in children of primary school with reading disabilities or with typical development in general.

Considering all that, the current investigation aims to provide new scientific evidence associated with reasoning skills in adults and children, and more specifically, to look into the relationship between reasoning and reading skills in adults and children with typical development and also, in children with reading disabilities.

The main aim of this investigation is to create a new reasoning task similar with the traditional propositional transitive inference task (paper and pencil task), but without reading requirements that allow to study the visual impedance effect. The design of the task is planned to be very simple, and therefore, it could be utilized in research in reasoning for both adults and children with and without reading disabilities. The task will be based on pictures, and thus it will not include the impediment that the written language may pose.

The specific aims are:

- To design a transitive reasoning task without propositional content for studying reasoning skills and the visual impedance effect without the use of written language. Instead the new task will use pictures (pictorial task). This will be a very simple task that can be easily implemented and useful in children and adult populations.
- To investigate the presence of the visual impedance effect in adults and test if this new pictorial task could be utilized to detect this effect.
- To investigate the presence of the visual impedance effect in primary school children and test if this new pictorial task could be utilized to detect this effect in children, as well as in adults.

- To examine the relationship between transitive reasoning and reading abilities and other associated abilities like working memory and visuospatial memory.

The hypotheses of this investigation are:

- The new reasoning task, even though it utilizes only pictorial and oral stimuli, will perform as like the traditional propositional task that is generally used for studying reasoning skills.
- The new reasoning task should find the principal reasoning effects: the complexity effect, showing that there will be a lower performance in complex problems than in simple problems, and the validity effect, showing a lower performance in invalid problems versus valid problems.
- The new task will allow to detect the visual impedance effect, like the traditional propositional task.
- If the visual impedance effect is showed in children, it could be said that children and adults with typical development are affected by the visual characteristics of the premises, and that they therefore utilize an inferential o visuospatial strategy in transitive problems. However, if the visual impedance effect is not showed in children with reading difficulties, this may be explained by the exclusive use of the visual strategy instead of a verbal one, in these children, due to their reading problems.

In order to test these hypothesis and reach the objectives, three experiments were design. They are briefly explained below.

Experiment 1. The goal of this experiment was to evaluate reasoning, reading, visual processing, and other basic cognitive skills like intelligence and memory as control measures. The participants were undergraduate university students (50 women, 11 men, age range: 18–44 years). The first hypothesis was that the new task, even though utilizing only pictorial and oral stimuli, would work equally to the traditional propositional task for studying reasoning skills. Hence, the new task should work in finding the main reasoning effects, namely, validity (better performance in tasks with valid problems than those with invalid ones), and complexity (better performance in simple problems than in complex ones). The second hypothesis was that that the new task, like the traditional propositional task, would be sensitive to the detection of the visual impedance effect.

The experiment was performed in accordance with the ethical standards of the American Psychological Association and the approval of the Research Ethics Board of the University of Granada. The participants signed respective consent forms for their participation to the experiment.

A 2 × 2 × 2 × 2 (Imaginability × Validity × Complexity × Task) mixed design with four factors was performed, utilizing three within-subject factors (Imaginability, Validity, and Complexity) and one between-subjects factor (Task).

The three independent variables manipulated are Imaginability, Validity, and Complexity. Imaginability has two levels: Imaginable (adjectives easy to visualize) and Neutral (adjectives not easy to visualize). Validity also has two levels: Valid (the problem has a valid conclusion) and Invalid (the problem has no conclusion). Complexity also with two levels: Simple (same adjective) and Complex (two opposite adjectives). Task also has two levels: propositional task (premises presented with written propositions in a booklet) and visual (premises presented orally in images).

For the reasoning tasks, in the propositional version, the participants had to read the premises and write down their conclusion. In the visual version, the participants had to listen to the premises that the experimenter was reading aloud and then, to move pictures with images that represented the animals included in the premises, in the space in front of them in order to represent the relations given in the premises, and also represent their conclusion by using these pictures. Reading measures included two tests, the Text Comprehension subtest from the "Bateria de Evaluación de los Procesos Lectores" (Reading processes assessment battery, PROLEC-SE Battery, Ramos & Cuetos, 1999), and the Word Attack test from the Woodcock-Johnson III NU Tests of Achievement (McGrew & Woodcock, 2001). Visual processing also included two tests, the Corsi Cubes (McLean & Hitch, 1999) and the Visual Patterns Test (VPT, Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). Intelligence was measured by Raven's Progressive Matrices - General Scale (Raven, 2000). Memory was measured by the Digit Span from the Wechsler Intelligence Scale (WISC-R, Wechsler, 1974)—both Digits Forward and Digits Backward subtests were used. All the tests were performed in two sessions.

Experiment 2. The goal of this experiment was to test if the new pictorial/visual reasoning task, could be utilized in children of primary school level. The participants were children of primary school age. The experiment was performed in accordance with the ethical standards of the American Psychological Association and the approval of the Research Ethics Board of the University of Granada. The school principal and the parents signed respective consent forms so as to give their authorization for the children's participation.

A 2 x 2 x 2 x 2 within-subject design with four factors (Imaginability × Validity × Complexity × Task) was carried out.

Two different sessions were performed in which, two versions of the reasoning task were presented (propositional and visual version). The design of the problems was based on previous studies in English (Bacon et al., 2003; Knauff & Johnson-Laird, 2002). The two reasoning tasks used for this experiment, were the same used before in Experiment 1 (see Experiment 1).

This experiment was designed for piloting the visual reasoning task in children population, and thus, after guaranteeing scientifically its applicability; once this was guarantee, Experiment 3 was carried out.

Experiment 3. The goal of this experiment is to study reasoning skills and the visual impedance effect in children participants of primary school age with and without dyslexia or reading difficulties, by utilizing the new picture task. The hypothesis was that if the effect is found in children, it could be said that children and adults, unlike adults with RD, are influenced by the visual characteristic of the premises and that they therefore utilize a similar inferential strategy in transitive problems.

Participants were 84 children (32 boys and 52 girls; age range: 8–11 years) from three different primary schools. Of these, 26 children had RD. The experiment was performed in accordance with the ethical standards of the American Psychological Association and the approval of the Research Ethics Board of the University of Granada. The school principal and the parents signed respective consent forms so as to give their authorization for the children's participation.

A 2 × 2 × 2 × 2 × 2 (Imaginability × Validity × Complexity × RD × KS) mixed design with three within-subject factors (Imaginability, Validity and Complexity), and RD and KS as between subjects factors, was used.

Reasoning and reading skills, and intelligence as control measure, were evaluated. Reasoning included only the visual task used in Experiment 1 (see Experiment 1). Reading included two tests, the Text comprehension subtest from the PROLEC-R Battery (the Evaluation of Reading Processes for Children – Revised Edition, Cuetos, Rodríguez, Ruano, & Arribas, 2007) and the Pseudoword reading subtest from the PROLEC-R Battery. Intelligence was evaluated by Raven's Progressive Matrices - General Scale (Raven, 2000). All test were administered in three sessions.

Part II. Experimental Section

The studies reported in the Experimental section (Experiment 1, 2 and 3) have been published as:

Experiment 1:

Panagiotidou, E., Serrano, F., & Moreno.Ríos, S. (2018). Reasoning and Reading in Adults. A New Reasoning Task for Detecting the Visual Impendance Effect. *Advances in Cognitive Psychology*, *14*(4), 150-159. DOI: 10.5709/acp-0246-4

Experiment 2 and 3:

Panagiotidou, E., Serrano, F., & Moreno‐ Ríos, S. (2020). Testing the visual impedance effect in children with and without reading difficulties using a new visual reasoning task. *Dyslexia, 26*, 67–86. DOI: 10.1002/dys.1640 (Accepted: 21 October 2019)

Chapter 6. Reasoning and Reading in Adults. A New Reasoning Task for Detecting the Visual Impedance Effect.

Experiment 1.

The "Visual Impedance Hypothesis" states that at the time of reasoning, the reading context provokes visual images, which may add irrelevant details to an inference and thus could hamper reasoning. This study aims to create a new visual version of a reasoning task, similar to the traditional propositional task of relational syllogisms but based on visuospatial components. Using this, it would be possible to investigate the deductive ability of relational inferences in tests without the need for reading. Two reasoning tasks were used, and measures of working memory, visuospatial memory, intelligence and reading comprehension, were also taken. The participants were sixty-one university students without reading difficulties. Results show that both versions of the reasoning task work similarly in finding the main reasoning effects expected. Findings support the visual impedance effect, that is, fewer correct responses in problems with imaginable contents than with neutral ones. They indicate that this new visual task could be used to explore reasoning skills without reading being involved, and this would be useful for testing reasoning in people both with and without reading difficulties.

Keywords: visual impedance, transitive reasoning, new visual deductive task, reading difficulties.

6.1. Introduction

Reading and reasoning skills appear to be related, especially regarding reading comprehension, which involves making inferences, among other reasoning skills (Graesser, Singer, & Trabasso, 1994).

This relationship is also supported by findings from the scientific literature about reasoning. For instance, in deductive reasoning, Osana, Lacroix, Tucker, Idan and Jabbour (2007) tested the association between specific types of text and reasoning, showing that the type of text affects reasoning skills. Likewise, some studies have investigated differences in reasoning task performance as a function of reading skills (Bacon & Handley, 2010; Bacon & Handley, 2014; Bacon, Parmentier, & Barr, 2013; Cromley, et al., 2010). Moreover, it is shown that practice in extracting inferences from texts, improves reading comprehension skills (Cromley, Snyder-Hogan & Luciw-Dubas, 2010).

Following the Theory of Mental Models (Johnson-Laird, 1983; Johnson-Laird, 2006), when people make inferences, they construct mental models that keep the structure of the situations represented by the premises. Mental models can be created from perception, imagination or by understanding of the premises, and they can provoke visual images. Equally, they can be abstract, representing conditions that cannot be visualised (Johnson-Laird & Byrne, 2002). When reasoning, some people may rely on irrelevant visual images instead of on abstract spatial models to carry out relational inferences (Knauff & Johnson-Laird, 2002).

Knauff and Johnson-Laird (2002) found that "the relationships that elicit visual images containing details that are irrelevant to an inference should impede the process of reasoning" (p.364). This obstacle to reasoning is called "The Visual Imagery Impedance Hypothesis". Thus, relationships that are easily visualised but difficult to imagine spatially, could somehow interfere with reasoning in comparison with other types of relationships, while visuospatial relationships would facilitate it (Knauff & Johnson-Laird, 2002). Moreover, it is demonstrated that "depending on their cognitive style and how easily they are able to use imagery during reasoning, people are influenced in different ways by the imaginability of the content of reasoning problems" (Gazzo Castameda & Knauff, 2013, p.2378). Specifically, the results of Gazzo Castameda and Knauff (2013) indicate that people who prefer to envisage the premises of reasoning problems also attempt to envisage non-visual problems, which is why they present the visual impedance effect (also agreed by Knauff, 2018). Sato, Sugimoto and Ueda, (2017) recently showed the visual impedance effect in reasoning using real objects which could also be moved, supporting the idea that irrelevant details may impede reasoning.

Some of the existing research relating reasoning and reading and the visual impedance effect, have been carried out in people with reading disabilities (Bacon & Handley, 2010; Bacon et al., 2013). Some results suggest that people with dyslexia would not show the visual impedance effect (Knauff & Johnson-Laird, 2002), as opposed to participants without difficulties. More precisely, the results showed that people with dyslexia always used a visual strategy, by representing vividly in their written protocols the information of the premises, even when the adjectives of the premises were not imaginable. This could indicate that people with dyslexia may use visual strategies in reasoning tasks, while people without dyslexia would rely more on spatial or propositional strategies (Bacon & Handley, 2010; Bacon & Handley, 2014).

People with dyslexia may tend to rely on visual strategies instead of propositional ones to try and overcome their written language disabilities (MacCullagh, Bosanquet, & Badcock, 2017). It also suggests that people with dyslexia have difficulty finding a suitable strategy as they seem to insist on a sequential approach (Bacon et al., 2013), which does not help them in successfully solving reasoning problems.

Moreover, the results of the visual impedance effect of Bacon et al. (2010) came from propositional problems that had to be read, so that people with reading difficulties would have had trouble due to the obstacle posed by written content. It would be interesting to validate the effect with a task with no propositional form, thus avoiding the problem of people with dyslexia having difficulties reading the premises, due to their specific literacy problem. This would be a more suitable approach to study the inference process in reasoning.

Additionally, Bacon & Handley´s (2010) results would indicate that participants with dyslexia may use the visual strategy without receiving any benefit from the content, which those without dyslexia can organise spatially. Furthermore, results indicated that people with dyslexia normally add physical characteristics to the premises, even when the terms given are relatively abstract. This addition could distract them from reaching an appropriate solution for the premises. Bacon, Handley & McDonald (2007) claimed that ease of visualisation of the premises is the reason for people with dyslexia having problems, as the majority of their participants used a strategy that confused their reasoning.

Thus, these previous studies have shown singularities in the way people with dyslexia reason. However, with other reading disabilities (e.g., comprehension difficulties, non-specific reading disabilities, like those in children with previous oral language problems, SLI), there is less information about how these can influence reasoning strategies. Therefore, it is not known whether the differences in performing reasoning tasks found between people with and without reading disabilities are specific to components of text comprehension, limitations in working memory (phonological or visuospatial) or the process of reasoning.

This study, comparing elements of both reading and reasoning, should offer new knowledge on the scientific background related to reading and reasoning skills in a typical developing population. This study is a first step towards further investigation. To start with, it will focus on typically developed readers, thereby trying to clarify what is expected in a population without difficulties. Findings could lead to future research on reasoning in populations with reading difficulties.

The aim is to create a task similar to the traditional propositional transitive inference task but reducing the reading (propositional) requirements. In a few studies, other deductive tasks were adapted to use diagrammatic and graphical premises in order to avoid the use of propositional premises. Moreno-Ríos & García-Madruga (2002) used a task of this type with adults to test priming effects during deduction. Also, Moreno-Ríos, Rojas-Barahona, & García-Madruga (2014) used graphical premises to test differences in deduction between children, adolescents and adults. These tasks showed similar general deductive effects, but allowed the propositional processing of the premises, which were irrelevant to the objective of the task, to be eliminated. Even though inference processing should be the same, the new task based on pictures should also show the visual impedance effect. The new task is designed to be very simple, and could be used in reasoning research for both adults and children with difficulties in reading and writing, without the interference of written language.

More specifically this study aims to:

1. Design a very easy task of transitive reasoning with no propositional content, in order to study reasoning skills and validate the "visual impedance effect" without the need for written language.
2. Investigate the relationship between transitive reasoning and reading abilities and other related abilities like working memory and visual memory.

It is hypothesised that the new task, although using only pictorial and oral stimuli, would work similarly to the traditional propositional task for studying reasoning skills. Thus, the new task would work in finding the main reasoning effects, namely, Validity (better performance in tasks with valid problems than those with invalid ones), and Complexity (better performance in simple problems than in complex ones). Moreover, it is hypothesised that the new task, like the traditional propositional task, would be sensitive to the detection of the "visual impedance effect".

6.2. Method

Participants

Sixty-one adults (50 women, 11 men, age range: 18-44 years), all students at undergraduate and postgraduate level. They were contacted in their classes by giving information about the experiment. Participation was voluntary and offered extra marks in their courses as a reward for participation. They were all native Spanish speakers, typically developed readers, without reading disabilities, as assessed through a previous interview and several reading tasks.

Instruments

Reasoning, reading, visual processing and cognitive skills (intelligence and memory) were tested as control measures. All tests were administered in the Spanish language.

Reasoning. Participants completed two versions of a reasoning task: one task was a written task (propositional task) and the other, a visual non-written task (picture task). Eight different questionnaires were designed, randomising the order of the problems. Half of the participants completed the propositional task (N=31) first and the other half (N=30) the visual non-written task (picture task). Only the first task was considered here because the second could have been influenced by the previous experience. We were interested in the participants' impressions of using different strategies with the two tasks. No differences were found.

In each task version, participants had to solve 16 three-term series problems, displayed in a different random order. Eight problems included adjectives (translated from English to Spanish, aiming to replicate previous studies in English) that were easily imaginable according to previous tests performed by Knauff & Johnson-Laird (2002; ugly-pretty; clean-dirty) and Bacon, Handley, & Newstead (2005; tall-short; rough-smooth). The other eight morphologically equal problems included neutral adjectives (from Knauff & Johnson-Laird, 2002; smart-dumb; and from Bacon et al., 2005; kind-cruel, rich-poor). Half of the imaginable problems had a valid conclusion (i.e. when the premises are true, the conclusion must also be true); the other half had an invalid conclusion (conclusion is not true, given that the premises are true, or there is no conclusion). Among the valid problems, two were simple problems (including the same adjective in both premises) and the other two were complex problems (including opposite adjectives in the two premises). A similar classification was developed for invalid problems and neutral problems.

Propositional task. Participants were presented with written premises that they had to read aloud. They then had to conclude what the relationship was between the last two terms in the context of the related adjectives given. They were asked to write the conclusion under the written problem; this blank space under the written problem would equally serve to write down any other information (about the premises), helping them to explain their reasoning process. The 16 problems were presented in a booklet, one per page, with space given under each for participants to write. An additional practice problem was used to explain the task.

Table 1. *Examples of problems in the Propositional task.*

Valid Simple problem The dog is taller than the cat. The cat is taller than the monkey. What can we say about the dog and the monkey?	**Invalid Simple problem** The dog is taller than the cat. The monkey is taller than the cat. What can we say about the dog and the monkey?
Valid complex problem The dog is taller than the cat. The monkey is shorter than the cat. What can we say about the dog and the monkey?	**Invalid complex problem** The dog is taller than the cat. The cat is shorter than the monkey. What can we say about the dog and the monkey?

Table 1 shows an example of a valid simple problem, an invalid simple problem, a valid complex problem and an invalid complex problem in the propositional task.

Picture task. Participants were presented with pictures instead of written premises, to solve the same 16 three-term series problems, also displayed in a different random order for each participant. Black pictures presented in cardboard squares with a white background (3 x 3 cm) were used. Pictures of a dog, a cat and a monkey were used (the same animals used in the propositional task). This was aimed at aiding participants to symbolise the idea of "more" (or the opposite "less") included in the premises; figures of a square (more) and a circle (less) were used (black cardboard squares, 1 x 1 cm). Although the premises only used the term "more", "less" could be used by participants if they chose. For this reason, two different elements (square and circle) were provided, to represent the two ideas. The picture task did not use any written information. Premises were read aloud to the participants, who had to listen and use the pictures to "represent" them.

Figure 3 shows an example of a valid problem constructed by a participant in the Picture task.

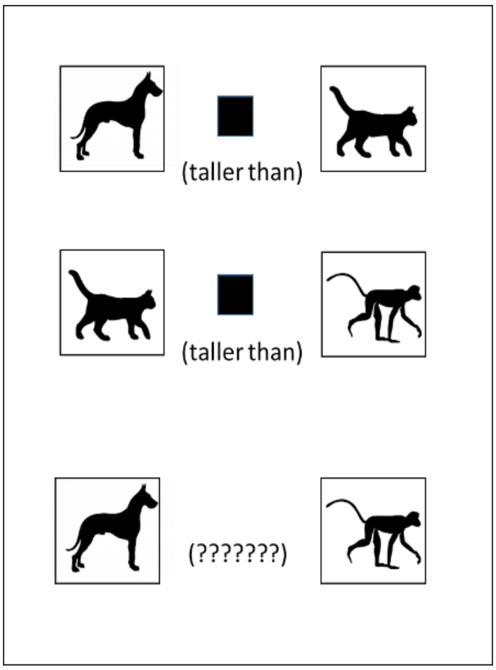

Figure 3. Example of a valid problem with pictures in the Picture task.

An additional practice problem was used to explain the task. Different pictures of animals were used (fox, duck and wolf).

Reading. Participants completed two reading tests.

The Text Comprehension subtest from the PROLEC-SE Battery (Ramos & Cuetos, 1999), measuring reading comprehension, was used. Participants had to read two texts followed by 10 questions on each, and write down their answers. Half of the questions were literal and the other half inferential. The test scores ranged from 0 to 20 points. Reading time for each text was also measured (in seconds).

The Word Attack test (McGrew & Woodcock, 2001) from the WJ III NU Tests of Achievement (Woodcock-Johnson® III NU Tests of Achievement) evaluates the participant's phoneme/grapheme awareness, both in phonological and orthographical procedures. Participants read 28 pseudowords; this had two practice items. The test scores ranged from 0 to 28 points. Time measures were also taken (in seconds).

Visual processing. Participants completed two visual processing tasks.

The CORSI Cubes (McLean and Hitch, 1999) measures visuospatial working memory, concentration and attention. Participants were presented with nine cubes (2.5 cm each), randomly arranged on a board of 25.4 x 27.94 cm. Only the examiner could see the cubes, numbered from 1 to 9. The examiner presented a sequence (two to nine elements), increasing the complexity. Participants had to reproduce it. Each trial included two sequences. The task stopped when the participant failed to correctly complete both sequences of one trial. Both the direct and inverse versions of the task were used. Each version had a maximum score of 16 points; total score was the sum of both.

The Visual Patterns Test (VPT) (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999) evaluates visual working memory. Participants were presented with a chequerboard pattern for three seconds and had to reproduce it on a blank grid of the same size and shape as the pattern. The grids advanced in size, from the smallest, a 2 x 2 matrix (with two filled squares), to the largest, a 5 x 6 matrix (with 15 filled squares). There were three patterns at each Complexity level. A pattern was correct when all the squares were appropriately represented in the grid. Testing stopped at the time when the participant failed to represent correctly on the grid any of the three patterns at a given level of complexity. Total score was calculated as the mean number of filled squares correctly recalled in the last three patterns recalled entirely correctly.

Intelligence. Raven's Progressive Matrices - General Scale (Raven, 2000) was used to measure participants' non-verbal intelligence. Raw scores were measured. The test scores ranged from 0 to 60 points.

Memory. Digit Span from the Wechsler Intelligence Scale (WISC-R) (Wechsler, 1974) - with both Digits Forward and Digits Backward subtests - was used. The maximum score was 28 points.

Procedure

All tests were individually applied in two sessions (approximately 1 hour each). Each reasoning task was presented in a different session (counterbalanced order) and was always the first task performed in the session. Both reasoning tasks presented the same set of problems. The rest of the tests were distributed in the two sessions.

For the propositional task, students read the problems aloud, wrote down both their thoughts and the conclusion (written protocol) and detailed their reasoning process aloud while writing. After writing their conclusions, participants were also asked to explain aloud how they got to that conclusion. The session was recorded with a digital camera.

For the picture task, the examiner read the problems aloud while the participant looked at a display of 20 pictures placed in front of him/her on the table (four images of a dog, four images of a cat and four images of a monkey; four circles and four squares). Pictures were placed in three different columns: dog in the first column, cat in the second and monkey in the third. Circles and squares were located in columns next to them. While listening to the premises, participants had to pick up the pictures from the columns and move them on the table in such a way that each premise was represented; the same procedure was required to represent their conclusion. Participants were also asked to describe their reasoning aloud while performing the task, and after finishing, explain how they got to that conclusion. The session was recorded with a digital camera.

For the remaining tests, normalised instructions were followed. Testing took part in a quiet laboratory.

Design

A 2 x 2 x 2 x 2 (Imaginability x Validity x Complexity x Task) mixed design with 4 factors was carried out, using three within-subject factors (Imaginability, Validity, and Complexity) and one between-subjects factor (Task).

6.3. Results

A 2 x 2 x 2 x 2 (Imaginability x Validity x Complexity x Task) mixed analysis of variance (ANOVA) with Task as a between subjects factor, was carried out. Only accuracy data were analysed. Table 2 shows the results in both Propositional and Picture reasoning tasks.

Table 2. *Mean percentages of correct responses (*M*) and Standard Deviation (SD) as a function of problem type in both Propositional and Picture task.*

		Neutral				Imaginable			
		Valid		Invalid		Valid		Invalid	
		M	*SD*	M	*SD*	M	*SD*	M	*SD*
Propositional Task	Simple	92	*23*	95	*20*	94	*21*	92	*23*
	Complex	79	*38*	76	*41*	81	*31*	74	*41*
Picture Task	Simple	98	*6*	98	*9*	97	*13*	95	*15*

A significant main effect of Complexity was found; participants showed more correct responses in Simple problems than in Complex problems (95% vs 80%; $F(1, 59) = 28.070$; $\eta^2 = .322$; $p < .01$). No significant main effects of Imaginability ($F(1, 59) = 2.626$; $\eta^2 = .043$; $p > .05$) or Validity ($F(1, 59) = 2.349$; $\eta^2 = .038$; $p > .05$) were found. Finally, there was no significant main effect of Task ($F(1, 59) = 1.188$; $\eta^2 = .020$; $p > .05$).

A significant interaction between Imaginability and Validity was found; $F(1, 59) = 4.058$; $\eta^2 = .064$; $p < .05$. This shows the “visual impedance effect” in the Invalid problems (88% vs 82%; $F(1, 60) = 4.678$; $\eta^2 = .060$; $p < .05$), that is, more accurate answers in Neutral vs. Imaginable problems. There were no significant differences in the Valid problems ($F(1, 60) = 0.128$; $\eta^2 = .002$; $p > .05$).

A significant interaction between Validity and Complexity was also observed; $F(1, 59) = 4.547$; $\eta^2 = .072$; $p < .05$. Participants gave more correct responses in Valid Difficult problems than in Invalid Difficult problems (84% vs 75%; $F(1, 60) = 4.324$; $\eta^2 = .042$; $p < .05$). In Simple problems, no significant effects were found ($F(1, 60) = 0.002$; $\eta^2 = .000$; $p > .05$).

The analysis for each task was carried out separately to test whether the predicted effects were present in the new task.

Picture Task. A 2 (Imaginability) X 2 (Validity) X 2 (Complexity) analysis of variance (ANOVA) showed significant main effects of Validity; participants gave more correct responses in Valid problems (94% vs 86%; $F(1, 29) = 6.735$; $\eta^2 = .188$; $p < .05$) than in Invalid problems.

Participants gave more correct responses in Neutral problems than in Imaginable (92% vs 86%), even though this effect of Imaginability was only marginally significant ($F(1, 29) = 3.832$; $\eta^2 = .117$; $p = .06$).

A significant main effect of Complexity was also found; the participants gave more correct responses in Simple problems than in Complex problems (97% vs 81%; $F(1, 29) = 13.956$; $\eta^2 = 0{,}325$; $p < .01$).

A significant interaction between Validity, Complexity and Imaginability was found; $F(1, 29) = 5.191$; $\eta^2 = .152$; $p < .05$. In Valid problems, only the effect of Complexity was marginally significant ($F(1, 29) = 3.702$; $\eta^2 = .113$; $p = .06$). However, in Invalid problems, there was a significant main effect of Complexity; participants gave more correct responses in Simple problems than in Complex problems (97% vs 75%; $F(1, 29) = 13.767$; $\eta^2 = .322$; $p < .01$). Additionally, in Invalid problems only, a significant effect of Imaginability was found; participants gave more correct responses in Neutral problems than in Imaginable problems (91% vs 81%; $F(1, 29) = 4.767$; $\eta^2 = .141$; $p < .05$). This last result would support the finding of the “visual impedance effect”.

Propositional Task. A 2 (Imaginability) X 2 (Validity) X 2 (Complexity) analysis of variance (ANOVA) showed significant main effect of Complexity; participants showed more correct responses in Simple problems than in Complex problems (93% vs 77%; $F(1, 30) = 14.162$; $\eta^2 = .321$; $p < .01$).

No significant main effects of Imaginability ($F(1, 30) = 0.033$; $\eta^2 = .001$; $p > .05$) or Validity ($F(1, 30) = 0.134$; $\eta^2 = .004$; $p > .05$) were found. There were no significant interactions.

Correlation between tasks. In order to observe how reasoning measures (correct responses in valid and invalid problems, complex and simple problems, and neutral and imaginable problems) were connected with reading and related cognitive measures, a Pearson’s correlation analysis for each reasoning task was carried out separately.

Results showed that the processes applied in the two reasoning tasks could be different.

Picture task. Table 3 shows the correlation matrix for the Picture task.

Table 3. *Correlation matrix for the Visual task.*

	PS_A	PS_T	Intelligence	COMP_A	COMP_T	COMP LIT	COMP INF	DIG DIR	DIG INV	DIG Total	CORSI DIR	CORSI INV	CORSI Total	VPT
PS_A	1													
PS_T	,185	1												
Intelligence	,435*	,100	1											
COMP_A	-,120	,106	,431*	1										
COMP_T	-,010	,230	-,161	,046	1									
COMP_LIT	-,075	,051	,489**	,815**	-,064	1								
COMP_INF	-,122	,122	,238	,846**	,133	,380*	1							
DIG_DIR	,152	-,338	,348	-,158	-,290	-,117	-,144	1						
DIG_INV	,456*	,095	,290	-,236	-,079	-,252	-,144	,134	1					
DIG_Total	,421*	-,133	,418*	-,265	-,232	-,253	-,191	,696**	,804**	1				
CORSI_DIR	,037	-,009	,047	,075	-,077	,049	,074	-,022	-,063	-,059	1			
CORSI_INV	,125	-,014	-,029	,062	-,384*	,103	,004	-,071	,020	-,028	,385*	1		
CORSI_Total	,103	-,014	,006	,081	-,296	,095	,043	-,059	-,020	-,050	,790**	,870**	1	
VPT	,286	,186	,312	,304	,076	,093	,400*	-,012	,251	,175	,142	,271	,256	1
ImInCx	,212	,455*	,479**	,331	-,053	,393*	,166	,072	-,053	,004	-,045	,120	,056	,119
ImInS	-,198	,091	,043	,144	-,059	,314	-,059	-,100	,062	-,015	-,259	-,141	-,233	-,397*
ImVaCx	,329	,024	,317	,277	-,024	,245	,216	-,076	,011	-,037	-,108	,336	,165	-,090
ImVaS	,040	-,211	,208	,115	-,209	,215	-,014	,145	,174	,213	,156	,055	,120	,217
NInvCx	,261	,144	,317	,402*	-,162	,495**	,185	-,073	,130	,050	,294	,298	,355	,251
NInS	-,268	,065	,024	,080	-,012	,072	,061	,049	,293	,241	,108	-,137	-,033	-,113
NVaCx	,006	,080	,137	,235	-,195	,350	,053	-,028	-,162	-,134	-,236	,159	-,020	-,277
NVaS	,205	,044	-,096	-,009	,266	-,082	,061	,153	-,138	-,008	,108	-,050	,025	,033
Total_N	,176	,174	,292	,441*	-,177	,559**	,190	-,025	,030	,006	,116	,267	,240	-,003
Total_Im	,245	,300	,511**	,399*	-,101	,487**	,188	,021	,017	,025	-,107	,202	,077	-,008
Total_S	-,133	-,014	,110	,173	-,060	,301	-,001	,080	,189	,185	-,004	-,125	-,085	-,163
Total_Cx	,302	,309	,490**	,460*	-,146	,547**	,231	-,021	-,025	-,031	-,023	,315	,197	,039
Total_Va	,254	,008	,313	,333	-,135	,393*	,170	,006	-,060	-,040	-,135	,302	,128	-,143
Total_In	,177	,397*	,475**	,446*	-,124	,568**	,189	-,002	,078	,055	,059	,165	,141	,087
Tot_Reasoning	,251	,288	,490**	,479**	-,151	,595**	,218	,003	,025	,020	-,021	,263	,163	-,007

	ImInCx	ImInS	ImVaCx	ImVaS	NInvCx	NInS	NVaCx	NVaS	Total_N	Total_Im	Total_S	Total_Cx	Total_Va	Total_In	Total Reasoning
ImInCx	1														
ImInS	,256	1													
ImVaCx	,354	,287	1												
ImVaS	-,205	-,089	-,099	1											
NInvCx	,343	,000	,000	,299	1										
NInS	-,142	,557**	-,069	-,050	-,104	1									
NVaCx	,335	,516**	,447*	-,126	,188	-,087	1								
NVaS	-,142	-,062	-,069	-,050	-,104	-,034	-,087	1							
Total_N	,382*	,412*	,236	,117	,780**	,081	,689**	,081	1						
Total_Im	,850**	,513**	,713**	-,007	,292	-,005	,514**	-,150	,480**	1					
Total_S	-,046	,751**	,078	,420*	,080	,671**	,191	,250	,368*	,260	1				
Total_Cx	,829**	,367*	,620**	-,067	,572**	-,154	,661**	-,154	,734**	,900**	,084	1			
Total_Va	,322	,429*	,824**	,142	,171	-,111	,784**	,076	,579**	,697**	,319	,705**	1		
Total_In	,859**	,475**	,291	-,027	,669**	,123	,414*	-,161	,714**	,814**	,270	,874**	,375*	1	
Tot_Reasoning	,768**	,546**	,605**	,049	,559**	,034	,673**	-,068	,791**	,916**	,349	,963**	,751**	,894**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Note. PS_A = Pseudoword Reading (Word attack) Accuracy; PS_T = Pseudoword Reading (Word attack) Time; COMP_A=Text Comprehension Accuracy; COMP_T=Text Comprehension Time; COMP_LIT=Text Comprehension Accuracy in literal questions; COMP_INF=Text Comprehension Accuracy in inferential questions; DIG_DIR=Digit span direct/Forward; DIG_INV==Digit span inverse/Backward; DIG_Total=Digit span Total; CORSI_DIR= Corsi direct; CORSI_INV= Corsi inverse; VPT= Visual Patterns Test; ImInCx = Imaginable, Invalid, Complex problems; ImInS=Imaginable, Invalid, Simple problems; ImVaCx=Imaginable, Valid, Complex problems; ImVaS=Imaginable, Valid, Simple problems; NInvCx=Neutral, Invalid, Complex problems; NInS=Neutral, Invalid, Simple problems; NVaCx=Neutral, Valid, Complex problems; NVaS=Neutral, Valid, Simple problems; Total_N=Total Neutral problems; Total_Im=Total Imaginable problems; Total_S=Total Simple problems; Total_Cx=Total Complex problems; Total_Va=Total Valid problems; Total_In=Total Invalid problems.

The reasoning results correlated with intelligence and reading comprehension. The hardest conditions, Complex problems and Invalid ones, showed correlations. Thus, there was a significant correlation between Intelligence and Complex problems ($r(30) = .490$), and also a significant correlation between Intelligence and Invalid problems ($r(30) = .475$) and Imaginable problems ($r(30) = .511$). The same was shown with reading comprehension, which correlated with Complex problems ($r(30) = .460$), with Invalid problems ($r(30) = .446$), with Imaginable problems ($r(30) = .399$) and with Neutral problems ($r(30) = .441$). Finally, a significant correlation was found between the standard scores of the Digit span and Intelligence ($r(30) = .418$).

Propositional task. Table 4 shows the correlation matrix for the Propositional task.

There was a significant correlation between the scores in the inverse trials of the Corsi blocks and the total of the Correct responses in reasoning problems, particularly with the Imaginable problems ($r(30) = .389$), and the Complex problems ($r(30) = .358$).

Table 4. *Correlation matrix for the Propositional task.*

	PS_A	PS_T	Intelligence	COMP_A	COMP_T	COMP LIT	COMP INF	DIG DIR	DIG INV	DIG Total	CORSI DIR	CORSI INV	CORSI Total	VPT	ImInCx	ImInS	ImVaCx	ImVaS	NInvCx	NInS	NVaCx	NVaS	Total_N	Total_Im	Total_S	Total_Cx	Total_Va	Total_In	Total Reasoning
PS_A	1																												
PS_T	,226	1																											
Intelligence	-,287	-,244	1																										
COMP_A	,071	-,389*	,352	1																									
COMP_T	,215	,051	,083	,233	1																								
COMP_LIT	,173	-,220	,287	,857**	,149	1																							
COMP_INF	-,084	-,439*	,288	,769**	,242	,330	1																						
DIG_DIR	,145	-,242	,246	,012	,037	,003	,019	1																					
DIG_INV	,172	-,102	,180	-,015	-,135	,085	-,132	,520**	1																				
DIG_Total	,183	-,186	,238	-,004	-,070	,057	-,077	,831**	,907**	1																			
CORSI_DIR	-,056	-,266	,152	,168	-,076	,214	,041	,356*	,261	,346	1																		
CORSI_INV	-,098	-,282	,361*	,172	,039	,244	,012	,223	,418*	,382*	,701**	1																	
CORSI_Total	-,098	-,284	,283	,174	-,013	,243	,016	,290	,380*	,391*	,898**	,941**	1																
VPT	,122	-,390*	,067	,232	,067	,257	,106	,036	,305	,217	,171	,211	,206	1															
ImInCx	,214	,139	-,093	,023	-,056	,043	-,012	-,122	,326	,152	,027	,337	,225	,004	1														
ImInS	,100	,175	-,002	-,110	-,157	,006	-,209	,112	,165	,163	,109	,238	,201	-,231	,490**	1													
ImVaCx	,080	-,051	,114	,219	-,031	,306	,021	,310	,261	,323	,199	,212	,198	,273	,121	,127	1												
ImVaS	,079	,211	,088	-,032	,100	-,005	-,053	-,132	,019	-,052	,063	,179	,142	,220	,186	-,111	,437*	1											
NInvCx	,279	-,088	,032	,104	,032	,170	-,021	,078	,294	,230	,078	,278	,188	,100	,672**	,505**	,347	-,090	1										
NInS	,023	,056	,031	-,054	-,277	,146	-,279	-,050	-,010	-,031	,171	,239	,230	-,181	,358*	,836**	,115	-,076	,472**	1									
NVaCx	,147	,075	,235	,071	-,002	,139	-,043	,061	,155	,131	,079	,233	,159	,178	,392*	-,009	,635**	,645**	,307	,082	1								
NVaS	,128	,130	-,033	-,110	-,131	-,089	-,091	,033	-,074	-,032	-,032	-,127	-,112	,054	-,053	-,130	,485**	,576**	,143	-,090	,374*	1							
Total_N	,248	,041	,125	,041	-,089	,160	-,124	,064	,195	,159	,108	,270	,192	,104	,589**	,413*	,632**	,398*	,794**	,490**	,744**	,502**	1						
Total_Im	,199	,166	,021	,059	-,062	,148	-,075	,057	,335	,247	,146	,389*	,301	,106	,784**	,583**	,632**	,526**	,627**	,468**	,647**	,292	,808**	1					
Total_S	,138	,237	,032	-,127	-,187	,017	-,255	-,009	,043	,023	,122	,209	,182	-,055	,397*	,641**	,482**	,574**	,418*	,663**	,447*	,572**	,736**	,762**	1				
Total_Cx	,249	,030	,089	,129	-,018	,207	-,021	,089	,346	,270	,119	,358*	,256	,172	,766**	,389*	,656**	,372*	,799**	,357*	,763**	,291	,921**	,898**	,576**	1			
Total_Va	,139	,096	,149	,068	-,021	,138	-,046	,107	,139	,143	,107	,179	,138	,231	,234	-,019	,823**	,792**	,259	,033	,874**	,701**	,740**	,678**	,624**	,698**	1		
Total_In	,223	,070	-,019	,015	-,099	,115	-,114	-,002	,282	,183	,099	,345	,255	-,046	,846**	,784**	,237	-,001	,872**	,713**	,293	-,010	,739**	,784**	,598**	,781**	,199	1	
Tot_Reasoning	,236	,106	,079	,052	-,080	,162	-,106	,064	,276	,212	,133	,344	,257	,110	,718**	,520**	,665**	,484**	,750**	,504**	,733**	,422*	,955**	,947**	,788**	,957**	,747**	,800**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Note. PS_A = Pseudoword Reading (Word attack) Accuracy; PS_T = Pseudoword Reading (Word attack) Time; COMP_A=Text Comprehension Accuracy; COMP_T=Text Comprehension Time; COMP_LIT=Text Comprehension Accuracy in literal questions; COMP_INF=Text Comprehension Accuracy in inferential questions; DIG_DIR=Digit span direct/Forward; DIG_INV==Digit span inverse/Backward; DIG_Total=Digit span Total; CORSI_DIR= Corsi direct; CORSI_INV= Corsi inverse; VPT= Visual Patterns Test; ImInCx = Imaginable, Invalid, Complex problems; ImInS=Imaginable, Invalid, Simple problems; ImVaCx=Imaginable, Valid, Complex problems; ImVaS=Imaginable, Valid, Simple problems; NInvCx=Neutral, Invalid, Complex problems; NInS=Neutral, Invalid, Simple problems; NVaCx=Neutral, Valid, Complex problems; NVaS=Neutral, Valid, Simple problems; Total_N=Total Neutral problems; Total_Im=Total Imaginable problems; Total_S=Total Simple problems; Total_Cx=Total Complex problems; Total_Va=Total Valid problems; Total_In=Total Invalid problems.

6.4. Discussion

This study presents some new evidence for detection of the visual impedance effect (Knauff & Johnson-Laird, 2002) by using an innovative reasoning task in which pictures are used instead of verbal content.

Results have indicated that this new task is similar to the traditional propositional task used to measure transitive reasoning with simple problems. Results also indicated that the participants presented the visual impedance effect in the Imaginable Invalid Difficult problems, showing that the picture task can be used to detect this effect. Actually, the traditional propositional task did not show the effect and only the "Complexity" factor was significant. This could be due to the very simple problems used and the fact that participants were adults. The new task was more "sensitive" to detecting traditional effects, such as validity and the visual impedance effect. Even with this task, the visual impedance effect was showed only in the most difficult conditions, with complex and invalid problems.

Another aim of this study was to investigate the relationship between transitive reasoning and reading abilities and other related abilities like working memory and visual memory. Diverse studies have revealed a connection between reasoning and reading comprehension in adults (Glenberg, Meyer, & Lindem, 1987; Swanson, 2012), given that inference-making is essential to connect ideas and data that are not described in text (Cromley, et al., 2010). A variety of studies (Graesser, et al., 1994; Johnson-Laird, Legrenzi, Girotto, Legrenzi, & Caverni, 1999; Kendeou, van den Broek, Helder & Karlsson, 2014) have shown that individuals spontaneously make inferences to compose a mental model from the conditions mentioned in the text while reading. The results of the present study are in line with previous results indicating an association between reasoning and reading comprehension in adult participants. Results with the new task showed that correlations between the most complicated reasoning conditions (complex problems, invalid problems and, interestingly, the imaginable problems, which generate impedance) correlated with comprehension and with intelligence. More similar effects in the traditional propositional task would have been expected. However, maybe participants in this very simple, traditional task use a more automatic strategy to solve problems (system 1; see Khemlani & Johnson-Laird, 2013). This could explain why there is no visual impedance effect and why the reasoning results do not correlate with comprehension and intelligence.

Additionally, some studies suggested a connection between reasoning and intelligence (i.e., Ackerman, Beier, & Boyle, 2002), given that intelligence implicates compound cognitive processes like inductive and deductive reasoning (Colom, Flores-Mendoza, & Rebollo, 2003); also, that reasoning capacity is a basic component in the formation of intelligence (Su¨ß, Oberauer, Wittmann, Wilhelm & Schulze, 2002). The results of the present study agree with these previous findings, showing an association between reasoning and intelligence.

As in most studies of reasoning with this task, differences by sex were not found (but see, Wright & Smailes, 2015, with children). In contrast, other spatial cognition tasks have demonstrated differences by sex, particularly in mental rotation (see Uttal et al., 2013), with better performance by males, while females perform better in verbal abilities (see Scheiber, Reynolds, Hajovsky, & Kaufman, 2015). Some of these differences have been attributed to the use of different strategies of resolution (see Gold et al., 2018). Participants' reports in the present study did not allow the detection of a differential use of strategies. However, caution should be applied to the interpretation of this absence of differences, because the number of women was much greater than that of men.

Finally, a variety of studies indicate a connection between working memory and intelligence (i.e., Ackerman, et al., 2002; Van Dyke, Johns & Kukona, 2014), suggesting that working memory is a factor of performance in cognitive tasks (Oberauer, Su¨ß, Schulze, Wilhelm, & Wittmann, 2000). The results of this study, obtained from the correlation analysis in the picture task, are in line with previous results, showing a connection between working memory storage capacity and intelligence.

Thus, this new picture task measuring reasoning has shown the effects of Validity and Complexity with very simple problems. In addition, it provides a measure of the visual impedance effect, which could help us understand people's reasoning at different ages and with different reading abilities. It does not lack the characteristics of other previously available reasoning tasks concerning related abilities, but it adds the value of providing a new measure free of literacy interference.

Consequently, it would seem to be a useful task for measuring reasoning, giving the opportunity to expand reasoning testing and offering possibilities beyond those of the previously available, traditional tasks.

Additional studies are needed to validate this task in other age-groups, for example in children. A task demanding lower literacy skills would also be suitable for studying reasoning skills at school levels before children have mastered written skills. This applies too to special populations with written-language problems (e.g., dyslexia, hearing problems and specific language impairment – SLI).

Moreover, the complexity (or simplicity) of reasoning problems should be considered. Although the aim was to design a very simple task, given that most of the problems were quite simple, participants could reach solutions easily, thus showing ceiling effects in some cases. Also, the information spoken out loud by the participants did not reveal enough. Participants merely repeated the premises while reasoning. More complex problems would allow the experimenters to elicit some talk that could help in studying the reasoning process performed when participants think aloud.

Chapter 7. Testing the visual impedance effect in children with and without reading difficulties using a new visual reasoning task.

Experiments 2 & 3.

This study examined reasoning skills in children, specifically transitive reasoning and the visual impedance effect, with a new visual/pictorial task. The visual impedance effect is the effect produced by the possible interference in the reasoning process of irrelevant details elicited from the premises of a reasoning task.

The new task had no reading requirements, which made it suitable for testing reasoning in primary school children, especially children with reading difficulties (RD), such as dyslexia. The study aimed also to validate the possible use of the task for studying reasoning and detecting the visual impedance effect without the interference of reading skills and to investigate the association between transitive reasoning and reading abilities.

Experiment 2 is a pilot study that was used to test the suitability of the new task for primary school children.

Afterwards, in Experiment 3 the task was tested on a larger sample of children of 3rd to 6th Grade, with and without reading difficulties.

Results showed that the new task is able to detect the main reasoning effects as well as the visual impedance effect. The findings are discussed, with the new task considered appropriate for studying reasoning skills in child populations both with and without reading difficulties.

Keywords: Reasoning, visual impedance effect, visual/pictorial task, reading difficulties, primary school.

7.1. Introduction

Reasoning and inferring are basic abilities implicated in the reading process (Ribeiro, Cadime, Freitas, & Viana, 2016). Arriving at a conclusion or fully understanding information, requires inferences in order to acquire the part of the information that is not explicitly given in a phrase, a paragraph or a text (McKoon & Ratcliff, 1992). The present work focuses on how children make deductive transitive inferences.

In deductive reasoning, a conclusion is true in all the cases in which the premises are true (Knauff, Fangmeier, Ruff, & Johnson-Laird, 2003). Transitive reasoning, also called relational reasoning, is a kind of deductive reasoning that is the basis for many cognitive processes, including text processing skills (Wright & Smailes, 2015). A common example of a transitive inference is: If A is cleaner than B, and B is cleaner than C, what can be concluded about the relationship between A and C is that A is cleaner than C (Goodwin & Johnson-Laird, 2005). Transitivity is a logical property possessed by some relations (Goodwin & Johnson-Laird, 2008).

There are different types of transitive reasoning tasks as a function of difficulty, depending on the complexity of the processes required to deduce the transitive relation (Bouwmeester, Vermunt, & Sijtsma, 2007). The most usual tasks in transitive reasoning include “three-term series problems”, as in the previous example. Transitive reasoning leads people to make conclusions with information that is not given in the premises; to do this, they must infer (e.g., if A is cleaner than B; and B is cleaner than C; then A is cleaner than C) (Knauff et al., 2003).

Other types of transitive task have used concrete and manipulative materials such as towers of coloured blocks and sticks with relations like “higher than-lower than” (Markovits, Dumas, & Malfait, 1995; Thayer & Collyer, 1978); coloured footballs using labels like “on the left-on the right” (Luo & Beck, 2010; Mou, Province, & Luo, 2014); and height tasks using coloured wooden cylinders (Wright, Robertson, & Hadfield, 2011).

It has been suggested that reasoning with transitive problems occurs at different stages (Knauff & May, 2006) that involve different processes, which might change during school years (Wright & Smile, 2015) and that this could account for difficulties found, for example, in children with Attention Deficit/Hyperactivity disorder (Brunamonti et al., 2017). During reasoning, the information of the premises is first mentally represented and then integrated, providing the basis for generating conclusions.

Research on reasoning in adults has found that adults represent the premises at the time of reasoning by creating visual images, which contain irrelevant details that interfere with and could hinder reasoning. These visual images are evoked by the premises, causing an effect known as *the visual impedance effect* (Knauff & Johnson-Laird, 2002).

More recently, Sato, Sugimoto and Ueda (2017) studied the visual impedance effect in external representation and diagrammatic reasoning in adults with typical development, using real objects that could be manipulated and objects designed on a computer in the form of a graphic (two-dimensional objects). Their results showed a better performance in the task with manipulative features than in the computer task. They explained that the negative effect of real objects could be explained naturally by the visual impedance effect.

In adults with reading difficulties (RD), specifically dyslexia, some studies have shown that there is no such impediment by visual characteristics at the time of reasoning. Interestingly, contrary to the findings of Knauff and Johnson-Laird (2002), who tested the effect of visual impedance in participants without RD, Bacon and Handley (2010, 2014) found that adults with RD, specifically dyslexia, did not present the visual impedance effect. Visual information (even mental visual images) did not interfere because people would normally be using this to compensate for their reading difficulty.

Some studies have suggested that people with RD rely on a visuospatial strategy at the time of reasoning (Bacon & Handley, 2010, 2014; Bacon, Handley, & McDonald, 2007; Bacon, Parmentier, & Barr, 2013). More specifically, in propositional reasoning tasks that use written information - whether with a computer (e.g., Experiments 2 and 3 in Bacon & Handley, 2010) or with a paper and pencil presentation (e.g., Experiment 1 in Bacon & Handley, 2010) in which reading and writing skills are required, written and verbal protocols of people with dyslexia show that when they have to read the premises of problems with abstract terms, they may experience difficulties. Therefore, it seems likely that they add visible characteristics to the premises in order to create an image of them, which helps them to maintain the information in their minds (Bacon & Handley, 2010). In contrast, people without difficulties tend to use a simpler verbal strategy, relying on language information from the reading (Bacon & Handley, 2010; 2014).

The relevance of literacy skills (reading and writing) in the performance of reasoning tasks has been shown both in research with children (Elbro & Buch-Iversen, 2013, in a population with typical development; Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007, in a population with RD) and with adults (Falmagne, 2015, in people with typical development; Lindgrén & Laine, 2011, in those with RD). Thus, the connection between the two abilities – literacy and reasoning – has been repeatedly reported in the previous literature; as an example, inference-making skills, a main process in reasoning, predict performance in reading comprehension (Daugaard, Cain, & Elbro, 2017). Likewise, practice in extracting inferences can enhance reading comprehension (Elbro & Buch-Iversen, 2013). In fact, the literacy skill most related with reasoning may be reading comprehension. Reading comprehension is affected in most types of RD, either as a primary problem (e.g., comprehension difficulties) or as a consequence (e.g., dyslexia). Moreover, some studies have shown that together with their reading problems, people with reading comprehension difficulties manifest deficiencies when performing tests in inference-making and comprehension monitoring (Cain & Oakhill, 2006). More specifically, it has been found that children with RD do not estimate their perception of the text as precisely as children with typical development (Oakhill, Hartt & Samols, 2005), and they show a lower level of skills in inference-making (Segers & Verhoeven, 2016).

Further research on the visual impedance effect has been focused on the possibility of studying it without the intervention of writing skills in the reasoning tasks. The study of Panagiotidou, Serrano, & Moreno-Rios (2018) tested a newly designed visual version of a reasoning task, similar to the traditional propositional task of relational syllogisms, but based on pictorial components. In this new task, pictures were used instead of verbal content, with the aim of studying reasoning skills without the need for reading. It was expected that reasoning would not be affected by literacy skills.

This study with adults without any RD (Panagiotidou et al., 2018) showed that the new pictorial task was similar to the traditional propositional task used to measure transitive reasoning with simple problems and to detect the visual impedance effect (in the Imaginable Invalid Difficult problems of the pictorial task), showing that this task was also useful to detect this effect (Panagiotidou et al., 2018). The absence of the impedance effect in adults with RD strongly indicates that they are processing transitive inferences in a different way that could be related to difficulties in reading (Bacon & Handley, 2010; 2014). The question is whether that different way of processing is also present in children, who are less experienced in reading, and children who present reading difficulties.

Until now there has been no other investigation connecting the study of transitive reasoning skills in primary school children with reading skills, using the visual impedance effect as a marker of reasoning. All the reported studies have been carried out on adults, with and without RD (Bacon & Handley, 2010, 2014; Knauff & Johnson-Laird, 2002; Panagiotidou et al., 2018). It was therefore thought it would be interesting to study the relationship between reasoning and reading comprehension skills already suggested in previous research (e.g., Daugaard et al., 2017; Kendeou, van de Broek, Helder, & Karlsson, 2014), using the new reasoning task. Moreover, by extending this study to skills considered as prerequisites of comprehension, like phonological decoding-reading skills (pseudoword reading) and basic cognitive skills (intelligence) (Tzeng, 2010), it should be possible to test their relationship with reasoning skills measured by the new task.

The aim of Experiment 2 and 3, therefore, is to study reasoning skills, specifically transitive reasoning with simple problems, in children by using the new visual/pictorial task (Panagiotidou et al., 2018). As the task has no reading requirements, it is more suitable for testing reasoning in primary school children, especially if they have RD. The study also aims to validate the possible use of a reasoning task without the interference of reading skills, which are less automatized in children of primary school age. Finally, the study examines the manifestation of the visual impedance effect in primary school children and attempts to ascertain whether this new pictorial task could be used to detect it in children, with the same results as those found in adults. If the effect is found in children, it could be said that children and adults, unlike adults with RD, are influenced by the visual characteristic of the premises and that they therefore use a similar inferential strategy in transitive problems. Additionally, the association between transitive reasoning and reading abilities will be studied.

Experiment 2 and 3 would contribute with new and innovative information to the scientific and educational research about reasoning skills in children and its relation to reading skills.

As part of the study, a pilot experiment was carried out first in order to test whether the new pictorial task, validated in adults (Panagiotidou et al., 2018), could be used in a child population (Experiment 2).

Once this was determined, another study (Experiment 3) was performed in order to test reasoning skills and the visual impedance effect in children with and without RD, all studying in primary school.

7.2. Experiment 2.

Experiment 2 used the new pictorial task and aimed to examine whether this task could help test reasoning skills without the mediation of reading, and also whether it was useful to identify the visual impedance effect observed in more traditional propositional reasoning tasks.

This was a pilot study was performed aimed at assessing whether the pictorial/visual reasoning task using pictures instead of written protocols, designed in a previous investigation with adult participants (Panagiotidou et al., 2018), could be used with a child population at primary school level.

If this new task worked similarly to the traditional propositional task in detecting the main deductive effects for studying reasoning skills in this pilot investigation with a small sample of children, it was hypothesised that it could be used for further investigation of reasoning skills, including the detection of the visual impedance effect.

7.2.1. Method

Participants

Ten primary school children participated in the pilot study: three children of 3^{rd} grade (three girls – age range: 8.3 - 9.1 years), three children of 4^{th} grade (three girls – age range: 9.8 - 10.4 years), and four of more advanced grades, that is, three children of 5^{th} grade and one of 6^{th} grade (two girls – age range: 10.4 – 12 years). A larger sample of children at an early school level was selected because the goal in this pilot study was to test both reasoning tasks in different child populations; it was therefore important to make sure that younger children were able to perform the two tasks. Two of the ten children had reading difficulties (RD), based on previous diagnoses available at the school's educational guidance centre: one child in 3rd grade (girl) and another in 5th grade (boy).

The selection of children was made at the school by giving information about the experiment to the school principal, the school board and the parents. The study was conducted in accordance with the ethical standards of the American Psychological Association and the approval of the Research Ethics Board of the University of XXXXX. The school's board and the parents signed respective consent forms, giving authorisation for the children´s participation during school hours. Participation was voluntary. All participants were native Spanish speakers.

Materials

Two versions of a reasoning task were presented in two separate sessions. The first was based on a paper and pencil task (propositional task); the second did not use written material, but instead used pictures (picture task) for presenting the terms of the premises. Participants could also use the pictures they were given to represent the premises and find the conclusion.

Overall, each task required the participants to solve 16 three-term series problems, displayed in a different random order. The problems were designed based on previous studies in English (Bacon, Handley, & Newstead, 2005; Knauff & Johnson-Laird, 2002) and the terms of the problems (adjectives) were taken from those studies and translated from English to Spanish. Eight easily imaginable adjectives were used in the Imaginable problems condition (e.g., Knauff & Johnson-Laird, 2002; clean-dirty/

limpio-sucio; and Bacon et al., 2005; tall-short / *alto-bajo*; original Spanish in *italics*). Eight non-imaginable/neutral adjectives were used for the Neutral problems condition (e.g., Knauff & Johnson-Laird, 2002; smart-dumb / *listo-tonto*; and from Bacon et al., 2005; rich-poor / *rico-pobre*). Half of the Imaginable problems had a valid conclusion (Valid problems), that is, "a conclusion that is true in all the cases in which the premises are true"; the other half had an invalid conclusion (Invalid problems), that is, "there is no true conclusion that applies to all the cases in which the premises are also true". Among the four valid problems were two simple problems that contained the same adjective in both premises (e.g. rich-rich) and two complex problems, in which the two premises included different adjectives (e.g., rich-poor). Complex problems with transitive relations are more difficult than simple ones, presumably because in the second case participants need to convert the second adjective into the first adjective, changing the premises (Andrews, 2010; Wright & Smailes, 2015). The same is true with the invalid problems (2 simple – 2 complex problems). The eight neutral problems were similarly organised (4 valid – 4 invalid problems/ 2 simple- 2 complex in each).

There follows a short description of each task's specific features:

Picture task. This task did not include written information; instead, pictures were used to present the premises. The premises were presented using black pictures in cardboard squares with a white background (3 x 3 cm). Pictures of a dog, a cat or a monkey were used in order to represent the premises and to help the participants in the development of the conclusion. Moreover, in order to help the participants symbolise the idea of "more" (square) or the opposite "less" (circle) included in the premises, figures of a square and a circle were provided (black cardboard, 1 × 1 cm). Although the premises only included the term "more", participants could choose the term "less" if they wished. It is important to note that the relational adjectives were not displayed in the figures, and therefore, as in the propositional task, they had to be considered by participants without any visual support.

The examiner verbally presented the 16 problems, one at a time. Participants had to use the cardboard squares with the pictures to represent the premises and the conclusion. They were asked to think aloud as they were performing the task. One practice-problem was used to explain the task, using different animal pictures (fox, duck and wolf).

The task score was 1 or 0. A correct answer (scored 1) was granted when the participant gave the right conclusion in valid problems or stated "there is no conclusion" in invalid problems. Otherwise, the answer was incorrect (scored 0). A case of a valid problem in the Picture task was presented in the Experiment 1 (Figure 1).

Propositional task. This task was structurally equivalent to the pictorial version. Each problem was presented in written format, one per page in a booklet. A booklet containing the 16 problems was provided. Participants had to read the premises aloud and reach a conclusion based on the connection between the last two terms, in the context of the associated adjectives. One practice-problem was used to explain the task. An example of a valid simple problem, an invalid simple problem, a valid complex problem and an invalid complex problem in the propositional task was presented in Experiment 1.

The task score was 1 or 0. A correct answer (scored 1) was granted when the participant gave the right conclusion in valid problems or stated "there is no conclusion" in invalid problems. Otherwise, the answer was incorrect (scored 0).

Procedure

The two reasoning tasks were randomly administered in different sessions (counterbalanced order). A digital camera was used to record the sessions, which took place in a silent room, free from any distraction. Each participant was tested individually.

For the picture task, the problems were read aloud by the experimenter while the participants looked at 20 pictures at the same time, located on the desk in front of them (four pictures of a dog, four pictures of a cat and four pictures of a monkey; four circles and four squares). The pictures were arranged in three different columns: pictures of a dog in one, pictures of a cat in another, and pictures of a monkey in a third. Circles and squares were also placed in columns next to the pictures. While listening to the premises, participants could take the pictures and move them on the desk, so that each premise could be displayed using the pictures. The same procedure was taught to represent the conclusion. Moreover, participants were required to reason aloud during the task and after completing it, explaining how they reached their conclusion.

In the propositional task, children had to read the problems aloud and write down their ideas in the blank space below the premises. They also had to explain aloud what they were writing down. After writing their conclusions, the children were asked to explain aloud how they reached them.

The explanation was asked in both tasks, as recommended in research on transitive reasoning, in order to verify by means of this verbal explanation that the child had really drawn a transitive inference (Bouwmeester & Sijtsma, 2004). Chapman and Lindenberger (1992) assumed that a child was able to draw a transitive inference when they were able to explain their judgments in the answers.

Design

A 2 x 2 x 2 x 2 within-subject design with 4 factors (Imaginability × Validity × Complexity × Task) was carried out. The tasks had a counterbalanced order.

7.2.2. Results.

Table 2 shows the results in each task as a function of problem type. Only accuracy data were analysed.

Table 2. Mean percentages of correct responses (and standard deviation) of all participants (Pilot study, N=10*) in each task as a function of problem type.*

Task		**Neutral**				**Imaginable**			
	N	Valid		Invalid		Valid		Invalid	
		Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
Propositional	(10)	85 (24)	90 (21)	85 (34)	20 (25)	95(16)	90 (21)	85 (33)	25 (26)
Picture	(10)	80 (34)	70 (42)	80 (35)	30 (42)	85 (34)	75 (42)	65 (41)	25 (35)

Given the small sample in this pilot study, the effect in the four factors was tested using the non-parametric Wilcoxon signed ranks test.

Participants gave more correct responses in Valid than in Invalid problems, both in the propositional task (90% *vs*. 54%; z = 2.820; p = .01) and in the visual task (78% *vs*. 50%; z = 2.113; p = .04). Participants gave more correct responses in Simple than in Complex problems, in the propositional task (88% *vs*. 50%; z = 2.821; p = .01) and in the visual task, although the analysis did not reach the significance level (78% *vs*. 50%; z = 1.895; p = .058). No significant differences were found for Imaginability in the propositional task (74% *vs*. 70%; $z = 1.342$; $p = .18$), nor in the visual task (63% *vs*. 65%; $z < .01$; $p = .90$).

7.2.3. Discussion

The objective of this pilot study was to test whether the classical deductive effects found in the traditional task would be shown in the new task: effects of validity and complexity.

The results showed no differences between the two tasks. Thus, in studying reasoning skills in children, it appears that both tasks work similarly, as was found in the study with adults (Panagiotidou et al., 2018). More important, both the visual and the traditional propositional tasks showed the effect of congruency of the adjective (better performance in simple than complex problems) and of the validity of the argument in reasoning (valid better than invalid). Additionally, the effect of congruency of the adjective (better performance in simple than complex problems) is suggested by the results but only to a slight degree; maybe a bigger sample would be needed to show this clearly.

It would therefore be worth using the new visual task with a larger sample of children in order to study their reasoning and to detect the visual impedance effect in children.

7.3. Experiment 3

This experiment aimed to study reasoning skills and the visual impedance effect in children of primary school age with and without dyslexia or reading difficulties, by using the new picture task (Panagiotidou et al., 2018). It is expected that the visual impedance effect will appear when the adjectives included in the premises are easy to visualise (for example, tall - *taller than*); that is, it is more likely to be observed in the conditions with Imaginable problems than in the Neutral ones. In particular, it is hypothesised that it will be more common in the Imaginable Complex Invalid condition, given that this is the most difficult one.

Because the picture task does not require reading skills, it might be more suitable for testing reasoning in children, especially those with reading difficulties. For this reason, Experiment 1 used only the picture task and not the propositional one. It is hypothesised that the picture task could be a suitable task for detecting the main reasoning effects and the visual impedance effect, without the demand for reading and writing skills. Even so, it is expected that older children with greater experience will have developed more effective deductive strategies that could be tested with different tasks (Markovits, 2014). For the same reason, children with higher scores in intelligence and memory and higher reading comprehension abilities will have had more opportunities than less skilled children to engage in reasoning activities, and are likely, therefore, to perform better in deductive tasks. If this is so in this task with low cognitive demands that does not require reading skills, we expect to find a positive correlation between deductive reasoning performance and intelligence and comprehension abilities. However, the relation between intelligence and reasoning has not been found conclusive in previous studies (e.g., Stanovich, 2015; Markovits, Doyon, & Simoneau, 2002). It will be interesting, therefore, to investigate the relationship between transitive reasoning and reading skills as relevant and related skills in infancy (especially at school).

7.3.1. Method

Participants. Participants were 84 children (32 boys and 52 girls; age range: 8-11 years) from three different primary schools. Of these, 26 children had reading difficulties, based on previous diagnoses available at the school's educational guidance centre and following some of the tests carried out in this study (see below).

The children were students of Key Stage[1] KS 2 (3rd and 4th Grades) and KS 3 (5th and 6th Grades). Participation was requested by giving information about the experiment to the school principal, the school board and the parents. The study was conducted in accordance with the ethical standards of the American Psychological Association and the approval of the Research Ethics Board of the University of XXXXX. The school board and the parents signed respective consent forms, giving authorisation for the children's participation at school. It was always voluntary. All the children were native Spanish speakers.

Materials. Reasoning and reading skills, plus intelligence as control measure, were tested. All the tests were carried out in Spanish.

Reasoning test. Participants completed the visual reasoning task with pictures (explained previously). This task was structurally equivalent to the propositional version. The propositional task was not tested as it was not an objective in this experiment. The children were presented with 16 reasoning problems (one at a time) in random order. The 16 problems were divided into 8 Neutral problems and 8 Imaginable problems: 4 Valid and 4 Invalid in each; and 2 Simple and 2 Complex in each.

Reading tests. Participants performed two reading tests: Text comprehension and Pseudoword reading. These were used for testing reading skills and for validating previous diagnoses of reading difficulties and dyslexia. Children with reading difficulties were those with a reading performance below the expected (<25^{th} percentile), either in accuracy or time measures or both, in one or two of the reading tests (following DSM – 5's diagnostic criteria; APA, 2013).

The Text Comprehension subtest from the PROLEC-R Battery (Cuetos, Rodriguez, Ruano, & Arribas, 2014), evaluating reading comprehension, was carried out. Participants had to read four texts and orally answer some questions after each text. The test score ranged from 0 to 16 points.

The Pseudoword reading subtest from the PROLEC-R Battery was used, measuring both reading speed and accuracy. Children had to read 40 pseudowords aloud. Accuracy (correct reading) and time measures (in seconds) were registered. The test score ranged from 0 to 40 points (accuracy).

The presence of reading difficulties was computed as a *reading difficulties index* in the correlation analysis. This index was computed as a dichotomous variable (0 = no reading difficulties and 1 = reading difficulties).

Intelligence test. Raven's Progressive Matrices - General Scale (Raven, 1996) was used to test participants' non-verbal intelligence. The test score ranged from 0 to 60 points. Raw score and IQ measure were calculated.

Procedure. All tests were individually administered in three sessions (approx. 35 minutes each). The reasoning task was performed in the first session and was the only task in that session. The remaining tests were administered in sessions 2 and 3 (counterbalanced order). The sessions were performed on consecutive days, one on each.

For the reasoning task, the same procedure described above was used. A digital camera was used for recording performance in this task. For the remaining tests, the examiner followed the standard instructions determined by each one. All testing took place in a silent room in the school, free from any distraction.

Design. A 2 × 2 × 2 × 2 × 2 (Imaginability × Validity × Complexity × RD × KS) mixed design with three within-subject factors (Imaginability, Validity and Complexity) and RD and KS as a between subjects factors.

7.3.2. Results

The results of the reasoning task are presented, organised according to school KS and reading difficulties (RD). In addition, correlations between reasoning and the other measures (intelligence and reading) are presented.

Analyses of the correct responses of all children by school KS and RD.

A 2 × 2 × 2 × 2 × 2 (Imaginability × Validity × Complexity × RD × KS) mixed analysis of variance (Anova) with RD and KS as between subjects factors, was carried out.

Table 3 shows the results in the picture reasoning task for all participants, as a function of school KS and problem type.

Table 3. *Mean percentages of correct responses (and standard deviation) in the reasoning task in all participants (N=84),* as a function of school Key Stage (KS) and problem type.

KS	**Neutral**				**Imaginable**			
N	Valid		Invalid		Valid		Invalid	
	Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
2 (44)	65 *(38)*	77 *(29)*	53 *(47)*	25 *(35)*	69 *(38)*	67 *(37)*	43 *(44)*	18 *(31)*
3 (40)	79 *(34)*	83 *(29)*	64 *(45)*	29 *(37)*	89 *(24)*	80 *(34)*	59 *(47)*	30 *(42)*
Total (84)	71 *(37)*	80 *(29)*	58 *(46)*	27 *(36)*	79 *(33)*	73 *(36)*	51 *(46)*	23 *(37)*

A significant main effect of Validity was found $F(1, 80) = 50.658$, $p < .001$; $\eta^2 = .388$. Participants gave more correct responses in Valid than in Invalid problems (74% *vs*. 38%). A significant main effect of Complexity was found $F(1, 80) = 14.126$; $p < .001$; $\eta^2 = .015$). Participants gave more correct responses in Simple than in Complex problems (63% *vs.* 50%). There was not a significant main effect of Imaginability $F(1, 80) = 1.952$; $p = .17$; $\eta^2 = .024$).

Regarding between subjects effects, there was a significant effect of KS ($F(1, 80) = 9.217$; $p < .01$; $\eta^2 = .103$). As expected, children in KS 3 gave more correct answers than children in KS 2 (64% *vs*. 45%), who were younger and had less academic experience. Global differences between children with and without reading difficulties did not reach the significance level (52% *vs*. 61%; $F(1, 80) = 3.208$; $p = .08$; $\eta^2 = .039$).

A significant interaction between Imaginability and Complexity was observed $F(1, 80) = 4.282$; $p = .04$; $\eta^2 = .051$). The visual impedance effect was only observed when participants were dealing with complex problems ($F(1, 83) = 4.777$; $p = .04$; $\eta^2 = .054$); only in complex problems did participants give more correct responses in neutral problems than in imaginable problems (53% *vs*. 49%). In simple problems, the visual impedance effect was not found (F(1, 83) = .016; p = .89; $\eta^2 < .001$). Likewise, no differences were found between responses in imaginable and neutral problems (63% *vs*. 63%).

A significant interaction between Validity and Complexity was also observed F(1, 80) = 36.603; $p < .001$; $\eta^2 = .314$. In the case of invalid problems, an effect of Complexity was found (F(1, 83) = 51.111; $p < .001$; $\eta^2 = .381$): participants gave more correct responses in simple than in complex problems (54% *vs*. 25%). There was no significant effect of Complexity in valid problems (F(1, 83) =.189; p = .66; $\eta^2 = .002$; simple 75% *vs*. complex 76%).

A significant interaction between Imaginability x Validity was observed (F(1, 83) = 9.420; p = .003; $\eta^2 = .102$). In the case of Invalid problems, a significant effect of Imaginability was found (F(1, 83) = 7.264; p = .01; $\eta^2 = .080$): participants gave more correct responses in Neutral problems than in Imaginable problems (58% *vs*. 51%), confirming the visual impedance effect. In the case of Valid problems, this effect was not found (F(1, 83) = 3.532; p = .06; $\eta^2 = .041$).

A significant interaction between the three factors, Imaginability, Validity and Complexity, was also observed, F(1, 80) = 6.582; p = .01; $\eta^2 = .076$). In the case of the Complex problems, a significant effect of Imaginability was found (F(1, 83) = 4.777; p = .03; $\eta^2 = .054$), which indicates the visual impedance effect: participants gave more correct responses in Neutral problems than in Imaginable problems (53% *vs*. 49%).

In the case of the Simple problems, no significant effect of Imaginability was found (F(1, 83) = .016; p = .89; $\eta^2 < .001$); this result also supports the absence of the visual impedance effect. A significant effect of Validity was found (F(1, 83) = 16.903; $p < .001$; $\eta^2 = .162$): participants gave more correct responses in Valid problems than invalid problems (74% *vs*. 54%).

Finally, the 4-way interaction Imaginability × Complexity × KS × RD was statistically significant ($F(1, 80) = 7.570$; $p < .01$; $\eta^2 = .086$). This interaction is critical for the initial predictions: the visual impedance effect was predicted only in children without reading difficulties. The analysis of this interaction led us to test the two groups of children separately; these analyses are presented below.

Analyses of the interaction with correct responses of children without reading difficulties by school KS.

To analyse the data of children without difficulties, a 2 × 2 × 2 (Imaginability × Complexity × KS) mixed analysis of variance (Anova) with KS as a between subjects factor, was carried out.

Results in the picture reasoning task in participants without difficulties as a function of school KS and problem type appear in Table 4.

Table 4. *Mean percentages of correct responses (and standard deviation) in the reasoning task in participants without difficulties (N=58),* as a function of school KS and problem type.

KS	N	**Neutral**				**Imaginable**			
		Valid		Invalid		Valid		Invalid	
		Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
2	(33)	70	77	62	26	71	71	47	21
		(37)	*(31)*	*(45)*	*(38)*	*(38)*	*(38)*	*(45)*	*(33)*
3	(25)	78	82	64	34	92	84	60	28
		(32)	*(32)*	*(49)*	*(40)*	*(19)*	*(31)*	*(46)*	*(41)*
Total	(58)	73	79	63	29	80	77	53	24
		(35)	*(31)*	*(46)*	*(39)*	*(32)*	*(35)*	*(45)*	*(37)*

A significant main effect of Complexity was found ($F(1, 56) = 33.421$; $p < .001$; $\eta^2 = .374$). The participants gave more correct responses in Simple problems than in Complex problems (78% *vs*. 42%). There was no significant main effect of Imaginability ($F(1, 56) = 1.634$; $p = .21$; $\eta^2 = .0281$), nor of KS ($F(1, 52) = 3.612$; $p = .06$; $\eta^2 = .061$).

A significant interaction between Imaginability and KS was found $F(1, 56) = 4.491$; $p = .04$; $\eta^2 = .074$. In KS 2, the participants showed the visual impedance effect: they gave more correct responses in Neutral problems than in Imaginable problems (59% *vs*. 53%; $F(1, 32) = 5.146$; $p < .05$; $\eta^2 = .139$). However, in KS 3, the visual impedance effect did not appear: participants gave almost the same number of correct responses in Imaginable as in Neutral problems (66% *vs*. 65%; $F(1, 24) = .519$; $p = .08$; $\eta^2 = .021$).

A significant interaction between Imaginability and Complexity was also observed ($F(1, 56) = 6.484$; $p = .01$; $\eta^2 = .104$). In the case of Complex problems, the visual impedance effect was observed: participants gave more correct responses in Neutral problems than in Imaginable problems (46% *vs*. 38%; $F(1, 57) = 10.469$; $p < .001$; $\eta^2 = .155$). In the case of Simple problems, no significant differences were found ($F(1, 57) = 0.528$; $p = .47$; $\eta^2 = .009$).

Analyses of the interaction with correct responses of children with reading difficulties by school KS.

The same analysis described above was performed with the data of children with difficulties. A 2 × 2 × 2 (Imaginability × Complexity × KS) mixed analysis of variance (Anova) with KS as a between-subjects factor, was carried out.

Results in the Picture reasoning task in participants with reading difficulties as a function of school KS and problem type are shown in Table 5.

Table 5. *Mean percentages of correct responses (and standard deviation) in the reasoning task in participants with difficulties (N=26), as a function of school KS and problem type.*

KS		**Neutral**				**Imaginable**			
	N	Valid		Invalid		Valid		Invalid	
		Easy	Complex	Easy	Complex	Easy	Complex	Easy	Complex
2	(10)	50	75	20	20	60	55	25	50
		(41)	*(26)*	*(42)*	*(26)*	*(39)*	*(37)*	*(35)*	*(16)*
3	(16)	78	84	66	22	84	71	60	34
		(36)	*(24)*	*(40)*	*(31)*	*(30)*	*(36)*	*(49)*	*(43)*
Total	(26)	67	81	48	21	75	65	46	23
		(40)	*(25)*	*(46)*	*(29)*	*(35)*	*(37)*	*(47)*	*(38)*

The results showed a significant main effect of Complexity ($F(1, 24) = 30.397$; $p < .001$; $\eta^2 = .559$). Participants gave more correct answers in Simple than in Complex problems (70% *vs*. 33%). There was a significant effect of KS, $F(1, 24) = 4.782$; $p = .04$; $\eta^2 = .166$. Participants in KS 3 gave more correct answers than participants in KS 2. There was no effect of Imaginability ($F(1, 24) = .659$; $p = .425$; $\eta^2 = .03$). There was no significant interaction.

Correlation analysis between the reasoning task and the other measures

Table 6 shows the results of intelligence and reading measures. A one-way ANOVA was carried out to test the differences in these measures between the two groups (with and without RD). There were statistically significant differences between the two groups in Intelligence ($F(1, 83) = 13.897$; $p < .001$; $\eta^2 = .145$), Pseudoword reading – accuracy ($F(1, 83) = 26.465$; $p < .001$; $\eta^2 = .244$), Pseudoword reading – time ($F(1,83) = 17.217$; $p < .001$; $\eta^2 = .174$), Reading comprehension – accuracy ($F(1, 83) = 9.359$; $p < .01$; $\eta^2 = .102$) and Reading comprehension – time ($F(1, 83) = 7.547$; $p < .01$; $\eta^2 = .084$). No differences were found as a function of Age ($F(1, 83) =.222$; $p = .64$; $\eta^2 = .003$).

Table 6. *Descriptive data: mean (and standard deviation) in Intelligence -raw score and IQ-, Pseudoword reading – accuracy and time- and Text comprehension – accuracy and time- in all participants (Experiment 1) as a function of group: with RD (wRD), without RD (woRD) and Total.*

		wRD (N =26)	woRD (N=58)	Total (N=84)
Intelligence	Raw score	32.46 *(9.89)*	40.44 *(12.11)*	37.32 *(11.00)*
	IQ	96.69 *(11.25)*	106.73 *(10. 84)*	103.79 *(13.23)*
Pseudoword reading	Accuracy	30.81 *(4.24)*	35.05 *(2.50)*	34.21 *(3.51)*
	Time	67.50 *(26.08)*	50.31 *(13.06)*	34.21 *(3.51)*
Text comprehension	Accuracy	10.46 *(2.80)*	12.24 *(1.93)*	11.47 *(2.73)*
	Time	63.31 *(31.57)*	50.85 *(14.69)*	52.93 *(20.93)*

In order to examine how the visual reasoning task (correct responses in Valid and Invalid problems, Complex and Simple problems, and Neutral and Imaginable problems) was related to the other measures (pseudoword reading – accuracy and time measures - reading comprehension – accuracy and time measures - and intelligence), a Pearson's correlation analysis was performed. Age, KS and a reading difficulties index (presence of reading difficulties) were also included in the analysis. Given that the KS is a dichotomous categorical variable and Reasoning is a continuous variable, the KS variable was categorized with 0 and 1 values (corresponding to KS 2 and KS 3 respectively). A point-biserial correlation coefficient was computed, which is equivalent to Pearson correlation coefficient. Correlation analysis was performed considering the results of all the participants as one group.

Results are shown in the correlation matrix in Table 7.

The results showed that reasoning results are correlated with Intelligence. To be precise, there was a significant correlation between Intelligence and correct responses in all reasoning measures: Imaginable problems ($r(84) = .391$, $p < .001$), Neutral problems ($r(84) = .480$, $p < .001$), Complex problems ($r(84) = .281$, $p = .01$), Simple problems ($r(84) = .425$, $p < .001$), Valid problems ($r(84) = .363$, $p = .001$) and Invalid problems ($r(84) = .276$, $p = .01$). Intelligence also correlated negatively with Learning Difficulties ($r(84) = .-381$, $p < .001$).

Table 7. *Correlation matrix.*

	ImInvCx	ImInvS	ImVaCx	ImVaS	NInvCx	NInvS	NVaCx	NVaS	Cycle	Age	LD	InCx	InvS	VaCx	VaS
ImInvCx	1														
ImInvS	,406**	1													
ImVaCx	-,040	-,009	1												
ImVaS	,009	,208	,372**	1											
NInvCx	,545**	,486**	-,067	-,018	1										
NInvS	,373**	,837**	,153	,313**	,478**	1									
NVaCx	-,040	-,195	,511**	,262*	-,339**	-,119	1								
NVaS	-,286**	,119	,395**	,506**	-,212	,195	,242*	1							
Cycle	,102	,172	,181	,294**	,052	,112	,090	,192	1						
Age	,153	,245*	,117	,371**	,089	,206	,100	,128	,860**	1					
LD	-,025	-,037	-,168	-,090	-,087	-,146	,005	-,097	,109	,112	1				
InCx	,808**	,550**	-,044	-,022	,906**	,528**	-,228*	-,242*	,118	,152	-,046	1			
InvS	,407**	,957**	,076	,272*	,503**	,959**	-,163	,164	,148	,235*	-,096	,562**	1		
VaCx	-,046	-,106	,897**	,370**	-,217*	,036	,838**	,375**	,161	,125	-,104	-,145	-,035	1	
VaS	-,168	,185	,442**	,853**	-,138	,289**	,290**	,881**	,277*	,281**	-,108	-,158	,248*	,429**	1
ImInv	,730**	,898**	-,012	,121	,643**	,778**	-,164	-,041	,192	,251*	-,022	,816**	,874**	-,092	,042
ImVa	-,019	,115	,843**	,813**	-,053	,277*	,473**	,541**	,284**	,288**	-,158	-,040	,205	,778**	,772**
NInv	,520**	,793**	,066	,195	,819**	,896**	-,249*	,020	,100	,179	-,139	,804**	,882**	-,086	,119
Nva	-,224*	-,026	,565**	,503**	-,339**	,071	,730**	,839**	,185	,146	-,065	-,298**	,024	,734**	,783**
TotalIm	,542**	,751**	,501**	,584**	,456**	,759**	,162	,297**	,318**	,365**	-,112	,595**	,788**	,401**	,499**
TotalN	,306**	,666**	,413**	,485**	,490**	,815**	,246*	,546**	,202	,246*	-,161	,503**	,773**	,388**	,595**
TotalCx	,711**	,345**	,569**	,253*	,563**	,422**	,410**	,021	,186	,203	-,122	,704**	,401**	,572**	,151
TotalS	,216*	,806**	,282**	,637**	,303**	,860**	,027	,572**	,251*	,318**	-,126	,337**	,869**	,193	,694**
TotalVa	-,129	,053	,783**	,733**	-,208	,197	,656**	,753**	,261*	,243*	-,125	-,179	,131	,834**	,857**
TotalInv	,711**	,872**	,020	,174	,755**	,860**	-,207	-,037	,140	,222*	-,093	,849**	,903**	-,094	,073
PS_A	,044	,150	,146	,163	,134	,197	-,028	,131	,152	,232*	-,494**	,113	,181	,078	,169
PS_T	-,056	-,251*	-,106	-,289**	-,097	-,261*	-,015	-,198	-,391**	-,411**	,417**	-,122	-,267*	-,074	-,278*
Intelligence	,073	,302**	,241*	,253*	,159	,324**	,193	,363**	,286**	,209	-,381**	,179	,327**	,252*	,358**
COMP_A	,183	,308**	,005	,283**	,241*	,302**	-,090	,096	,146	,164	-,320**	,241*	,318**	-,043	,213
COMP_T	-,088	-,112	-,250*	-,360**	-,122	-,206	-,129	-,134	-,402**	-,430**	,290**	-,145	-,167	-,225*	-,278*

	ImInv	ImVa	NInv	Nva	TotalIm	TotalN	TotalCx	TotalS	TotalVa	TotalInv	PS_A	PS_T	Intelligence	COMP_A	COMP_T
ImInv	1														
ImVa	,063	1													
NInv	,834**	,155	1												
Nva	-,121	,646**	-,125	1											
TotalIm	,797**	,653**	,727**	,300**	1										
TotalN	,641**	,540**	,781**	,522**	,813**	1									
TotalCx	,586**	,504**	,561**	,245*	,749**	,637**	1								
TotalS	,670**	,547**	,716**	,417**	,840**	,878**	,375**	1							
TotalVa	-,027	,916**	,023	,898**	,534**	,586**	,419**	,535**	1						
TotalInv	,957**	,113	,945**	-,142	,795**	,723**	,624**	,708**	-,009	1					
PS_A	,133	,186	,196	,076	,213	,217*	,135	,221*	,147	,166	1				
PS_T	-,223*	-,234*	-,220*	-,147	-,311**	-,282**	-,122	-,340**	-,212	-,215*	-,329**	1			
Intelligence	,277*	,298**	,292**	,364**	,391**	,480**	,281**	,425**	,363**	,276*	,251*	-,418**	1		
COMP_A	,297**	,167	,319**	,017	,327**	,285**	,168	,345**	,105	,325**	,267*	-,061	,150	1	
COMP_T	-,144	-,365**	-,197	-,167	-,330**	-,274*	-,253*	-,266*	-,298**	-,167	-,360**	,628**	-,383**	-,129	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Note. ImInvCx= Imaginable, Invalid, Complex problems; ImInvS= Imaginable, Invalid, Simple problems; ImVaCx= Imaginable, Valid, Complex problems; ImVaS= Imaginable, Valid, Simple problems; NInvCx= Neutral, Invalid, Complex problems; NInvS= Neutral, Invalid, Simple problems; NVaCx= Neutral, Valid, Complex problems; NVaS== Neutral, Valid, Simple problems; RD= Reading Difficulties; InvCx=Invalid, Complex problems; InvS=Invalid, Simple problems; VaCx=Valid, Complex problems; VaS=Valid, Simple problems; ImInv=Imaginable, Invalid problems; ImVa= Imaginable, Valid problems; NInv=Neutral, Invalid problems; NVa=Neutral, Valid problems; TotalIm= Total Imaginable problems; TotalN= Total Neutral problems; TotalCx=Total Complex problems; TotalS=Total Simple problems; TotalVa= Total Valid problems; TotalInv= Total Invalid problems; PS_A= Pseudoword Reading Accuracy; PS_T = Pseudoword Reading Time; COMP_A=Text Comprehension Accuracy; COMP_T=Text Comprehension Time.

Reading comprehension correlated significantly with Reasoning. More specifically, regarding the accuracy measure, with Imaginable problems ($r(84) = .327$, $p < .01$), Neutral problems ($r(84) = .285$, $p < .01$), Simple problems ($r(84) = .345$, $p < .01$) and Invalid problems ($r(84) = .325$, $p < .01$). Moreover, regarding the comprehension time measure, significant negative correlations were found with Imaginable problems ($r(84) = -.330$, $p < .01$), Neutral problems ($r(84) = -.274$, $p < .01$), Complex problems ($r(84) = -.253$, $p = .02$), Simple problems ($r(84) = -.266$, $p = .02$), and Valid problems ($r(84) = -.298$, $p < .01$).

A significant negative correlation between Learning Difficulties and Reading comprehension – accuracy measure, was found ($r(84) = -.320$, $p < .01$). There was also a significant positive correlation with the time measure of Reading comprehension ($r(84) = .290$, $p < .01$).

Pseudoword reading also correlated significantly with correct responses in the reasoning measures. More specifically, regarding the accuracy measure, there was a positive significant correlation with Neutral problems ($r(84) = .217$, $p = .05$) and Simple problems ($r(84) = .221$, $p = .04$). Additionally, regarding the time measure, a significant negative correlation was found with Imaginable problems ($r(84) = -.311$, $p < .01$), Neutral problems ($r(84) = -.282$, $p < .01$), Simple problems ($r(84) = -.340$, $p < .01$) and Invalid problems ($r(84) = -.215$, $p = .05$).

There was a significant correlation between KS and Reasoning, especially with correct responses in Imaginable problems ($r(84) = .318$, $p < .01$), Simple problems ($r(84) = .251$, $p = .02$) and Valid problems ($r(84) = .-261$, $p = .02$).

Finally, a significant correlation between Age and Reasoning was also found. In particular, Age correlated with correct responses in Imaginable problems ($r(84) = .365$, *p* < .01), Neutral problems (*r*(84) = .246, *p* = .02), Simple problems (*r*(84) = .318, *p* < .01), Valid problems (*r*(84) = 243, *p* = .03) and Invalid problems (*r*(84) = .222, *p* = .04). Age also significantly correlated with the accuracy measure of pseudoword reading (*r*(84) = .232, *p* = .03), the time measure of pseudoword reading (*r*(84) = .-411, *p* < .001) and the time measure of reading comprehension (*r*(84) = .-430, *p* < .001).

7.3.3. Discussion

This study provides new results on reasoning skills in children with and without reading difficulties (RD). It aims to validate the effectiveness of a reasoning task that can be used without the interference of reading skills.

The findings provide evidence about transitive reasoning skills and the visual impedance effect (Knauff & Johnson-Laird, 2002) in children with and without reading problems, using a new reasoning task in which the written content is replaced by pictures. As this task does not require expert reading and writing skills, it is more suitable for testing reasoning in primary school children, even in child populations with RD.

In previous studies, Bacon and Handley (2010) showed that adults with RD, specifically dyslexia, did not show the visual impedance effect when they made inferences in transitive problems, unlike adults without dyslexia. Different reasoning processes could be operating in the two groups of adults. Because inferring is a basic process in reading comprehension, the reading difficulties of people with RD could be related to their way of inferring, and the lack of the visual impedance effect would be a marker of that particular way of processing inferences. This study investigated whether children with and without RD showed the particular way of inferring seen in adults with RD. If this were so, the presence of the visual impedance effect would not be expected.

Moreover, if adults' way of inferring (showing the effect) is induced by the experience of reading, it could be expected that older children with more reading experience would show a similar effect, whereas younger children or children with dyslexia would not. The present results do not support this idea.

The pilot study helped to determine that the new picture task is able to test transitive reasoning in children just as well as the traditional propositional task. Likewise, the new visual task can detect the traditional reasoning effects, such as validity and complexity, which makes it a suitable task for measuring reasoning in children as well as adults (Panagiotidou et al., 2018).

Additionally, the visual impedance effect and its influence in a reasoning task were found by using this new task (more correct answers in Neutral problems than in Imaginable problems). However, the effect was more detectable in younger primary school children (KS 2, but not KS 3). A possible explanation could be that many children in KS 2 (3rd and 4th Grades of primary school) are focusing, while reasoning, on their prior knowledge for the relations presented in the premises, and also on the physical characteristics of the animals presented, which could interfere with their answers to the problems (Rapp et al., 2007). Older students may be more able to focus on the abstract representation of the problem. This explanation is in line with the findings of Knauff and Johnson-Laird (2002), which showed that the premises containing adjectives that can be easily visualised (Imaginable adjectives) elicit images that could cause difficulties in the process of reasoning. Another possible explanation could be that children of a younger age are still restricted in their prior knowledge, in attentional abilities or in choosing strategies in order to make deductive relationships, which means they cannot identify some relationships from the text they are reading (Rapp et al., 2007).

The visual impedance effect was more evident in problems including the most complex conditions (complex problems with two opposite adjectives, invalid problems with no conclusion and imaginable problems). This finding agrees with the results of Knauff and Johnson-Laird (2002), showing that the visual impedance effect is present when the premises of the reasoning problems are complex (two opposite adjectives) and can be visualised easily. In general, simple problems, may lead to jumping to conclusions automatically (System I) without considering alternatives and without the opportunity to produce the deductive effect (System II; See Khemlani, Byrne, & Johnson-Laird, 2018).

Moreover, these findings indicate that the new visual task can be used in children with and without RD. This new task does not demand any literacy skills, thus making it appropriate for studying reasoning skills in children before they acquire written skills and in children with written-language difficulties (e.g., dyslexia, hearing problems and specific language impairment – SLI). Both groups of children (with and without difficulties) showed the visual impedance effect when the premises were complex and could be easily visualised. These results are in contrast with the results of Bacon and Handley (2010) in adult participants with dyslexia, who did not show the visual impedance effect. It is possible that children might be more sensitive to this effect: children with difficulties may rely more on visual features and get distracted more easily by them. Adults with difficulties would maybe use the visual features as a strategy to overcome their problems with verbal content, but this strategy may not yet have been developed in children of school age.

Previous research using reasoning tasks based on pictures (graphic representation of the premises), showed similar general results in deductive effects (Moreno-Ríos, Rojas-Barahona, & García-Madruga, 2014) in children, adolescents and adults. Therefore, those tasks using visual elements to present the information allow reasoning without the need for propositional processing of the premises, which is relevant to the goal of the task. Inference processing should be the same in those tasks using pictorial elements.

As expected, measures of performance in intelligence, comprehension and reasoning increased with age. In general, the measures of intelligence and reading comprehension were significantly related to most of the reasoning conditions, without showing differential association with the imaginable and neutral conditions, which were used to compute the visual impedance effect. A relation between reasoning and reading (accuracy, time and, especially, comprehension) has been validated through this study's findings, in agreement with previous studies (Ahmed, Francis, York, Fletcher, Barnes, & Kulesz, 2016; Cromley & Azevedo, 2007; Graesser, Singer, & Trabasso, 1994; Kendeou et al., 2014; Segers & Verhoeven, 2016; Tzeng, 2010). Inference-making, which is a basic process in reasoning, is also a significant element of reading comprehension (Daugaard et al., 2017). While reading a text, in order to understand a sentence, individuals have to visually handle each word of the sentence, classify their depictions and relate them in order to construct a perception of the sentence's meaning. This perception is a consistent mental representation of the text in people's memory. This mental representation involves prior connected knowledge about word meanings, relations between words and propositions, and the interplay between top-down and bottom-up processes, which leads to important inferential procedures (Kintsch, 1988, 2013). By adding each new piece of information while reading a sentence, an additional unification of cognitive procedures, one of which is inference-making, is performed (Kendeou et al., 2014).

Some limitations may be noted, mainly regarding the sample size of children with RD. Further investigation should be conducted by increasing this sample, which would lead to a better characterisation of the usefulness of this new task. Different kinds of reasoning problem, such as syllogistic, would help us to determine the deductive role in reading comprehension difficulties. It might also be interesting to extend the study to different types of reading disability (specific *vs.* general). Moreover, the small size effect in the group difference in intelligence measured using the Raven's Matrices test ($\eta^2 = .15$) could also be included as a potential limitation of the current study.

This investigation opens the way for more research on reasoning skills in child populations, especially children with RD, thus complementing the available evidence in adults. It provides evidence from a new visual reasoning task, similar to the traditional paper and pencil tasks but without the requirement for reading and writing skills, making it appropriate for use with children and with special populations with literacy problems, like children with RD. Thus, it gives the opportunity to expand reasoning testing and research with a new and useful tool, which offers possibilities beyond those of the previously available traditional tasks in a population poorly studied until now.

Part III. General Discussion and Conclusions

This Doctoral Thesis aimed to provide new scientific evidence associated with reasoning skills in adults and children, and more specifically, to look into the relationship between reasoning and reading skills in adults and children with typical development and also, in children with reading disabilities. For that, the main aim was to create a new reasoning task similar with the traditional propositional transitive inference task (paper and pencil task), but without reading requirements that allow to study the visual impedance effect.

It has been showed that relations which are easily visualized but difficult to imagine spatially, could hinder reasoning in comparison with other types of relations. In contrast, visuospatial relations could aid reasoning (Knauff & Johnson-Laird, 2002).

Moreover, it has also been showed that "depending on their cognitive style and how easily they are able to use imagery during reasoning, people are influenced in different ways by the imaginability of the content of reasoning problems" (Gazzo Castameda & Kauff, 2013, p. 2378).

From the other hand, Bacon and Handley (2010) have found that people with dyslexia prefer using a visual strategy while reasoning, by adding physical characteristics to the premises, even though the adjectives contained in the premises are not easy to visualize. Such strategy is not beneficial to these people because: a) it distracts them with irrelevant features to solve the problems and b) they spend more time to answer to the reasoning problems increasing the probability for losing relevant information and also, a lot of times their answers are not correct (Bacon et al., 2007).

In these studies mentioned (Bacon et al., 2007; Bacon & Handley, 2010; Knauff & Johnson-Laird, 2002), the reasoning tasks used required the involvement of reading comprehension (participants had to read the premises). In the case of people with dyslexia such type of tasks could cause difficulties to these people because their reading comprehension is affected and presents difficulties (Bacon et al., 2007; Bacon & Handley, 2010).

Thus, it is not clear if the differences found between individuals with and without RD in their performance in reasoning tasks, are specific to elements of text comprehension, limitations in working memory (phonological or visuospatial), or the reasoning process.

The present investigation compared components of both reading and reasoning, and thus it could contribute new information in the scientific environment, which information is related with reading and reasoning abilities first in an adult population with typical development, and second, in children population with typical development and with RD. For that reason, the principal aim of the present investigation was to test reading and reasoning abilities in adults with typical development and in children with typical development and RD, by using a new designed visual reasoning task, in which pictures replace verbal content. The second aim is to test the visual impedance effect in both populations (adults and children; with typical development and children with RD), by using the new designed visual reasoning task. The hypothesis was that only the children without RD would show the visual impedance effect.

In order to test such abilities, three experiments were performed: Experiment 1 with adult population with typical development, Experiment 2 which is a pilot study in which the participants were children with typical development, and Experiment 3 in which the participants were two groups of children, one group with typical development and the other group with RD.

In the first study (Experiment 1), new evidence was provided for the detection of the visual impedance effect, through the utilization of an innovative reasoning task in which pictures substitute the verbal content. The first aim was to design a very simple task of transitive reasoning with no propositional content, and which, could be utilized to study reasoning skills and also, to confirm the visual impedance effect without the use of written language. The second aim was to study the relation between transitive reasoning and reading skills and other related abilities such as working memory and visual memory.

The results in Experiment 1 have showed that this new visual reasoning task is equivalent to the traditional propositional task, which was utilized in a lot of studies in order to measure transitive reasoning with simple problems. It was also showed that the participants manifested the visual impedance effect in the most difficult conditions, with Complex and Invalid problems and especially, in the Imaginable Invalid Complex problems, indicating in this way that the new picture task can be utilized for the detection of such effect. In contrast, in the traditional propositional task, such effect was not manifested. Moreover, the results showed correlations between the most difficult reasoning conditions (Complex problems, Invalid problems and Imaginable problems) and reading comprehension, indicating a connection between reasoning and reading comprehension, which is in line with previous studies (Glenberg, Meyer, & Lindem, 1987; Swanson, 2012), where such connection was also presented. Also, in the results, there were not any differences between reasoning task and sex, contrary to other studies in which other spatial cognition tasks (mental rotation tasks) were utilized, and in which, differences by sex were observed (Uttal, Meadow, Tipton, Hand, Alden, Warren, & Newcombe, 2013).

In Experiment 2 (pilot study), the goal was to test whether the new visual task, which was tested before in adults with typical development in Experiment 1, could be used in children of primary school age. The results showed no differences between the two reasoning tasks used (propositional and visual task). Thus, both reasoning tasks work comparably in testing reasoning skills in children, like it was found in the study with adults (Panagiotidou et al., 2018).

In Experiment 3, new evidence was provided about transitive reasoning skills and the visual impedance effect in children with and without RD, by using the new picture reasoning task, applied also in Experiment 1, and in which, verbal content is replaced by pictures. In this new task, reading and writing skills are not needed, hence, it is more suitable for studying reasoning skills in primary school children, even in children with RD.

Moreover, the results of the Experiment 3 showed that the visual impedance effect and its influence in the reasoning task, were detected by the utilization of this new picture task. Such effect was presented in younger children of primary school age without RD (KS 2, but not KS 3), confirming in this way the hypothesis of the present work. A possible explanation of why such effect was presented only in KS 2 could be the fact that many children in KS 2 (3rd and 4th Grades of primary school), are based on their prior knowledge at the time of reasoning for the existed relations presented in the premises. Additionally, they focus in the physical characteristics of the animals provided in the premises, fact that affects and can hinder their responses to the problems (Rapp, Broek, McMaster, Kendeou, & Espin, 2007). Contrary to that, older children may focus more in the abstract representation of the problem. This explanation is in line with the results of Knauff and Johnson-Laird (2002), in which, it is suggested that, premises which contain adjectives that can be easily visualized (Imaginable adjectives), elicit images that could hinder the process of reasoning. Another explanation could be that younger children are still limited to their prior knowledge, in attentional abilities or in choosing strategies for elaborating deductive relations. Hence, they cannot detect some relations in the text that they are reading (Rapp et al., 2007).

Interestingly, findings showed that the visual impedance effect was not presented in children with RD. Hence, it is suggested that children with RD seems to be unaffected from the imaginability of the adjectives presented in the premises. This result is in line with the results in Bacon and Handley's study (2010), in which adults with dyslexia did not present the visual impedance effect. The present finding for the children with RD showing no visual impedance effect, is innovative because it leads the research of reasoning in children with RD one step further.

Moreover, it was found that the visual impedance effect was presented in problems which included the hardest conditions and premises that could be easily visualized (complex problems with two opposite adjectives, invalid problems with no conclusion and imaginable problems).

This finding is in agree with the results of Knauff and Johnson-Laird (2002), showing that when the premises are complex (two opposite adjectives) and can be visualized easily, then the visual impedance effect is presented. This finding is the most innovative of this study because it indicates that the new reasoning visual task can be used in children with and without RD. In this new reasoning task there is no demand of using reading and writing skills, and that is why the new reasoning task is an appropriate tool for evaluating reasoning skills in children before they develop written skills. Additionally, it could be an appropriate tool also in children with written-language difficulties (like dyslexia, hearing problems and specific language impairment – SLI).

Finally, the results in Experiment 3 showed a relation between reasoning and reading (accuracy, time and comprehension), in agree with previous studies (Ahmed et al., 2016; Kendeou et al., 2014; Segers & Verhoeven, 2016).

Overall, the findings of the present work suggest that the visual impedance effect is presented in problems including the most difficult conditions (Complex, Invalid and especially, Imaginable problems). Particularly, Imaginable problems include adjectives that can be easily visualized, and previous investigations indicate that such type of adjectives provoke the creation of visual images that could hinder reasoning (Knauff & Johnson-Laird, 2002).

Furthermore, in the present work it is also suggested that children with RD do not present the visual impedance effect. This is an innovative finding because to our knowledge, no other research have shown such finding. Additionally, the present work provides this new information by using a new designed visual reasoning task, which was showed that is suitable for children with RD, due to that fact that it does not include any verbal content but only pictures. This is what makes this new visual task innovative, the fact that it uses only pictures and that is very useful for children with RD because they don't have to read in order to perform the task, and so they do not struggle with the reading problems that they already present due to their reading deficiencies.

The work in this Doctoral Dissertation opens a new way in which reasoning abilities in children with RD can be tested. More investigation is needed utilizing this new visual reasoning task with a larger sample and also, with a more extended sample including children with dyslexia, SLI, or writing disabilities.

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