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

Elpida Panagiotidou | **Francisca Serrano** | **Sergio Moreno-Ríos**

The Mind, Brain and Behavior Research Center (CIMCYC-UGR), University of Granada, Granada, Spain

Correspondence
Francisca Serrano. Faculty of Psychology, University of Granada, Campus de Cartuja, s/n, 18017 Granada, Spain.
Email: fdserran@ugr.es

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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. A pilot study (N = 10) was used to test the suitability of the new task for primary school children. Afterwards, the task was tested on a larger sample of children of third to sixth Grade, with and without RD (N = 84). 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 RD.

KEYWORDS

primary school, reading difficulties, reasoning, visual impedance effect, visual/pictorial task

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) (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 & Smailes, 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 (2018) 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 focused on the possibility of studying it without the intervention of writing skills in the reasoning tasks. A recent study (Panagiotidou, Serrano, & Moreno-Ríos, 2018) has 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 (Authors, 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 RD.

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 this work, 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.

The present study 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. Once this was determined, a second study (Experiment 1) was performed in order to test reasoning skills and the visual impedance effect in children with and without RD, all studying in primary school. This study—Experiment 1—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.

2 | PILOT EXPERIMENT

A pilot study was performed that 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 hypothesized that it could be used for further investigation of reasoning skills, including the detection of the visual impedance effect.

2.1 | Method

2.1.1 | Participants

Ten primary school children participated in the pilot study: three children of third grade (three girls—age range: 8.3–9.1 years), three children of fourth grade (three girls—age range: 9.8–10.4 years), and four of more advanced grades, that is, three children of fifth grade and one of sixth 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 10 children had RD, based on previous diagnoses available at the school's educational guidance centre: one child in third grade (girl) and another in fifth grade (boy).

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 Granada. The school's board and the parents signed respective consent forms, giving authorization for the children's participation during school hours. Participation was voluntary. All participants were native Spanish speakers.

2.1.2 | Design

A 2 × 2 × 2 × 2 within-subject design with 4 factors (imaginability × validity × complexity × task) was carried out. The tasks had a counterbalanced order.

2.1.3 | Materials and procedure

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 premise. 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 (two simple—two complex problems). The eight neutral problems were similarly organized (four valid—four invalid problems/two simple—two 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 × 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 symbolize 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). Figure 1 shows a case of a valid problem in the picture task.

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. 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.

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).

2.1.4 | 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.

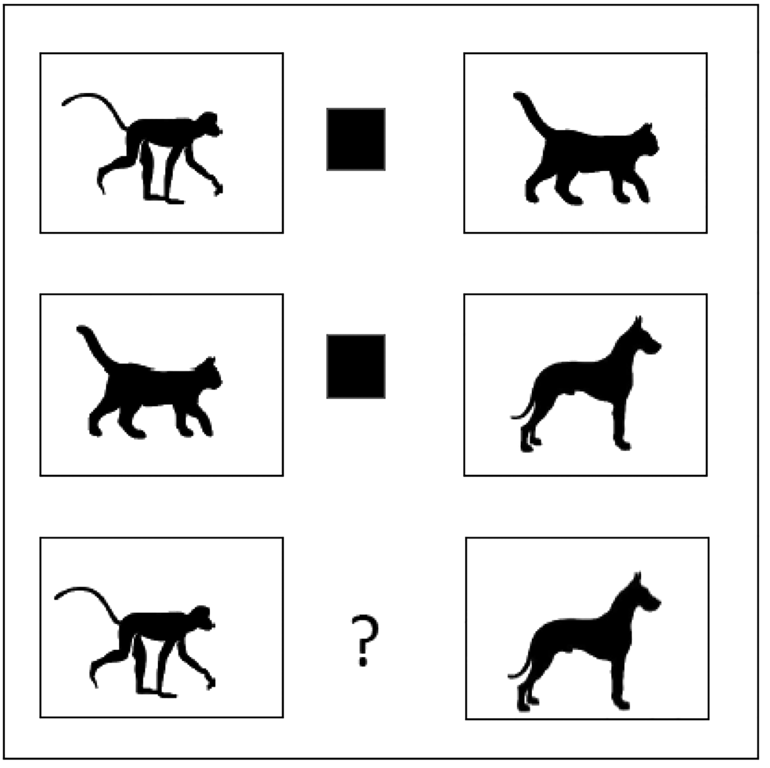

FIGURE 1 Valid problem in the picture task

TABLE 1 Examples in the propositional task: valid simple problem, invalid simple problem, valid complex problem, and invalid complex problem

Valid simple problem	Invalid simple problem
The monkey is richer than the cat.	The monkey is richer than the cat.
The cat is richer than the dog.	The dog is richer than the cat.
What can we say about the monkey and the dog?	What can we say about the monkey and the dog?
Valid complex problem	Invalid complex problem
The monkey is richer than the cat.	The monkey is richer than the cat.
The dog is poorer than the cat.	The cat is poorer than the dog.
What can we say about the monkey and the dog?	What can we say about the monkey and the dog?

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 for 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.

3 | RESULTS AND DISCUSSION

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

Given the small sample in this pilot study, the effect in the four factors was tested using the nonparametric 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).

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 (Authors, 2018). More importantly, 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 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.

4 | EXPERIMENT 1

This experiment aimed to study reasoning skills and the visual impedance effect in children of primary school age with and without dyslexia or RD, 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 visualize (for example, tall—*taller than*); that is, it is more likely to be observed in the conditions with imaginable problems than in the neutral

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

		Neutral				Imaginable			
		Valid		Invalid		Valid		Invalid	
Task	*N*	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)

ones. In particular, it is hypothesized 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 RD. For this reason, Experiment 1 used only the picture task and not the propositional one. It is hypothesized 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., Markovits, Doyon, & Simoneau, 2002; Stanovich, 2015). 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).

4.1 | Method

4.1.1 | 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 RD, 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 (KS)[1] KS 2 (third and fourth grades) and KS 3 (fifth and sixth 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 Granada. The school board and the parents signed respective consent forms, giving authorization for the children's participation at school. It was always voluntary. All the children were native Spanish speakers.

4.1.2 | 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.

4.1.3 | 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 eight neutral problems and eight imaginable problems: four valid and four invalid in each; and two simple and two 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 RD and dyslexia. Children with RD were those with a reading performance below the expected (<25th 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, Rodríguez, Ruano, & Arribas, 2007), 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 RD 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' nonverbal intelligence. The test score ranged from 0 to 60 points. Raw score and IQ measure were calculated.

4.1.4 | Procedure

All tests were individually administered in three sessions (approximately 35 min 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.

4.2 | Results

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

4.2.1 | 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 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.

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 RD did not reach the significance level (52% vs. 61%; $F(1, 80) = 3.208$; $p = .08$; $\eta^2 = .039$).

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

		Neutral				Imaginable			
		Valid		Invalid		Valid		Invalid	
KS	N	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)

Abbreviation: KS, key stage.

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 and 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 four-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 RD. The analysis of this interaction led us to test the two groups of children separately; these analyses are presented below.

4.2.2 | Analyses of the interaction with correct responses of children without RD by school KS

To analyse the data of children without difficulties, a 2 × 2 × 2 (imaginability × complexity × KS) mixed 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

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

Abbreviation: KS, key stage.

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 ($F(1, 57) = 0.528$; $p = .47$; $\eta^2 = .009$).

4.2.3 | Analyses of the interaction with correct responses of children with RD 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 ANOVA with KS as a between-subjects factor was carried out.

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

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.

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

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

Abbreviation: KS, key stage.

4.2.4 | 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 ($F(1, 83) = .222$; $p = .64$; $\eta^2 = .003$).

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 an RD index (presence of RD) 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 ($r(84) = .381$, $p < .001$).

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 ($r(84) = .217$,

TABLE 6 Intelligence and Reading measures. 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

Intelligence and Reading measures will substitute Descriptive data		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)

Abbreviation: RD, reading difficulty.

TABLE 7 Correlation matrix

	ImInvCx	ImInvS	InVaCx	ImVaS	NInvCx	NInvS	NVaCx	NVaS	KS	Age	RD	InvCx	InvS	VaCx	VaS	ImInv
ImInvCx	1															
ImInvS	.406**	1														
InVaCx	−.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								
KS	.102	.172	.181	.294**	.052	.112	.090	.192	1							
Age	.153	.245*	.117	.371**	.089	.206	.100	.128	.860**	1						
RD	−.025	−.037	−.168	−.090	−.087	−.146	.005	−.097	.109	.112	1					
InvCx	.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	1
ImVa	−.019	.115	.843**	.813**	−.053	.277*	.473**	.541**	.284**	.288**	−.158	−.040	.205	.778**	.772**	.063
NInv	.520**	.793**	.066	.195	.819**	.896**	−.249*	.020	.100	.179	−.139	.804**	.882**	−.086	.119	.834**
Nva	−.224*	−.026	.565**	.503**	−.339**	.071	.730**	.839**	.185	.146	−.065	−.298**	.024	.734**	.783**	−.121
TotalIm	.542**	.751**	.501**	.584**	.456**	.759**	.162	.297**	.318**	.365**	−.112	.595**	.788**	.401**	.499**	.797**
TotalN	.306**	.666**	.413**	.485**	.490**	.815**	.246*	.546**	.202	.246*	−.161	.503**	.773**	.388**	.595**	.641**
TotalCx	.711**	.345**	.569**	.253*	.563**	.422**	.410**	.021	.186	.203	−.122	.704**	.401**	.572**	.151	.586**
TotalS	.216*	.806**	.282**	.637**	.303**	.860**	.027	.572**	.251*	.318**	−.126	.337**	.869**	.193	.694**	.670**
TotalVa	−.129	.053	.783**	.733**	−.208	.197	.656**	.753**	.261*	.243*	−.125	−.179	.131	.834**	.857**	−.027
TotalInv	.711**	.872**	.020	.174	.755**	.860**	−.207	−.037	.140	.222	−.093	.849**	.903**	−.094	.073	.957**
PS_A	.044	.150	.146	.163	.134	.197	−.028	.131	.152	.232*	−.494**	.113	.181	.078	.169	.133

TABLE 7 (Continued)

	ImInvCx	ImInvS	InVaCx	ImVaS	NInvCx	NInvS	NVaCx	NVaS	KS	Age	RD	InvCx	InvS	VaCx	VaS	ImInv
PS_T	−.056	−.251*	−.106	−.289**	−.097	−.261*	−.015	−.198	−.391**	−.411**	.417**	−.122	−.267*	−.074	−.278**	−.223*
Intelligence	.073	.302**	.241*	.253*	.159	.324**	.193	.363**	.286**	.209	−.381**	.179	.327**	.252*	.358**	.277*
COMP_A	.183	.308**	.005	.283*	.241*	.302**	−.090	.096	.146	.164	−.320**	.241*	.318**	−.043	.213	.297**
COMP_T	−.088	−.112	−.250*	−.360**	−.122	−.206	−.129	−.134	−.402	−.430**	.290**	−.145	−.167	−.225*	−.278*	−.144

	ImVa	NInv	Nva	Total Im	TotalN	TotalCx	TotalS	Total Va	Total Inv	PS_A	PS_T	Intelligence	COMP_A	COMP_T
ImInvCx														
ImInvS														
InVaCx														
ImVaS														
NInvCx														
NInvS														
NVaCx														
NVaS														
KS														
Age														
RD														
InvCx														
InvS														
VaCx														
VaS														
ImInv														
ImVa	1													
NInv	.155	1												
Nva	.646**	−.125	1											

TABLE 7 (Continued)

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

Abbreviations: COMP_A, text comprehension accuracy; COMP_T, text comprehension time; ImInv, Imaginable Invalid problems; ImInvCx, imaginable invalid complex problems; ImInvS, imaginable invalid simple problems; ImVa, imaginable valid problems; ImVaCx, imaginable valid complex problems; ImVaS, imaginable valid simple problems; InvCx, invalid complex problems; InvS, invalid simple problems; KS, school key stage; NInv, neutral invalid problems; NInvCx, neutral invalid complex problems; NInvS, neutral invalid simple problems; Nva, neutral valid problems; NVaCx, neutral valid complex problems; NVaS, neutral valid simple problems; PS_A, pseudoword reading accuracy; PS_T, pseudoword reading time; RD, reading difficulties index; TotalCx, total complex problems; TotalIm, total imaginable problems; TotalInv, Total Invalid problems; TotalN, total neutral problems; TotalS, total simple problems; TotalVa, total valid problems; VaCx, valid complex problems; VaS, valid simple problems.

**Correlation is significant at the .01 level (two tailed).

*Correlation is significant at the .05 level (two tailed).

$p = .05$) 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 ($r(84) = −.430$, $p < .001$).

4.3 | Discussion

This study provides new results on reasoning skills in children with and without 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 RD 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 (third and fourth 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 visualized (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 visualized 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). Both groups of children (with and without difficulties) showed the visual impedance effect when the premises were complex and could be easily visualized. 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 et al., 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 characterization 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 (η^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 in 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.

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ENDNOTE

[1]There are three key stages (KS) at the primary school level of the state education system in Spain; Ks 1 comprises first to second grades (school years) of primary school; Ks 2 comprises third to fourth grades; and Ks 3 comprises fifth to sixth grades.

ORCID

Francisca Serrano https://orcid.org/0000-0001-9000-6892

Sergio Moreno-Ríos https://orcid.org/0000-0001-5553-207X

REFERENCES

Ahmed, Y., Francis, D. J., York, M., Fletcher, J. M., Barnes, M., & Kulesz, P. (2016). Validation of the direct and inferential mediation (DIME) model of reading comprehension in grades 7 through 12. *Contemporary Educational Psychology*, *44*, 68–82. https://doi.org/10.1016/j.cedpsych.2016.02.002

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. Arlington, VA, USA: American Psychiatric Pub.

Andrews, G. (2010). Belief-based and analytic processing in transitive inference depends on premise integration difficulty. *Memory & Cognition*, *38*(7), 928–940. https://doi.org/10.3758/MC.38.7.928

Panagiotidou, E., Serrano, F., & Moreno-Rios, S. (2018). Reasoning and reading in adults. A new reasoning task for detecting the "visual impedance effect". *Advances in Cognitive Psychology*, *14*(4), 150–159. https://doi.org/10.5709/acp-0246-4

Bacon, A. M., & Handley, S. J. (2010). Dyslexia and reasoning: The importance of visual processes. *British Journal of Psychology*, *101*(3), 433–452. https://doi.org/10.1348/000712609X467314

Bacon, A. M., & Handley, S. J. (2014). Reasoning and dyslexia: Is visual memory a compensatory resource? *Dyslexia*, *20*(4), 330–345. https://doi.org/10.1002/dys.1483

Bacon, A. M., Handley, S. J., & McDonald, E. L. (2007). Reasoning and dyslexia: A spatial strategy may impede reasoning with visually rich information. *British Journal of Psychology*, *98*(1), 79–92. https://doi.org/10.1348/000712606X103987

Bacon, A. M., Handley, S. J., & Newstead, S. E. (2005). Verbal and spatial strategies in reasoning. In M. J. Roberts, & E. J. Newton (Eds.), *Methods of thought: Individual differences in reasoning strategies* (pp. 80–105). NY, NY, USA: Psychology Press.

Bacon, A. M., Parmentier, F. B. R., & Barr, P. (2013). Visuospatial memory in dyslexia: Evidence for strategic deficits. *Memory*, *21*(2), 189–209. https://doi.org/10.1080/09658211.2012.718789

Bouwmeester, S., & Sijtsma, K. (2004). Measuring the ability of transitive reasoning, using product and strategy information. *Psychometrika*, *69*(1), 123–146. https://doi.org/10.1007/BF02295843

Bouwmeester, S., Vermunt, J. K., & Sijtsma, K. (2007). Development and individual differences in transitive reasoning: A fuzzy trace theory approach. *Developmental Review*, *27*(1), 41–74. https://doi.org/10.1016/j.dr.2006.08.001

Brunamonti, E., Costanzo, F., Mammì, A., Rufini, C., Veneziani, D., Pani, P., … Menghini, D. (2017). Evaluation of relational reasoning by a transitive inference task in attention-deficit/hyperactivity disorder. *Neuropsychology*, *31*(2), 200–208. https://doi.org/10.1037/neu0000332

Cain, K., & Oakhill, J. (2006). Profiles of children with specific reading comprehension difficulties. *British Journal of Educational Psychology*, *76*, 683–696. https://doi.org/10.1348/000709905X67610

Chapman, M., & Lindenberger, U. (1992). Transitivity judgments, memory for premises, and models of children's reasoning. *Developmental Review*, *12*, 124–163. https://doi.org/10.1016/0273-2297(92)90006-N

Cromley, J. G., & Azevedo, R. (2007). Testing and refining the direct and inferential mediation model of reading comprehension. *Journal of Educational Psychology*, *99*(2), 311–325. https://doi.org/10.1037/0022-0663.99.2.311

Cuetos, F., Rodríguez, B., Ruano, E., & Arribas, D. (2007). PROLEC-R. In *Evaluación de los procesos lectores, revisada* (5ª edición ed.) [PROLEC-R. Assessment of Reading processes. Reviewed 5th edition). Madrid, Spain: TEA.

Daugaard, H. T., Cain, K., & Elbro, C. (2017). From words to text: Inference making mediates the role of vocabulary in children's reading comprehension. *Reading and Writing*, *30*, 1773–1778. https://doi.org/10.1007/s11145-017-9752-2

Elbro, C., & Buch-Iversen, I. (2013). Activation of background knowledge for inference making: Effects on reading comprehension. *Scientific Studies of Reading*, *17*(6), 435–452. https://doi.org/10.1080/10888438.2013.774005

Falmagne, R. J. (2015). *Reasoning: Representation and process: In children and adults*. London, U.K.: Psychology Press.

Goodwin, G., & Johnson-Laird, P. N. (2005). Reasoning about relations. *Psychological Review*, *112*(2), 468–493. https://doi.org/10.1037/0033-295X.112.2.468

Goodwin, G. P., & Johnson-Laird, P. N. (2008). Transitive and pseudo-transitive inferences. *Cognition*, *108*(2), 320–352. https://doi.org/10.1016/j.cognition.2008.02.010

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, *101*(3), 371–395. https://doi.org/10.1037/0033-295X.101.3.371

Kendeou, P., van de Broek, P., Helder, A., & Karlsson, J. (2014). A cognitive view of reading comprehension: Implications for reading difficulties. *Learning Disabilities Research & Practice*, *29*(1), 10–16. https://doi.org/10.1111/ldrp.12025

Khemlani, S. S., Byrne, R. M. J., & Johnson-Laird, P. N. (2018). Facts and possibilities: A model –based theory of sentential reasoning. *Cognitive Science*, *42*(6), 1887–1924. https://doi.org/10.1111/cogs.12634

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological review*, *95*(2), 163.

Kintsch, W. (2013). Revisiting the construction – Integration model of text comprehension and its implications for instruction comprehension: A paradigm for cognition. In N. Unrau, & R. Ruddell (Eds.), *Theoretical models and processes of reading* (pp. 807–841). Newark, DE: International Reading Association.

Knauff, M., Fangmeier, T., Ruff, C. C., & Johnson-Laird, P. N. (2003). Reasoning, models, and images: Behavioral measures and cortical activity. *Journal of cognitive neuroscience*, *15*(4), 559–573. https://doi.org/10.1162/089892903321662949

Knauff, M., & Johnson-Laird, P. N. (2002). Visual imagery can impede reasoning. *Memory & Cognition*, *30*(3), 363–371. https://doi.org/10.3758/BF03194937

Knauff, M. and May, E. (2006). Mentalimagery, reasoning, and blindness. *Quarterly Journal of Experimental Psychology*, *59* 161–177. https://doi.org/10.1080/17470210500149992

Lindgrén, S. A., & Laine, M. (2011). Cognitive-linguistic performances of multilingual university students suspected of dyslexia. *Dyslexia*, *17*(2), 184–200. https://doi.org/10.1002/dys.422

Luo, Y., & Beck, W. (2010). Do you see what I see? Infants' reasoning about others' incomplete perceptions. *Developmental Science*, *13*(1), 134–142. https://doi.org/10.1111/j.1467-7687.2009.00863.x

Markovits, H. (2014). On the road toward formal reasoning: Reasoning with factual causal and contrary-to-fact causal premises during early adolescence. *Journal of Experimental Child Psychology* *128*, 37–51. https://doi.org/10.1016/j.jecp.2014.07.001

Markovits, H., Doyon, C., & Simoneau, M. (2002). Individual differences in working memory and conditional reasoning with concrete and abstract content. *Thinking & Reasoning*, *8*(2), 97–107. https://doi.org/10.1080/13546780143000143

Markovits, H., Dumas, C., & Malfait, N. (1995). Understanding transitivity of a spatial relationship: A developmental analysis. *Journal of Experimental Child Psychology*, *59*, 124–141. https://doi.org/10.1006/jecp.1995.1005

McKoon, G., & Ratcliff, R. (1992). Inference during reading. *Psychological review*, *99*(3), 440–466. https://doi.org/10.1037/0033-295X.99.3.440

Moreno-Ríos, S., Rojas-Barahona, C. A., & García-Madruga, J. (2014). Perceptual inferences about indeterminate arrangements of figures. *Acta Psyhcologica*, *148*, 216–225. https://doi.org/10.1016/j.actpsy.2014.02.004

Mou, Y., Province, J. M., & Luo, Y. (2014). Can infants make transitive inferences? *Cognitive psychology*, *68*, 98–112. https://doi.org/10.1016/j.cogpsych.2013.11.003

Oakhill, J., Hartt, J., & Samols, D. (2005). Levels of comprehension monitoring and working memory in good and poor comprehenders. *Reading and Writing*, *18*(7), 657–686. https://doi.org/10.1007/s11145-005-3355-z

Rapp, D. N., van den Broek, P., McMaster, K. L., Kendeou, P., & Espin, C. A. (2007). Higher-order comprehension processes in struggling readers: A perspective for research and intervention. *Scientific Studies of Reading*, *11*(4), 289–312. https://doi.org/10.1080/10888430701530417

Raven, J. C. (1996). *RAVEN, Matrices progresivas. Escalas CPM Color y SPM General [Raven's progressive matrices: CPM and SPM scales]*. Madrid: TEA Ediciones.

Ribeiro, I., Cadime, I., Freitas, T., & Viana, F. L. (2016). Beyond word recognition, fluency, and vocabulary: The influence of reasoning on reading comprehension. *Australian Journal of Psychology*, *68*, 107–115. https://doi.org/10.1111/ajpy.12095

Sato, Y., Sugimoto, Y., & Ueda, K. (2018). Real objects can impede conditional reasoning but augmented objects do not. *Cognitive science*, *42*(2), 691–707. https://doi.org/10.1111/cogs.12553

Segers, E., & Verhoeven, L. (2016). How logical reasoning mediates the relation between lexical quality and reading comprehension. *Reading and Writing*, *29*, 577–590. https://doi.org/10.1007/s11145-015-9613-9

Stanovich, K. E. (2015). Rational and irrational thought: The thinking that IQ tests miss. *Scientific American Mind Special Collector's Edition*, *23*(4), 12–17.

Thayer, E. S., & Collyer, C. E. (1978). The development of transitive inference: A review of recent approaches. *Psychological Bulletin*, *85*(6), 1327–1343. https://doi.org/10.1037//0033-2909.85.6.1327

Tzeng, J. Y. (2010). Designs of concept maps and their impacts on readers' performance in memory and reasoning while reading. *Journal of Research in Reading*, *33*(2), 128–114. https://doi.org/10.1111/j.1467-9817.2009.01404.x

Wright, B. C., Robertson, S., & Hadfield, L. (2011). Transitivity for height versus speed: To what extent do the under-7s really have a transitive capacity? *Thinking & Reasoning*, *17*(1), 57–81. https://doi.org/10.1080/13546783.2010.544548

Wright, B. C., & Smailes, J. (2015). Factors and processes in children's transitive deductions. *Journal of Cognitive Psychology*, *2015*, *27*(8), 967–978. https://doi.org/10.1080/20445911.2015.1063641

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