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REVIEW

Interventions aimed at overcoming intuitive interference: insights from brain-imaging and behavioral studies

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Abstract

Students experience difficulties in comparison tasks that may stem from interference of the tasks' salient irrelevant variables. Here, we focus on the comparison of perimeters task, in which the area is the irrelevant salient variable. Studies have shown that in congruent trials (when there is no interference), accuracy is higher and reaction time is shorter than in incongruent trials (when the area variable interferes). Brain-imaging and behavioral studies suggested that interventions of either activating inhibitory control mechanisms or increasing the level of salience of the relevant perimeter variable could improve students' success. In this review, we discuss several studies that empirically explored these possibilities and their findings show that both types of interventions improved students' performance. Theoretical considerations and practical educational implications are discussed.

Keywords Intuitive interference · Comparison of perimeters · Educational interventions · Inhibitory control mechanisms · fMRI

Introduction

Students react in similar ways to a wide variety of science and mathematics tasks that share some common external features (Stavy and Tirosh 2000). Irrelevant but salient variables of a given task, whether mathematical, scientific or logical, are thought to interfere with formal/logical reasoning, leading to incorrect responses. In order to unveil the reasoning processes associated with intuitive interference and how we overcome it, a task in geometry was developed as a model system. This task, comparison of perimeters, allows manipulations of the variables and design of task conditions with or without interference. This article reviews several interventions aimed at helping students overcome intuitive interference focusing on the comparison of perimeters task. The main objective and original contribution of the review is to present the literature on interventions aimed at helping students overcome intuitive interference coming from both education and neuroscience in an organized way. The secondary aim is formulating the relevance for education and directions for further research.

First we describe the intuitive interference and the comparison of perimeters task. Then we present empirical evidence regarding the reasoning processes and the neural correlates associated with overcoming intuitive interference in this task. Following that, we describe different intervention studies aimed at helping students overcome this intuitive interference and we discuss these results in light of neuroscientific evidence. Finally, we discuss possible educational implications.

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Intuitive interference in science and mathematics

A substantial body of scientific literature, as well as national and international surveys such as *Trends in International Mathematics and Science Study* (TIMSS) or *Programme for International Student Assessment* (PISA), consistently shows that many students encounter difficulties in solving a wide range of problems in science and mathematics (Duit 2007; Fischbein 1987; Martin et al. 2012; Mullis et al. 2012; Organisation for Economic Co-operation and Development 2014). In particular, students often experience difficulties when asked to compare quantities. These difficulties could stem from an interference of salient (automatically/intuitively processed) irrelevant variables in the task. For example, when students are presented with two objects that differ in a salient quantity A and are asked to compare the objects with respect to another quantity B, they tend to respond in line with the salient quantity A: larger A hence larger B (Stavy and Tirosh 1996, 2000). Such intuitive responses are observed in many tasks and are often correct (when quantity A changes in the same direction as quantity B). However, in some cases in science and mathematics, such responses could lead to incorrect judgments (when the salient quantity A does not change in the same direction as quantity B).

Stavy and Tirosh (2000) suggest that this intuitive interference is an expression of the natural tendency to attend to salient quantities. Students' responses are therefore often based on salient irrelevant external features of the task and not necessarily on relevant features, logic and/or formal knowledge related to the content domain. Such behavior is not desirable and causes a challenge in science and mathematics education that has been extensively addressed (Zazkis 1999; Eshach 2014; Osman and Stavy 2006; Yair and Yair 2004; Tsamir 2005; Deliyianni et al. 2006).

The comparison of perimeters task: a model system to study intuitive interference

In the current paper, we focus on a geometry task as a model system of intuitive interference. The comparison of perimeters task has been used by most studies exploring reasoning processes associated with overcoming intuitive interference in science and mathematics. Using this task, a large body of data regarding intuitive interference has been accumulated, including developmental aspects, brain correlates and interventions aimed at helping students overcome the interference.

The ability to compare quantities such as perimeters of geometrical shapes represents a fundamental prerequisite for the acquisition of higher-order mathematical and logical reasoning skills (e.g., Arcavi 2003; Bronowski 1947). It is known that students often intuit that shapes with a larger area must have a larger perimeter (Stavy and Tirosh 2000; Stavy and Babai 2008). In light of the intuitive interference approach described above, this difficulty may stem from the interference of the salient irrelevant variable, area, with the reasoning related to comparison of perimeters. It appears that the area variable is so salient that it is automatically or intuitively processed and thus interferes with correct reasoning (Stavy and Tirosh 2000).

Three task conditions were designed (congruent, incongruent inverse and incongruent equal) in the comparison of perimeters task (see Fig. 1).

In each test trial, two shapes are presented and the students are asked to compare the perimeters of the two shapes, i.e., to judge whether the right shape has a larger perimeter, the left shape has a larger perimeter or the two shapes have an equal perimeter. The students are asked to answer correctly and as quickly as possible. In the congruent condition, there is no interference of the irrelevant salient variable, area, with the relevant variable, perimeter, as one shape has a larger area and a longer perimeter than the other shape. In the incongruent conditions, there is interference of the irrelevant salient variable, area, with the relevant variable, perimeter, as one shape has a larger area, but not a longer perimeter, than the other shape. In the incongruent inverse condition, one shape has a larger area but a shorter perimeter than the other shape, while in the incongruent equal condition, one shape has a larger area but an equal perimeter compared to the other one.

Fig. 1 Examples of congruent and incongruent comparison of perimeters task trials

Reasoning processes and neural correlates associated with overcoming the intuitive interference

Previous studies of comparison of areas and comparison of perimeters tasks (using the same stimuli) have shown that accuracy rate was higher and reaction time was shorter for area comparisons as compared to perimeter comparisons (Babai et al. 2006). These findings further indicate that area is the salient variable in the comparison of perimeters task. Among children, adolescents and adults, it was also previously found that accuracy in incongruent conditions is significantly lower than that in the congruent condition. Findings also show that giving a correct response for the incongruent conditions required a longer reaction time than for the congruent condition. These results suggest that the cognitive processing that occurs while solving the incongruent conditions is more complex than that for the congruent one. It is likely that when the processing the area and perimeter results in the same conclusion (congruent trials), no further reasoning is needed, and therefore, participants answer correctly and fast. If, however, processing of area and perimeter results in two different conclusions (one based on intuitive processing of area and the other on appropriate processing of perimeter), the created conflict must be resolved by overcoming the intuitive interference, a demanding and time-consuming process, or giving an incorrect response (Babai et al. 2006; Stavy and Babai 2008).

To further understand the reasoning processes associated with overcoming the intuitive interference, an event-related fMRI study (Stavy et al. 2006) involving the comparison of perimeters task was conducted. Behavioral results of this neuroimaging study were in line with what has been previously found. Results revealed that reasoning in the congruent condition activated bilateral parietal brain regions (e.g., 60, −34, 28, Brodmann area (BA) 40) known to be involved in perceptual and spatial processing, including processing related to comparison of quantities (Fias et al. 2003; Pinel et al. 2004). This activation is likely to reflect the automatic processing of the salient irrelevant variable, area (Stavy et al. 2006). Reasoning when overcoming the intuitive interference in the incongruent condition activated bilateral orbital frontal gyrus (e.g., 40, 42, −16, BA 11), brain regions in the prefrontal cortex, suggesting that inhibition was required, as these brain regions are known for their executive inhibitory control during processing of different cognitive functions (Aron et al. 2004). These regions are also known to be activated during tasks that require overcoming interference (Goel et al. 2004; Houde et al. 2000; Konishi et al. 1999).

Comparing correct and incorrect responses in incongruent trials reinforces the findings described above. When answering intuitively (incorrectly) in the incongruent condition, greater activity was observed in the parietal lobe. Correct responses to these trials were found to be associated with enhanced activity in the bilateral orbital prefrontal cortex (Stavy et al. 2006). It was also found that varying the level of interference exerted by the irrelevant salient variable, area, by presenting filled and unfilled shapes, affected the level of activation of parietal regions (Stavy et al. 2006). Brain activity of the parietal area has been shown to be influenced by the salience of the irrelevant variable, area, and is more intensively activated with larger salience of area (filled shapes) and less activated with less salience of area (framed shapes).

Interventions

In the following section, we describe several educational interventions aimed at helping students overcome the intuitive interference in the comparison of perimeters task and the results are discussed in light of neuroscientific evidence related to overcoming this intuitive interference.

A preliminary classroom intervention

Babai et al. (2010) conducted a preliminary classroom intervention study to help students overcome the intuitive interference when comparing perimeters of geometrical shapes. Before the classroom intervention, students participated in a comparison of perimeters pretest. Thirty-three eighth graders were assigned to the control ($n = 11$) and intervention ($n = 22$) groups. In the intervention group, a general and comprehensive class intervention of about 45 min was carried out. Students were first individually asked to compare perimeters of one congruent, one incongruent inverse and one incongruent equal trial (see Fig. 1) and record their responses, which were mostly incorrect for the incongruent trials. Next, students volunteered to present their solutions during a class discussion led by the teacher, who encouraged students who had answered correctly to propose appropriate solution strategies and convince their peers of their correctness. Finally, students were individually given 10 additional pairs of problems to consolidate their understanding.

This preliminary classroom intervention resulted in a significant improvement in accuracy of responses in the incongruent equal condition from pretest to posttest. A marked increase in reaction time for both congruent and incongruent conditions was evident. The increase in reaction time for both conditions probably reveals the activation of time-consuming and effortful control mechanisms. In the control group, no significant differences were found between the accuracy of responses in the pretest and posttest; in addition, no increase in reaction time was observed from pretest to posttest. The study suggests that it is possible to help students overcome the intuitive interference. However, class discussions are complex and may include different teaching approaches related to cognitive control, attention to relevant variables, suggestions or practice of solution strategies. Therefore, it is difficult to point to the specific approach that led to students' improvement in performance in this classroom intervention study. In the following interventions, we explored the effect of different approaches more specifically.

Mode of presentation interventions

Two focused interventions have used different modes of presentation to enhance the salience of the relevant variable, perimeter. Two different modes of presentation were tested in an intervention study described in Stavy and Tirosh (2000, pp. 17, 18). In one mode of presentation, two identical plastic rectangles were shown, each featuring a small square cut out at the upper right corner and a resulting polygon (see Fig. 2a). The small square was removed from one of the rectangles to create a polygon consisting of an incongruent equal trial. Ninth graders were asked whether the perimeter of the obtained polygon was equal to that of the original rectangle and, if not, which of the shapes had a larger perimeter. Only 30% of the students correctly claimed that the perimeters were equal. The second mode of presentation included two identical rectangles made using two identical threads on a pegboard (see Fig. 2b). The thread that formed one of the rectangles was removed from the upper right corner of the rectangle and rearranged, creating a polygon consisting of an incongruent equal trial. Such mode of presentation strongly enhances the salience of the relevant variable, perimeter, by explicitly showing the identity of the two threads conserved in the two shapes. This time, 55% of the students gave correct responses. Results point to the conclusion that the mode of presentation using the thread helped students respond correctly based on identity arguments.

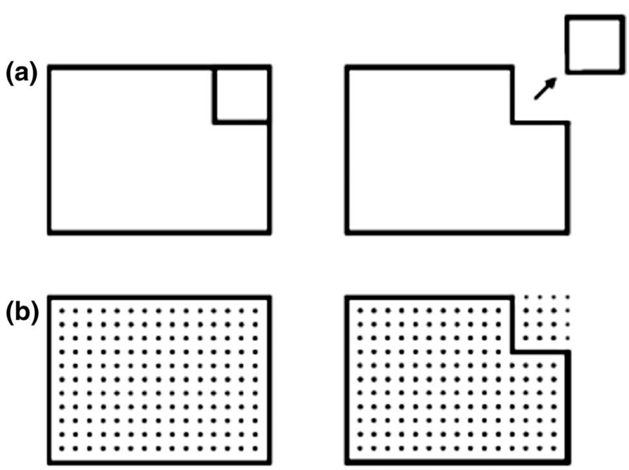

Fig. 2 **a** Plastic shapes and **b** thread shapes modes of presentation in incongruent equal trials

Tamsut (2014) also compared the plastic shapes and the thread shapes modes of presentation in an intervention study. Based on the earlier work of Stavy and Tirosh (2000), two groups of 34 sixth graders were presented with one of the two modes of presentation with an incongruent equal trial. Students were then asked whether the perimeter of the obtained polygon was equal to that of the original rectangle, and, if not, which of the shapes had a larger perimeter. As observed by Stavy and Tirosh (2000), the thread shapes mode of presentation yielded a higher accuracy rate for this incongruent equal trial than did the mode of presentation using the plastic shapes. Using thread-shaped shapes enhances the salience of the relevant variable, perimeter, by explicitly showing the identity of the two threads conserved in the two shapes.

All students were then given a comparison of perimeters task as a posttest. Findings show no effect of the previous presentation mode on accuracy and reaction time in the comparison of perimeters posttest. This is probably because the increased salience of the perimeter in the thread shapes mode of presentation specifically activates the conservation of perimeters scheme and does not suggest appropriate solution strategies or activate inhibitory control mechanisms. Therefore, this effect could not be transferred to the posttest.

Babai et al. (2016) explored an intervention that used a discrete mode of presentation that strongly enhanced the salience of the relevant variable, perimeter. Drawing the perimeters as built from matchsticks (discrete mode of presentation, Fig. 3b), rather than drawing them continuously (continuous mode of presentation, Fig. 3a) is likely to increase the salience of the perimeter and somewhat decrease the salience of the area. Such discrete mode of presentation may encourage appropriate solution strategies, such as mentally moving the discrete segments and/or counting them.

The study tested whether a discrete mode of presentation of the shapes would yield a higher success rate than did continuous mode of presentation and whether first performing the task with a discrete mode of presentation would improve students' success in the continuous mode.

Two comparisons of perimeters tests were designed: in one the continuous mode of presentation was used and in the other the discrete mode of presentation. Fifty-eight fifth and sixth graders were randomly assigned to the continuous mode of presentation test ($n=29$) or to the discrete mode of presentation test ($n=29$). Success in discrete mode of presentation was significantly higher than in continuous mode in all conditions, while no differences in reaction time between these modes of presentations were observed. The two groups performed a second test consisting of the alternative mode of presentation 10 days later. Success in continuous mode of presentation increased as a result of this intervention (i.e., when performed after discrete mode), while for discrete

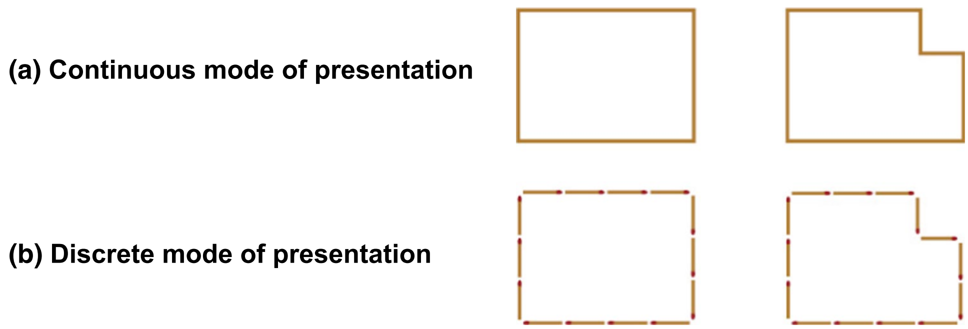

Fig. 3 **a** Continuous (drawn as solid line) and **b** discrete (drawn as built from matchsticks) modes of presentation of a comparison of perimeters incongruent equal trial

mode no significant effect was observed when performed after the continuous mode of presentation. There was no difference in reaction times between the two modes of presentation when performed as a second test.

Discrete mode of presentation probably enhanced the salience of the relevant variable perimeter and somewhat decreased that of area. This mode probably elicited appropriate solution strategies, such as mentally moving the discrete segments and/or counting them in order to solve the task correctly, and this effect transferred to continuous presentation for at least 10 days. In the continuous mode of presentation, however, no hint of such possibility of mentally "breaking" the solid line into relevant segments was given and the solver needed to come up with this idea independently.

A warning intervention

An intervention that focuses on enhancing students' inhibitory control mechanisms was recently carried out (Babai et al. 2015). This warning intervention explicitly cautioned students in the warning group about the trap in the comparison of perimeters task–the possible interference of the area variable when comparing perimeters. A similar approach was successfully used by Houde in conditional reasoning (Houde et al. 2000; Moutier et al. 2002; Moutier and Houde (2003); Dempster and Corkill 1999). In addition, Dempster and Corkill (1999) suggested that reasoning biases were due to the failure of control mechanisms in the reasoning processes.

The warning intervention tested whether a problem-specific warning would improve sixth graders' accuracy of responses in incongruent conditions of the comparison of perimeters task and whether it would affect their reaction times. A short, focused and task-specific warning intervention was shown to schoolchildren preceding the comparison of perimeters task. The warning intervention explicitly warned students that there is a tendency to compare the areas of the shapes instead of their perimeters and that this tendency may lead to errors. Students were then invited to try to overcome this tendency.

Eighty-four students were randomly assigned to the control group ($n=40$), which was not given any intervention, and to the warning group ($n=44$), which was given the task-specific warning intervention. The warning intervention resulted in a higher success rate in incongruent trials. Reaction time was longer in the warning intervention group than in the control group in both incongruent and congruent trials. In addition, it was found that the percentage of intuitive errors was significantly lower in the intervention group and that both groups had a similar rate of non-intuitive errors. These findings show that a task-specific intervention that explicitly warns about the possible interference of the irrelevant salient variable significantly improves students' accuracy of responses to incongruent trials. The accuracy and reaction time results suggest that the warning helped students overcome the intuitive interference by activating inhibitory control mechanisms.

A conflict teaching intervention

Goldenberg's (2016) intervention study is based on the conflict teaching approach used previously (Dreyfus et al. 1990; Limón and Carretero 1997; Mason 2000; Dewolf et al. 2014). This intervention consists of generating a conflict by first presenting students with a task known to trigger an incorrect response. Then students are presented with a task that contradicts their initial response.

Eighty-nine fourth graders were divided into experimental ($n=45$) and control ($n=44$) groups. The students in the experimental group were first presented with a pair of shapes using the continuous mode of presentation tested by Babai et al. (2016) (see Fig. 3a). Continuous mode of presentation is known to trigger intuitive incorrect responses in incongruent trials. Next, students were presented with an identical pair of shapes drawn discretely (see Fig. 3b). The second trial is known to elicit a significantly higher rate of correct responses (Babai et al. 2015). When students' answers differed, they were shown both trials side by side to generate a cognitive conflict: Children were asked whether the trials were similar and almost all students correctly answered that they were indeed similar trials. Then they were asked whether the answers they gave were also similar and, if not, what the correct response was. The majority of them answered correctly after being presented with this contradiction (cognitive conflict).

In the posttest, accuracy rate for incongruent conditions was significantly higher in the intervention group than in the control group. These results suggest that this conflict teaching intervention that explicitly encourages student to examine their answers and reconsider their initial responses helps students overcome the intuitive interference.

Deliyianni et al. (2006) intervention study also provides evidence to suggest that the conflict teaching approach may have an impact on students' ability to overcome the intuitive interference. In their study, Deliyianni et al. (2006) used a conflict with concrete evidence by using three tools: the ruler, the concrete geoboard and the virtual geoboard. A comparison of perimeters test was also administered as pretest and posttest. In the teaching interventions, a contradiction was created, for instance, by presenting students with concrete evidence. Students were all asked the following question (see Fig. 4): "George cut a part of Figure A and then Figure B was formed. Figure A has a: (1) bigger perimeter than Figure B; (2) smaller perimeter than Figure B; or (3) the same perimeter as Figure B. Explain your answer."

The first group used a ruler to measure the dimensions of the shapes that were constructed on the paper, the second group was asked to construct figures on the concrete geoboard using elastic bands and the group that worked on the computer constructed the figures on the virtual geoboard where corresponding area and perimeter appeared on the screen of the computer.

After the intervention, a higher percentage of participants answered correctly, overcoming the intuitive interference in the task.

Discussion

In the comparison of perimeters task, many students intuit that shapes with a larger area must have a larger perimeter. Previous studies have shown that in incongruent conditions, when one shape has a larger area but not a longer perimeter, students tend to answer incorrectly. It appears that the area variable is salient and is automatically/intuitively processed and thus interferes with correct reasoning about the comparison of the relevant variable, perimeter.

Results of the neuroimaging study show that answering in the congruent condition is associated with activity in bilateral parietal brain regions known to be involved in processing of quantities. Results also indicate that increasing the salience of the irrelevant variable, area, is associated with lower accuracy and higher activation in these parietal brain regions. On the other hand, overcoming the intuitive interference is associated with activity in prefrontal brain areas known to be involved in inhibitory control mechanisms. These findings point to two elements that are relevant for overcoming intuitive interference, executive inhibitory control mechanisms and salience of the variables. This suggests the possibility of helping students either by enhancing their inhibitory control mechanisms or by increasing the salience of the relevant variable in the task and/or decreasing the salience of the irrelevant interfering variable. The current paper describes and discusses these two possibilities that have been empirically explored using the comparison of perimeters task as a model system of intuitive interference. We believe that the findings could be applied more broadly to other tasks and problems in which salient irrelevant variables interfere with formal/logical reasoning (e.g., Stavy and Tirosh 2000). However, the generalizability of these effects on other tasks and problems needs to be further tested empirically.

Three interventions focus on enhancing students' inhibitory control mechanisms and are shown to be successful in helping them overcome the intuitive interference in the comparison of perimeters task. An explicit warning intervention about the possible interference of the irrelevant variable results in a significantly higher success rate and longer reaction time (Houde and Guichart 2001). The reaction time findings corroborate our suggestion that overcoming intuitive interference requires the activation of time-consuming and effortful inhibitory control mechanisms. A cognitive conflict intervention that aims at enhancing the inhibitory control mechanisms by creating a conflict between two contradictory responses to essentially the same task also significantly improves accuracy rate (Stavy and Berkovitz 1980). The work of Deliyianni et al. (2006) has shown similar results. A higher percentage of students overcome the intuitive interference after

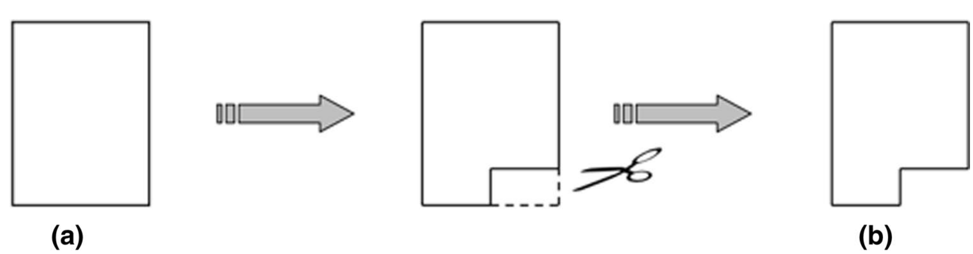

Fig. 4 Intervention used in Deliyianni et al. (2006)

an instructor confronts them with a conflict between their initial responses and concrete evidence.

A pioneering study by Houde et al. (2000) has shown that inhibition training results in performance improvement in conditional reasoning and is associated with a shift in brain activity from posterior to prefrontal brain areas. It will be very interesting to explore in future research whether a similar shift in brain activity is observed following the interventions described above in relation to intuitive interference.

Interestingly, other studies have tested a general rather than a task-specific warning intervention in order to improve students' performance. One intervention warned students about the nonstandard nature of arithmetic problems (Yoshida et al. 1997), while another study presented a warning that some problems were difficult or impossible to solve. Dewolf et al. (2014), for example, have reported that their warning was in fact minimally effective in solving problematic problems and raise the question whether a positive effect would have been found if they had worked with another operationalization, for example a more subject-specific and/or problem-specific form of warning.

A second line of interventions, supported by the brain-imaging findings, suggests that varying the salience level of the variables by increasing the salience of the relevant perimeter variable or decreasing the salience of the irrelevant area variable would improve students' performance. A mode of presentation intervention (Babai et al. 2015) that enhances the salience of the relevant perimeter variable by using a discrete mode of presentation significantly improves success rate, as compared with the continuous mode of presentation. Moreover, success in continuous mode of presentation increases when performed after discrete mode.

The visual information depicted in the discrete mode of presentation specifically relates to the salience of the perimeter's segments that should be mentally moved when solving the task, suggesting appropriate solution strategies. In the continuous mode of presentation, however, no hint of such possibility of mentally breaking the solid line into relevant segments is given. The role of presentations has been studied previously, yielding the suggestion that its effect is especially powerful when elements of the visualization can be moved or rearranged (Martin and Schwartz 2005), as is the case of the mode of presentation intervention (Babai et al. 2015).

Higher success rate in the discrete mode of presentation is evident in all conditions, suggesting that this mode of presentation affects solution strategies as opposed to control mechanisms, which were expected to affect only the incongruent conditions (Babai et al. 2010; Houde and Guichart 2001). In addition, reaction time findings that no difference is observed between the two modes of presentation suggest that similar strategies are used in both, but the discrete mode of presentation makes these strategies more available to the students.

Success rate in the continuous mode of presentation test improves after performing the discrete one. Enhancing the salience of the perimeter probably suggests appropriate solution strategies that lead to improved performance; this effect is robust and transfers to continuous mode of presentation for at least 10 days. Support for this conclusion is seen in the response of one student who performed the continuous test after the discrete one and reported that, "It [continuous] was harder this time but I used the previous shapes, because I could do tricks with the matchsticks." It would be interesting to determine whether this intervention has a long-term effect.

Interventions that have focused on showing students the conservation of perimeter (thread shapes) help students respond correctly and result in a higher rate of success (Stavy and Tirosh 2000; Tamsut 2014). Yet, no transfer effect is observed from the thread shapes presentation to the comparison of perimeters task. This is probably because the increased salience of the perimeter in the thread shapes problem specifically activates the conservation of perimeters scheme and does not suggest appropriate solution strategies; therefore, it cannot be transferred.

Implications for education

Many students encounter difficulties in solving a wide range of problems in science and mathematics. These difficulties may stem from intuitive interference of irrelevant salient quantities. This interference is robust, leading to a high percentage of errors in various content domains and across different age groups.

The findings presented in the current paper indicate the importance of inhibitory control mechanisms in reasoning associated with overcoming intuitive interference in science and mathematics. These findings point to the possibility of improving students' performance by simple interventions aimed at raising their awareness of the possible interference of irrelevant salient variables, rather than, or in addition to, supporting relevant content knowledge, which has been the traditional practice in schools. Such research-based simple interventions appear to require only teachers' knowledge and awareness.

In addition, the salience of the variables in the task can be manipulated. For example, increasing the salience of the relevant variable improves students' ability to compare quantities. Increasing the salience of the relevant variable probably suggests appropriate solution strategies that could be further transferred to a different presentation. Providing students with the opportunity to overcome difficulties by altering the mode or order of presentation is an important educational tool.

Overall, it is important that educators, researchers, curriculum developers and policymakers be aware of these two different approaches to help students overcome difficulties in science and mathematics. Knowledge and awareness about the intuitive interference and how we overcome it could direct educators in making rational decisions about the nature of interventions, tasks and examples that they use in educational settings.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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