The effect of a warning intervention on the ability to overcome intuitive interference

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Abstract

Students' difficulties in mathematics and science may stem from interference of the task's salient irrelevant variables. Here, we focus on a comparison of perimeters task, in which the area is the irrelevant salient variable. In congruent trials (no interference), accuracy is higher and reaction time is shorter than in incongruent trials (area variable interference). A brain-imaging study related to this task indicated that correctly answering the incongruent condition is associated with activation in prefrontal brain regions known for their executive inhibitory control. These findings suggested that intervention aimed at activating inhibitory control mechanisms could improve students' success. In this paper, we explore the effect of an intervention that explicitly warns about the possible interference of the variable area. Eighty-four sixth graders performed the same comparison of perimeters reaction time test, with warning intervention (warning group) or without it (control group). Accuracy in the warning group was significantly higher in incongruent conditions and reaction time was significantly longer in all conditions than in the control group. The results suggest that the explicit warning activates inhibitory control mechanisms and thus helps students overcome the interference. The findings point to the possibility of improving students' problem-solving abilities through simple and focused interventions that explicitly warn them about the trap in the task. Such research-based simple interventions appear to require only teachers' knowledge and awareness and could complement the traditional educational technique of supporting relevant content knowledge.

Keywords: comparison of perimeters; congruity; inhibitory control mechanisms; intuitive interference; reaction time; warning intervention

Introduction

It is well known that many students encounter difficulties in solving a wide range of problems in science and mathematics (e.g., OECD, 2014). We suggest that students' difficulties may stem from the interference of an irrelevant variable which is automatically processed with formal/logical reasoning about the relevant variable (Stavy & Tirosh, 2000). This interference is reflected in students' erroneous responses to numerous tasks in science and mathematics, even when students have the knowledge and skills to solve these tasks correctly.

Here we will focus on the comparison of perimeters of geometrical shapes task. It was shown that many students intuit that shapes with a larger area must have a larger perimeter (e.g., Stavy & Babai, 2008).

In several reaction time studies students were asked to compare the perimeters of two geometrical shapes (i.e., to decide whether the perimeter of the left/right shape was larger or if both perimeters were equal) in congruent and incongruent conditions (see Fig. 1).

The two conditions can be characterized as follows:

1. Congruent—in which 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.

2. Incongruent—in which 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 with the other one. There were two types of trials in each condition, simple and complex.

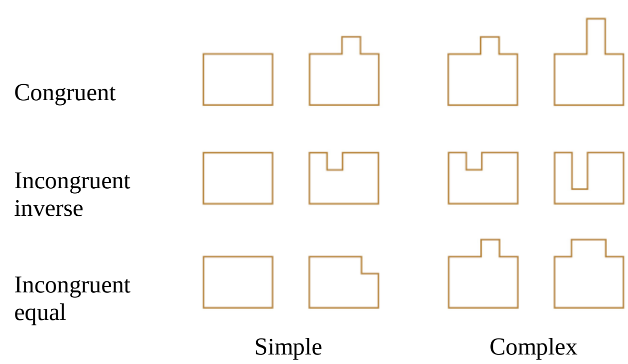

Figure 1: Examples of simple and complex congruent, incongruent inverse and incongruent equal task conditions.

Among schoolchildren, adolescents, and adults, findings have consistently shown higher accuracy and shorter reaction time in the congruent condition than in the incongruent conditions. These findings indicate that participants have difficulty in overcoming the intuitive interference of the salient (automatically processed) irrelevant variable area and in inhibiting it. Apparently they cannot avoid comparing this salient variable while comparing perimeters. Moreover, when participants were asked to compare the areas of the shapes, almost all of the responses were correct and relatively fast (significantly faster than for perimeters comparison) in all conditions (e.g., Babai et al., 2006; Babai et al., 2010). These findings support our conjecture that area is indeed the salient variable in this task and that participants have difficulty in ignoring it when comparing perimeters.

Level of complexity of the presented shapes was also shown to affect participants' performance in the comparison of perimeters task. It was suggested that in the case of the comparison of perimeters incongruent trials, complex trials are associated with higher cognitive load on working memory than simple trials (e.g., Babai et al., 2015; Stavy & Babai, 2008).

An event-related fMRI study involving the comparison of perimeters task that included both conditions (congruent and incongruent equal) indicated that different brain regions are activated during reasoning in the congruent and incongruent conditions (Stavy & Babai, 2010; Stavy et al., 2006). It was found that reasoning in the congruent condition activated parietal brain regions known to be involved in perceptual and spatial processing, including processing related to comparison of continuous quantities, such as found in the comparison of perimeters task. This activation is likely to reflect both the automatic processing of the salient irrelevant variable area and the processing of the relevant variable perimeter. We have suggested that when the processing of area and perimeter result in the same conclusion (congruent condition), this is the end of the processing (Stavy et al., 2006).

Reasoning in the incongruent condition activated regions in the prefrontal cortex, suggesting that inhibition was required as these brain regions are known for their executive inhibitory control over posterior and subcortical brain regions during processing of different cognitive functions. These regions are also known to be activated during tasks which require overcoming interference (e.g., Houdé et al., 2000). In the incongruent condition the processing of area and perimeter result in conflicting conclusions, one based on the area comparison and the other on perimeter comparison. This conflict has to be resolved. It was suggested that when answering correctly, the prefrontal brain regions inhibit the automatic unavoidable processing of the interfering irrelevant salient variable area in the parietal brain regions. Overcoming this conflict is a demanding and time-consuming process and is probably affected by the efficiency of inhibitory control mechanisms (Stavy et al., 2006). It is therefore possible that intervention aimed at activating inhibitory control mechanisms could improve participants' ability to overcome the intuitive interference.

The findings of our brain-imaging study, that different brain regions are activated during reasoning in the congruent and incongruent conditions, corroborate and extend previous studies related to interference between intuitive and logical reasoning in other domains (e.g., Goel & Dolan, 2003; Houdé et al., 2000). It has been shown that inhibitory training related to conditional reasoning resulted in improvement in participants' logical responses and in a shift in brain activation from posterior to frontal (Houdé et al., 2000). Inhibitory training in Houdé et al. (2000) consisted of warning the participants about the trap in their conditional reasoning task.

Here we explored, through a control/experimental design whether a problem-specific warning intervention aimed at activating students' inhibitory control mechanisms would improve sixth graders' accuracy of responses in incongruent conditions of the comparison of perimeters task and whether it would affect their reaction times. The 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. Students in the control group received no intervention.

Methodology

Participants

Eighty-four sixth graders (ages 11–12) were randomly assigned to the warning (n=44) and control (n=40) groups. They performed the same computerized comparison of perimeters reaction time test, with or without warning intervention.

Reaction time test

Each student was individually presented with a computerized comparison of perimeters test with/without warning intervention. In each test trial, two shapes were presented and the students were asked to compare the perimeters of the two shapes, that is, to judge whether the right shape had a larger perimeter, the left shape had a larger perimeter, or the two shapes had an equal perimeter. Each trial was presented on the screen until the participant responded by pressing an appropriate key. The students were asked to answer correctly and as quickly as they could.

The test included 16 congruent, 16 incongruent inverse, and 16 incongruent equal trials presented in pseudorandom order. The test session started with instructions, which included the warning intervention (see below) only in the experimental group, followed by 10 training trials (different from the ones presented in the test) for practice with the task and the experimental setting.

Warning intervention

The intervention consisted of an explicit warning on the possible interference of the area feature when comparing perimeters, emphasizing the tendency to compare areas instead of perimeters, which can lead to errors. During the instructions and before the 10 training trials participants in the experimental group were presented with the following warning intervention on the computer screen:

> **Pay attention**: you are requested to compare the perimeters and not the areas of the two shapes.
> There is a tendency to compare the areas of the shapes instead of their perimeters.
> This tendency may lead to errors.
> Try to overcome this tendency.

Data analysis

Accuracy of correct responses was calculated for each participant for each condition and level of complexity. Since there were too few correct responses in incongruent conditions, median reaction time was calculated for each participant for all the responses for each condition and level of complexity. Repeated measure GLM and Bonferroni post hoc tests were carried out in order to detect significant differences between conditions, levels of complexity, and the two experimental groups (control and warning).

Findings

Table 1 shows rates of success and their SEM for the comparison of perimeters task in each group (control and warning) for the three task conditions (congruent, incongruent inverse, and incongruent equal) and the two levels of complexity (simple and complex).

Table 1: Rate of correct responses for the comparison of perimeters task in control (n=40) and warning (n=44) groups.

Congruity	% Correct (SEM)	
	Control	Warning
Congruent	89.7 (2.2)	86.4 (2.9)
Simple	88.1 (2.9)	83.5 (3.7)
Complex	91.3 (3.2)	89.2 (3.2)
Incongruent inverse	35.2 (6.3)	59.4 (5.8)
Simple	31.6 (6.5)	54.0 (6.3)
Complex	38.8 (7.0)	64.8 (6.0)
Incongruent equal	18.8 (3.9)	32.5 (5.0)
Simple	30.0 (6.9)	44.6 (6.6)
Complex	7.5 (3.0)	20.5 (5.0)

Analysis of variance of success rate revealed significant main effects of intervention (F = 5.40, df = 82, p = 0.023, partial eta squared = 0.062), and congruity (F = 158.13, df = 81, p < 0.001, partial eta squared = 0.796). The success rate in the warning group was higher than in the control group and higher in congruent than in incongruent trials. A significant interaction of Group x Congruity (F = 5.65, df = 81, p = 0.005, partial eta squared = 0.122) was found. The warning intervention resulted in a higher success rate in incongruent (p = 0.006 for the incongruent inverse and p = 0.035 for the incongruent equal) but not in congruent trials. A significant interaction of Congruity x Complexity (F = 12.99, df = 81, p < 0.001, partial eta squared = 0.243) was found. In the incongruent equal condition a higher success rate was found for the simple than the complex trials (p < 0.001), while in the incongruent inverse condition a higher rate of success was observed for the complex trials (p = 0.008). Most errors in incongruent trials were found to be intuitive ones (i.e., larger area – longer perimeter).

Table 2 shows reaction times and their SEM for the comparison of perimeters task in each group (control and warning) for the three task conditions (congruent, incongruent inverse, and incongruent equal) and the two levels of complexity (simple and complex).

Table 2: Reaction time of responses (in msec) for the comparison of perimeters task in control (n=40) and warning (n=44) groups.

Congruity	Reaction time (SEM)	
	Control	Warning
Congruent	1695 (96)	1895 (117)
Simple	1746 (110)	1967 (138)
Complex	1644 (114)	1824 (118)
Incongruent inverse	1860 (110)	2269 (174)
Simple	1799 (123)	2367 (212)
Complex	1922 (119)	2172 (189)
Incongruent equal	1913 (112)	2399 (192)
Simple	1562 (97)	1867 (150)
Complex	2264 (158)	2932 (284)

Analysis of variance of reaction time revealed significant main effects of intervention (F = 4.07, df = 82, p = 0.047, partial eta squared = 0.047), congruity (F = 10.23, df = 81, p < 0.001, partial eta squared = 0.202), and complexity (F = 10.54, df = 82, p = 0.002, partial eta squared = 0.114). Reaction time was longer in the warning intervention group than in the control group, in incongruent trials than in congruent ones and in complex trials than in simple ones. In addition a significant interaction of Congruity x Complexity (F = 19.98, df = 81, p < 0.001, partial eta squared = 0.330) was found. In the incongruent equal condition, longer reaction time was found for the complex trials than for the simple ones (p < 0.001), while in the other two conditions no differences between complex and simple trials were found.

Discussion and Conclusions

Students' difficulties in science and mathematics may stem from an interference of a salient irrelevant variable in the task. Our earlier brain-imaging study on the comparison of perimeters task revealed that overcoming these difficulties is related to activation in prefrontal brain regions known to be associated with inhibitory control mechanisms. It seems that failure to overcome the salient irrelevant variable area in incongruent task conditions is related to inefficiency of participants' inhibitory control mechanisms. This led us to the idea that activating inhibitory control mechanisms could improve students' performance in the task.

Inspired by the work of Houdé and his colleagues (e.g., Houdé et al., 2000) we used a task-specific warning intervention of one slide that was shown to schoolchildren prior to the comparison of perimeters computerized test. The warning intervention explicitly warned students about the trap in the task. It reminded them that they were to compare the perimeters and not the areas and that comparing the areas might lead to errors. They were then encouraged to avoid the comparison of areas.

The findings show that this short, focused, and task-specific warning intervention significantly improved students' accuracy of responses to both incongruent conditions. This suggests that the warning intervention indeed activated inhibitory control mechanisms and thus helped students overcome the intuitive interference.

It would be very interesting to know how long the effects of the intervention last, and if a more general warning would have a positive effect as well. It would also be very interesting to explore whether such a warning intervention would improve adolescents' and adults' performance in the comparison of perimeters task and whether it would affect the pattern of brain activation. It could be that improvement in performance would be accompanied by a shift in brain activation from posterior to frontal, for example, in accordance with our earlier brain-imaging study (Stavy et al., 2006) and as was found by Houdé and his colleagues with regard to the conditional reasoning task (Houdé et al., 2000). Future studies will shed light on these issues.

The intervention effect was also expressed in a significant increase in reaction time for all conditions. It seems that the explicit warning regarding the trap in the task leads students to inhibit it and to focus their attention on the relevant variable, perimeter, leading to an increase in accuracy in the incongruent conditions and an increase in reaction time in all conditions. The effect of this inhibition is general and robust and increases reaction time in all conditions, even when it is not needed (i.e., in the congruent condition). The increase in reaction time for both conditions is interpreted as a result of activating students' inhibitory control mechanisms.

Our results have several educational implications. They indicate the importance of inhibitory control mechanisms in reasoning processes associated with overcoming interference in science and mathematics. While a recent study suggested that a general warning was largely ineffective in helping students overcome difficulties (Dewolf et al., 2014), the findings of the current study point to the possibility of improving students' problem-solving abilities through simple, focused, task-specific interventions that explicitly warn them about the trap in the task, that is, the possible interference of the irrelevant salient variable. Such research-based simple interventions appear to require only teachers' knowledge and awareness and could replace or complement the traditional educational technique of supporting relevant content knowledge. It is possible that, in other tasks, task-specific warning interventions would activate inhibitory control mechanisms that would help students overcome intuitive interference in each task. It would be very interesting to explore whether a repeated use of such interventions (with different tasks) would eventually lead students to take a more generally critical attitude toward reasoning. It would also be very interesting to explore why for some tasks a warning is effective while for other tasks it is not (e.g., Dewolf et al., 2014). This question deserves further research.

The current study demonstrates that applying cognitive psychology and neuroscience methodologies in science and mathematics education research can contribute to science and mathematics education and to cognitive psychology and neuroscience both theoretically and practically. We believe that construction of direct links between behavioral and brain data and pedagogical interventions is a particularly important field of research for future cognitive psychology and neuroscience (e.g., Sigman et al., 2014), as well as for science and mathematics education. This requires collaboration among educators and educational researchers and cognitive psychologists and neuroscientists (Grabner & Ansari, 2010).

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