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Evidence for children's error sensitivity during arithmetic word problem solving

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ABSTRACT

Solving simple arithmetic word problems is often challenging for children. Recent research suggests that children often fail to solve certain of these problems because they fail to inhibit erroneous heuristic intuitions that bias their judgment. However it is unclear whether these errors result from an error monitoring or inhibition failure. Our study focuses on this critical error detection. Eight to eleven year-old schoolchildren were given problems in which an intuitively cued heuristic answer conflicted with the correct answer and a control version in which this conflict was not present. After solving each version children were asked to indicate their response confidence. Results showed that children showed a sharp confidence decrease after having failed to solve the conflict problems. This indicates that erring children have some minimal awareness of the questionable nature of their answer and underscores that they have more arithmetic understanding than their errors might seem to suggest.

1. Introduction

Solving simple arithmetic word problems is a key ability that children need to master throughout their elementary school mathematics curriculum. These simple word problems involve basic mathematical operations such as addition and subtraction. Although even young infants have been shown to have precocious knowledge of elementary arithmetic operations (Lubin, Poirel, Rossi, Pineau, & Houdé, 2009; Wynn, 1992), solving arithmetic word problems is often challenging for school-aged children and even for adults (Verschaffel, 1994). In arithmetic word problems, compare problems are typically considered to be the most difficult[1] (e.g., De Corte & Verschaffel, 1987; Giroux & Ste-Marie, 2001; Lewis & Mayer, 1987; Morales, Shute, & Pellegrino, 1985; Riley & Greeno, 1988; Schumacher & Fuchs, 2012; Stern, 1993). Consider the following example (Riley, Greeno, & Heller, 1983):

> Mary has 8 marbles. She has 5 more marbles than John. How many marbles does John have?

What makes these problems hard is that they introduce relational terminology such as "less than" or "more than" (Schumacher & Fuchs, 2012). In addition, as the introductory problem illustrates, the relational term that is introduced can be inconsistent with the arithmetic operation (e.g., subtraction) required to solve the problem (Lewis & Mayer, 1987; called these "inconsistent language" problems). Hence, the relational term will cue a response that conflicts with the correct mathematical response. That is, children will be tempted to add rather than to subtract (e.g., they will answer "13" instead of "3"). The available evidence indeed suggests that the incorrect responses in these type of problems are typically so-called "reversal errors" characterized by adding the numbers instead of subtracting them or vice versa (Lewis & Mayer, 1987; Stern, 1993; Stern & Lehrndorfer, 1992; Verschaffel, de Corte, & Pauwels, 1992). The aim of the present study is to better understand the nature of these errors in this type of arithmetic word problem in elementary schoolchildren.

Recently, Lubin, Vidal, Lanoë, Houdé, and Borst (2013) suggested that failures to solve the problems are related to an executive failure

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[1] This specifically applies to the additive word problems (e.g., De Corte & Verschaffel, 1987; Giroux & Ste-Marie, 2001; Lewis & Mayer, 1987; Morales et al., 1985; Riley & Greeno, 1988; Schumacher & Fuchs, 2012; Stern, 1993).

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to inhibit an overlearned arithmetic strategy or heuristic. They hypothesized that errors occur because children will intuitively rely on an automatically activated “add if more, subtract if less” rule of thumb or heuristic. Interestingly, this intuitive strategy emerges precociously, is reinforced by academic learning, and is still present in adulthood (De Corte, Verschaffel, & Pauwels, 1990; Tirosh, Tsamir, & Hershkovitz, 2008; Vamvakoussi, Van Dooren, & Verschaffel, 2012). Note that the “add if more, subtract if less” heuristic can be considered as a special case of the “key-word” strategy (e.g., De Corte et al., 1990; Hegarty, Mayer, & Green, 1992; Stern, 1993; Verschaffel, 1994; Verschaffel et al., 1992). The key-word strategy refers to a general tendency whereby children base their choice of strategy (i.e., to add or subtract) on a superficial look at the key word in the problem statement (e.g., “more/less” in the examples here but more generally also related words such as “win/lose” or “gain/loss”).

Clearly, in and by itself, in many cases the “add if more, subtract if less” heuristic (or key word strategy) can be useful and will help children to arrive at a correct response. Consider the following example in which the relational term and required mathematical operation are consistent (Lewis & Mayer, 1987 called this a “consistent language problem”):

> Mary has 8 marbles. John has 5 more marbles than Mary. How many marbles does John have?

In this case applying the heuristic will cue the correct answer “13”. However, the point is that sometimes (i.e., when the relational term is inconsistent with the required mathematical operation) it will also cue a response that conflicts with the correct mathematical answer and bias our reasoning. Consequently, correctly solving such “conflict” problems will require that children inhibit the tendency to simply apply the heuristic.

To validate their claim about the role of inhibitory processing in avoiding arithmetic word problem errors, Lubin et al. (2013) adopted a negative priming paradigm (Tipper, 1985). The basic idea behind this paradigm is simple: if you inhibit a specific strategy on one trial, then activation of this same strategy on a subsequent trial should be hampered (Borst, Moutier, & Houdé, 2013). Bluntly put, when you block a strategy at Time 1, you will pay a price when trying to reactivate it again immediately afterwards. Therefore, Lubin et al. had children first solve a “conflict” arithmetic word problem in which they needed to refrain from using the “add if more, subtract if less” heuristic (e.g., the relational term and required mathematical operation were inconsistent, e.g., “Mary has 8 marbles. She has 5 more marbles than John. Does John have 13 marbles?”). Immediately afterwards they were presented with a “no-conflict” arithmetic word problem in which the heuristic cued the correct response (i.e., the relational term and required operation were consistent, e.g., “Mary has 8 marbles. John has 5 more marbles than Mary. Does John have 13 marbles?”). Lubin et al. observed that sixth-graders, nine-graders and adults were slowed down on the no-conflict problem when they had previously solved the conflict problem correctly. When the no-conflict problem was preceded by a control problem that did not require blocking the heuristic (e.g., “Joe has 25 pens. Marc has 10 pens. Does Joe have more pens than Marc?”) such slowing down was not observed. This pattern is consistent with the postulated role of inhibitory processing in arithmetic word problem solving.

In general, accounts that have stressed the importance of inhibition in human cognition and development have received wide support and have become increasingly popular (e.g., Babai, Eidelman, & Stavy, 2012; Dempster & Brainerd, 1995; De Neys & Everaerts, 2008; De Neys & Van Gelder, 2008; Houdé, 1997, 2000, 2007; Reyna, Lloyd, & Brainerd, 2003; Simoneau & Markovits, 2003). More specifically, there is also a rapidly growing field of literature on the importance of inhibition for mathematical learning (e.g., Attridge & Inglis, in press; Clayton & Gilmore, in press; Gillard, Van Dooren, Schaeken, & Verschaffel, 2009; Gilmore et al., 2013; Gilmore, Keeble, Richardson, & Cragg, in press; Lubin et al. 2013; Szücs, Devine, Soltesz, Nobes, & Gabriel, 2013; Van Hoof, Janssen, Verschaffel, & Van Dooren, 2014). However, the precise nature of children's inhibition failure when failing to solve arithmetic word problems is not clear. A key question is whether children fail the problems because they lack the executive resources to complete inhibiting the heuristic strategy or because they fail to detect that they need to inhibit the strategy in the first place. To clarify this point it is important to stress that inhibitory accounts do not posit that children always need to block their heuristic intuitions (e.g., Brainerd & Reyna, 2001; De Neys & Franssens, 2009; De Neys & Vanderputte, 2011; Houdé & Guichart, 2001; Jacobs & Klaczynski, 2002; Klaczynski, Byrnes, & Jacobs, 2001; Reyna et al., 2003; Stanovich, West, & Toplak, 2011). As we already noted, in many situations automatized heuristic strategies can provide a valid and useful basis for our judgment. Indeed, the no-conflict word problems that we introduced above are a very good illustration of this point. When the relational term does not conflict with the required mathematical operation, it is perfectly reasonable to rely on the heuristic. This implies that an efficient inhibition requires that one monitors for such conflict first and inhibits the heuristic strategy whenever it is detected. The detection might be quite implicit and boil down to a vague awareness that the heuristic response is not fully warranted (e.g., De Neys, 2012, 2014; Proulx, Inzlicht, & Harmon-Jones, 2012) but it is nevertheless a crucial building block for an efficient inhibition process. Hence, what we need to know is whether children show some minimal awareness of the questionability of their errors or not. Unfortunately, the efficiency of such an error detection process in simple arithmetic word problems has not been examined.

From a theoretical point of view, testing children's error detection skills is paramount to unravel the precise nature of their arithmetic failure. However, at a more applied level establishing whether or not children have some basic sensitivity with respect to their errors is also important to develop efficient intervention programs to *de-bias* their thinking. Existing general educational intervention programs aimed at reducing children's and adults' overreliance on heuristic impressions during reasoning have often focused on training participants' inhibitory processing capacities (e.g., Houdé, 2007; Houdé et al., 2000; Moutier, 2000; Moutier & Houdé, 2003). However, if younger children do not yet detect that the cued “add if more, subtract if less” heuristic is erroneous, such inhibition training will have less than optimal results in the case of arithmetic word problem solving. Clearly, any increase in inhibitory processing capacity per se is rather pointless if one is not able to determine whether or not it is needed to inhibit in the first place. Hence, examining children's error detection skills is paramount to determine which component an optimal intervention program needs to target.

In sum, both for theoretical and practical reasons it is important to test children's error detection efficiency during arithmetic word problem solving. In the present study we directly address this issue. We focused on the performance of a group of eight to eleven year-old elementary schoolchildren (third to fifth grade) because children in this age range are known to still have difficulties with arithmetic word problems (and we are obviously specifically interested in erroneous responses here, e.g., Lewis & Mayer, 1987; Morales et al., 1985; Riley et al., 1983). To test our hypothesis, children were given both conflict and no-conflict versions of simple arithmetic word problems. We therefore manipulated whether the relational term was consistent or inconsistent with the required