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Children's interpretations of covariation data: Explanations reveal understanding of relevant comparisons

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ABSTRACT

This research investigates children's understanding of the significance of comparisons between data categories for judgments of covariation. Past studies showed that children sometimes neglect some of the relevant data categories. This may occur because children fail to understand the relevance of the comparisons between data categories. To investigate this interpretation, 51 second graders and 43 fourth graders were tested in a between-subject design. In the standard condition, children were asked to explain their own covariation judgments. In the explain-correct condition, children were told the correct judgments and asked to explain them. Children in the explain-correct condition often provided explanations that were consistent with the correct judgments; children in the standard condition did so less often. Thus, when asked to explain correct judgments, elementary school children's explanations reveal that they possess a basic conceptual understanding of inference from covariation data.

1. Introduction

Imagine you want to observe birds in the park. You realize that on some days, there are birds to observe and on other days, there are no birds to observe. You wonder why that might be. You think that the weather might play a role. Suppose you keep track for a period of 60 days. You tabulate your data in a 2 × 2 contingency table showing the number of days there were birds and the number of days there were no birds, along with the number of sunny days and not sunny days. The ability to intuitively analyze such data is an important scientific reasoning skill. It requires, minimally, a conceptual understanding of the comparisons between cells that are necessary to draw an inference about the association between sunny days and the presence of birds.

The present research investigates children's abilities to make explicit covariation judgments based on data presented in 2 × 2 contingency tables (see Fig. 1). Research with adults indicates that interpreting covariation data is a challenging task. Judgment accuracy is often poor (e.g., Batanero, Estepa, Godino, & Green, 1996; Osterhaus, Magee, Saffran, & Alibali, 2018; Shaklee & Elek, 1988) and inadequate strategies are common (e.g., Batanero et al., 1996; Mata, Garcia-Marques, Ferreira, & Mendonça, 2015; Osterhaus et al., 2018; Shaklee, 1983; Shaklee & Hall, 1983; Shaklee & Mims, 1982; Shaklee & Tucker, 1980; Shaklee & Wasserman, 1986). A prominent problem is the tendency to neglect parts of the data. For example, Shaklee and colleagues showed in several studies that adults base their judgments mostly on cells A and B of the table, thus neglecting cells C and D (e.g., Shaklee & Hall, 1983; Shaklee & Mims, 1982; Shaklee & Tucker, 1980). This finding is in line with the result that people weight the four cells of the table in descending order for their judgments (Levin, Wasserman, & Kao, 1993); that is, the value in cell A influenced their judgments most, followed by cells B, C, and D.

The few existing studies of children also indicate a strong tendency to neglect substantial portions of the data as well as poor judgment accuracy (Obersteiner, Bernhard, & Reiss, 2015; Shaklee & Mims, 1981; Shaklee & Paszek, 1985). For example, in Shaklee and Paszek's (1985) study, 16.2% of second graders and 17.6% of fourth graders based their judgments only on cell A, and 40.5% of second graders and 70.6% of fourth graders based their judgments on cells A and B. In contrast, only 2.7% of second graders and 5.9% of fourth graders considered all four cells of the contingency table. More recently, Saffran, Barchfeld, Sodian, and Alibali (2016) found that, under facilitating task conditions that highlighted comparisons between rows, elementary school children referred more often to four cells (on about six out of nine items) than to two cells (on about three out of nine items) when explaining how they reached judgments about covariation data presented in contingency tables. Although these data point to more comprehensive

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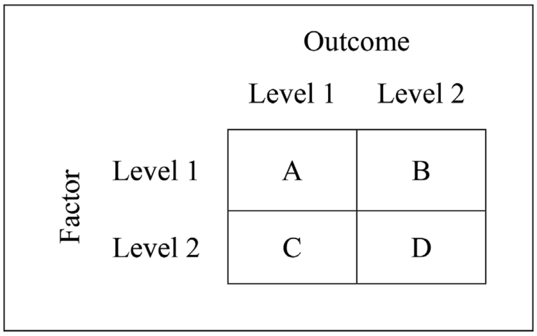

Fig. 1. Labeled 2 × 2 contingency table.

reasoning than the results reported by Shaklee and Paszek (1985), perhaps due to different methodological approaches, it remains the case that data category neglect and poor judgment accuracy is prevalent in children's interpretations of covariation data.

Since children often make incorrect judgments of covariation when presented with contingency tables, their post-hoc justifications are often flawed, as well (Saffran et al., 2016). They may fail to take parts of the data into account because their initial judgments rested solely on information from two cells and they attempt to be consistent with those initial judgments. Even if they consider all four cells, they may not integrate the information from the cells in an appropriate way.

However, despite these flaws in their reasoning, children may be aware, in principle, of the significance of all four data categories. That is, they may understand the relevance of the comparisons between data categories, but extraneous factors - such as limited working memory or inadequate executive control - may prevent them from taking all data into account or integrating the data appropriately. If this is the case, then children should be able to display their understanding in an alternative task that has lower task demands.

The present study examines whether children possess a basic conceptual understanding of the significance of comparisons between categories of covariation data presented in 2 × 2 contingency tables. To address this question, we eliminated some of the task demands involved in deriving an inference about covariation. If children are presented with the correct judgment and asked to explain why that judgment is correct, then they should be able to display their basic, conceptual understanding of the relations between the data categories, without having to apply a mathematically correct integration rule.

This approach builds on the self-explanation technique discussed in the education literature. In self-explanation studies, students are prompted to explain learning materials (e.g., worked-out examples, one's own problem solving efforts) to themselves. This technique yields positive effects on learning outcomes across a wide range of domains (for reviews, see Fonseca & Chi, 2011; Rittle-Johnson & Loehr, 2016). Although much of this research focuses on children's explanations of their own ideas, some studies have shown that self-explaining why correct information is correct or why incorrect information is incorrect is especially likely to enhance learning (Siegler, 2002; Siegler & Chen, 2008). Kuhn and Katz (2009) argued that explaining why a correct judgment is correct may help to divert attention from evidence that is in line with one's preexisting ideas and as such, it may help reasoners to take alternative evidence into account.

Following this line of reasoning, we propose to use self-explanations of correct judgments to investigate children's understanding of covariation data. We hypothesize that correct judgments may encourage children to focus on all relevant comparisons between cells, and thus overcome their tendency to neglect parts of the data. Thus, we propose to use self-explanations of correct judgments as a method to investigate children's conceptual understanding under optimal conditions (i.e., under reduced information processing demands). Thus, this research will yield important data about children's conceptual understanding that is needed to support future efforts to develop methods for promoting learning of covariation. We focus on elementary school children (Grades 2 and 4) because it has been shown that data category neglect is pronounced in this age group (e.g., Shaklee & Paszek, 1985).

To classify children's explanations, we concentrate on explanations that are *consistent* with the correct judgment as an indicator of conceptual understanding of covariation data. We define *consistent* explanations as explanations that are suitable to explain a correct judgment for a given covariation problem. The number and types of comparisons between data categories that are needed to make an explanation consistent with the correct judgment varies depending on the data pattern. For instance, comparing differences (e.g., (A-B) vs. (C-D)) is consistent with the correct judgment for an item with the numerical structure A = 18, B = 15, C = 18, and D = 4 (see Item 3 in Fig. 3), but not for an item with the numerical structure A = 30, B = 11, C = 20, and D = 1 (see Item 8 in Fig. 3).

Using a between-subject design, we compare a standard condition, in which participants were asked to provide and explain their own judgments (explain-own condition), and an explain-correct condition, in which participants were asked to explain provided correct judgments. We expect children to provide more explanations that are consistent with the correct judgment when asked to explain correct judgments (explain-correct condition) than when asked to provide and explain their own judgments (explain-own condition). In light of prior work (Obersteiner et al., 2015; Saffran et al., 2016; Shaklee & Mims, 1981; Shaklee & Paszek, 1985), we predicte that children will display low judgment accuracy and few explanations consistent with the correct judgments in the explain-own condition. If children produce comparable numbers of consistent explanations in the explain-correct condition, this would indicate that children fail to understand the meaning of the data categories, even with considerable task support. If children produce more consistent explanations in the explain-correct condition than in the explain-own condition, this would suggest that children's underlying conceptual understanding was masked in previous studies by other factors, such as processing demands.

2. Methods

2.1. Participants

Participants were 94 children, including 51 second graders (26 male; mean age $M = 8.23$ years, $SD = 0.32$, range = 7.59–8.87), and 43 fourth graders (29 male; mean age $M = 10.24$ years, $SD = 0.39$, range = 9.46–10.88). Children were recruited from four elementary schools in Munich, Germany.

2.2. Design

A 2 × 2 between-subject design with task condition and grade level as factors was used. To ensure that the experimental groups were comparable with respect to their data interpretation abilities, a paper-and-pencil pretest was administered in class four to ten weeks before the individual interview sessions. In this test, children were presented with a story context about the effectiveness of crèmes against pimples and were asked to decide for eight covariation problems which of two crèmes was more effective or if there was no difference. The experimental groups were matched based on their mean pretest performance and gender within each grade level. Table 1 shows the number of participants in each group.

2.3. Materials

Two series of nine pictures with 2 × 2 contingency tables were used. The context story was about the association between different varieties of apples and apple juice color (light vs. dark). The rows and columns of the tables were labeled with small illustrations, indicating