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Utilizing probabilities as decision weights in closed and open information boards: A comparison of children and adults ☆

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ABSTRACT

Decisions in preschoolers (6 years), elementary schoolers (9.7 years), and adults (21 years) were studied with an information board crossing three probabilistic cues (validities: .83, .67, .50) with two options. Experiment 1 ($n = 215$) applied a standard version of the information board (closed presentation format), in which information must be searched sequentially and kept in mind for the decision. Experiment 2 ($n = 217$) applied an open format (Glöckner & Betsch, 2008), in which all information was visible during decision making. Elementary schoolers but not preschoolers benefited from an open format — indicated by an increase in using probabilities as decision weights. In the open but not closed format, choices were biased by normatively irrelevant information (the lure). Variations in the prediction patterns of the cues influenced decisions in all age groups. Effects for presentation format, pattern, and lure jointly indicate that even children are capable of considering multiple information in their decisions.

1. Introduction

1.1. Representation and integration of probabilities in decision making

According to the normative theory of rational choice (utility theory: Von Neumann & Morgenstern, 1947) and its descriptive variants (e.g., prospect theory: Kahneman & Tversky, 1979, model of reasoned action: Fishbein & Ajzen, 1974), outcome values should be weighted by their (subjective) probabilities of occurrence. Probability weighting imposes some demands on the decision maker's cognitive abilities. Among those, *encoding* and *integration* are of paramount importance. Representation requires that available probabilistic information is effectively encoded and formed into subjectively meaningful representations in the mind. Encoding is not possible without a corresponding coding system (i.e., a concept of probability) activated in memory (Bruner, 1957). Such a concept need not be part of explicit knowledge. Rather, it is possible that experience based learning establishes an implicit understanding of risk or that probabilistic information is conveyed in a format that maps on basic coding systems such as frequency or mental magnitude. When a proper coding system is lacking, it is difficult to form a meaningful representation and use it for further processing. Given that a proper representation has been established and retained in working memory, the individual must be capable of using this piece of information as a decision weight. In simple gambles, weighting involves the integration of two representations per option — one value and one probability. In risky multi-attribute decisions, integration can additionally involve the mathematical addition of value–probability products if, for example, a weighted additive rule is applied (WADD; e.g., Payne, Bettman, & Johnson, 1993).

Adult decision makers sometimes deviate from that normative rule and are prone to numerous biases and fallacies in their probabilistic reasoning such as base rate neglect or the inflation of miniscule risks (Kahneman, Slovic, & Tversky, 1982). Some of these decision making errors can be linked to difficulty in encoding the available probabilistic information. Gigerenzer and Hoffrage (1995), for example, showed that natural frequency formats instead of formal probabilities can promote proper representation and understanding of probabilistic information. Gigerenzer and Hoffrage (1995) argued that the mind is designed to process frequencies rather than formal probabilities. Therefore, natural

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frequencies can be easily understood, whereas individuals find it difficult to understand problems that are conveyed in a mathematical probability format (see Fiedler, Brinkmann, Betsch, & Wild, 2000, for a discussion). These few examples indicate that deficits in encoding may be one important source for subsequent errors in using probabilities as decision weights.

Another factor that hampers weighting relates to processing capabilities. In the judgment-and-decision-making (JDM) literature, integration is commonly considered to be a difficult cognitive process that individuals tend to avoid. With reference to the WADD rule (assessing weights, using a linear weighted integration rule) – the decision rule proposed by utility theory – Shah and Oppenheimer (2008, p. 207) conclude:

> "Clearly, such an algorithm requires great mental effort; however, people do not have unlimited processing capacity. People must operate within the constraints imposed by both their cognitive resources and the task environment (…)".

This notion follows from the bounded rationality approach introduced to psychology decades ago by Nobel laureate Herbert Simon (1955). Its cornerstone assumptions are that human processing capacities are limited; and, therefore, individuals regularly use simple strategies. These strategies circumvent effortful processing, such as weighted integration, and are used contingent upon the environment. These simple strategies often lead to satisfying (Payne, Bettman, & Johnson, 1988) and, under certain circumstances, even good results (Gigerenzer & Gaissmaier, 2011).

1.2. Using probabilities as decision weights in children

Thus far, we have discussed two potential sources of shortcomings in probability weighting in adults: improper encoding and the avoidance of integration. Children may be especially prone to deficits in encoding and performing weighting operations and, as a result, have difficulty using probability information in their decisions. First, they may lack proper coding systems. According to the Piagetian view, humans do not begin to develop a concept of probability and chance that allows them to deal with probabilistic problems in a systematic fashion until secondary school age (11–12 years) (Hoemann & Ross, 1971; Kreitler & Kreitler, 1986; Piaget & Inhelder, 1951). As a consequence, younger children may fail to encode probabilistic information properly so that it can be used as a decision weight. Moreover, they should be likely to avoid weighting and integration due to cognitive limitations that are more severe in children than in adults. In comparison to young and middle-aged adults, children's working memory is less efficient (Case, Kurland, & Goldberg, 1982; Gathercole, Pickering, Ambridge, & Wearing, 2004; Kail, 1993). For example, Siegel reported that working memory skills are not fully developed until the age of nineteen (e.g., Siegel, 1994). One of the origins of limited memory performance in younger children stems from interference effects. Children under the age of eleven are more susceptible to false feature overwriting and confusion of memory entries (Göthe, Esser, Gendt, & Kliegl, 2012). With respect to the task-related differences in children's performance, Schlottmann and Wilkening (2012, p. 67) argued that choice tasks are often more complex than judgment task. Accordingly, children should be especially prone to avoiding integration due to capacity limitations when choosing between options.

Thus, both causes jointly render it less likely that children will weight values with probabilities, especially at an early age. Empirical evidence, however, provides an incoherent picture. On the one hand, there is evidence indicating that substantial portions of children below the age of ten are not able to systematically use probabilities as decision weights. Levin and coworkers (Levin & Hart, 2003; Levin, Weller, Pederson, & Harshman, 2007) employed a gambling task to study risky decisions in children as young as five to seven years. In line with the Piagetian view, they found that these young children failed to properly base their decisions on differences in the probability of winning or losing money. Using an information board paradigm, Betsch and Lang (2013) studied probabilistic inference decisions with two cues that made correct predictions with either low ($p = .50$) or high validity ($p = .83$). The authors demonstrated that some children systematically utilized probabilities according to the expectations of utility theory. Compared to adults, however, these portions were very small. Approximately 15% of preschoolers (6 years) and 30% of elementary schoolers (9 years) followed the high validity cue in at least three quarters (75%) of their decisions, whereas more than 80% of the adults did so.

These examples from studies using a standard decision task (gambling paradigm, information board) are in sharp contrast to research using different kinds of tasks, such as judgments. Schlottmann (2001) studied evaluative judgments in four to six year old children (and other age groups). Participants judged how happy a puppet would feel if it won games differing in gain size (number of crayons) and probability. Probabilities were visualized by a glass tube containing a bi-colored stripe. Each color occupied a varying number of segments in the tube corresponding to its relative probability. For the gamble, a marble was shaken in the tube; and the color of the segment it landed on determined the outcome, which consisted of a varying number of crayons. Results showed that even preschoolers integrated probability and value in accordance with utility theory's weighted additive rule. Because the children in the sample presumably lack a formal understanding of the probability concept due to their age, Schlottmann concluded that four to six year olds performed the weighting procedures intuitively (see also Schlottmann & Anderson, 1994; Schlottmann & Wilkening, 2012). Pasquini, Corriveau, Koenig, & Harris (2007) studied three and four year olds' sensitivity to informants' previous accuracy. In four year olds, subsequent trust in the informant varied systematically as a function of experienced probability, i.e. the rate at which the informant performed accurately in prior tasks. In causal reasoning, young children also show a systematic sensitivity to weight evidence related to probabilistic information (e.g., Sobel, 2009; Sobel, Tenenbaum, & Gopnik, 2004).

1.3. Origins of deficits in using probabilities as weights: encoding and representation or integration?

Unfortunately, previous studies with children are not overly informative with regard to the origins and conditions under which deficits in probability weighting emerge. Do deficits stem from difficulties with encoding and representation, information integration, or both (or other factors)?

We propose that children are already capable of performing weighting and integration operations. We further posit that these processes can function automatically without noticeable effort and, therefore, should not be considered the cause for any deficits in utilizing probabilities as weights.

This assumption is based on empirical evidence both inside and outside the field of JDM. Mata, von Helversen, & Rieskamp (2011) designed a probabilistic decision environment in which a strategy was reinforced that does not involve the integration of probabilities and values. Nevertheless, 10 year olds were almost immune to the reinforcement schedule and, instead, continued to use more complex strategies involving complex information integration. Similarly, Jansen, van Duijvenvoorde, and Huizenga (2012) found that younger children (eight years), in comparison to older children and adults, were more prone to employing integrative rules that process multiple information sources. These findings are not compatible with the bounded-rationality approach, which assumes that integration is likely to be circumvented because it is effortful.

In a similar vein, Glöckner and Betsch (2008) showed that adult participants spontaneously integrate multiple pieces of information when they did not require time consuming sequential search. They presented