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Probability in reasoning: A developmental test on conditionals

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ABSTRACT

Probabilistic theories have been claimed to constitute a *new paradigm* for the psychology of reasoning. A key assumption of these theories is captured by what they call *the Equation*, the hypothesis that the meaning of the conditional is probabilistic in nature and that the probability of *If p then q* is the conditional probability, in such a way that P(*if p then q*) = P(*q*|*p*). Using the probabilistic truth-table task in which participants are required to evaluate the probability of *If p then q* sentences, the present study explored the pervasiveness of *the Equation* through ages (from early adolescence to adulthood), types of conditionals (basic, causal, and inducements) and contents. The results reveal that *the Equation* is a late developmental achievement only endorsed by a narrow majority of educated adults for certain types of conditionals depending on the content they involve. Age-related changes in evaluating the probability of all the conditionals studied closely mirror the development of truth-value judgements observed in previous studies with traditional truth-table tasks. We argue that our modified mental model theory can account for this development, and hence for the findings related with the probability task, which do not consequently support the probabilistic approach of human reasoning over alternative theories.

1. Introduction

The capacity to reason is of paramount importance for members of the Homo sapiens species and, not surprisingly, understanding how human beings reason and how this capacity develops with age have been among the main aims of psychology. This enquiry has for a long time been connected with the questions of rationality and logic. Accordingly, Piaget described intellectual development as a progress toward rationality through the construction of mental operations structured in a logical way (Inhelder & Piaget, 1958; Piaget & Inhelder, 1959). More recently, prominent theories suggested the existence in human mind of logical rules constituting a form of mental logic (Braine & O'Brien, 1998; Rips, 1994). Alternative accounts were proposed that denied the existence of such rules, assuming that people reason by constructing and manipulating mental models of the state of affairs the available premises refer to (Johnson-Laird & Byrne, 1991). Despite their divergences, these approaches shared common conceptions about both the reasoning processes that deserve investigation, and the normative theory to which human reasoning should be compared. Theories rooted in this tradition focused on the processes of deduction and truth preservation based on binary distinctions between truth and falsity or validity and invalidity. How logical thinking is possible in humans and how far people conform to logical standards were questions of main interest, with the key discovery that human reasoning is prone to biases and often relies on heuristics instead of analytic thinking (Evans, 1982; Kahneman, 2003, 2011; Kahneman & Tversky, 1972, 1973).

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These divergences between the actual human reasoning performance and formal logic progressively turned the attention of psychologists to notions like degrees of belief, subjective probability, and utility (see Oaksford & Chater, 1994, for one of the first examples of this turn). This resulted in the emergence of new theories in keeping with the Bayesian movement that has recently developed in psychology and neurosciences. These theories that Elqayam and Over (2013) have suggested to widely name *probabilistic* are assumed by their defenders to constitute a *new paradigm* that goes far beyond the mere study of deductive processes (Chater & Oaksford, 2008; Evans, 2002, 2012; Oaksford & Chater, 2007, 2009). Accordingly, Elqayam and Over (2013, p. 259) do not hesitate to state that "studying probability judgments will tell us more about the psychology of reasoning than trying to figure out how far people conform to binary extensional logic in any deductive reasoning in which they engage".

However, though the new paradigm has certainly enriched the range of problems addressed by the psychology of reasoning, it has left almost unexplored key questions that were considered as central by the deduction paradigm. This is the case of development. Our remarkable reasoning capacities, including the ability to reason abstractly, are usually seen as a distinctive characteristic of human beings, and as such the question of their origin is central for understanding human cognition and, more generally, our human nature. Accordingly, the innate, learned, or constructed nature of our capacity to reason was one of the main questions debated by what Elqayam and Over (2013) call the "old" paradigm (Inhelder & Piaget, 1958; Overton, 1990). Notwithstanding its age, the questions that were debated by this "old" paradigm are not necessarily obsolete. If probability judgments are the basis of human reasoning as the new paradigm claims, how these judgments evolve with age becomes a major issue for psychology. The aim of the present study was to address this question in the domain of conditional reasoning.

1.1. The new paradigm and the question of development

One of the main innovations of the new paradigm is undoubtedly the renewal it has introduced in the study of conditional reasoning (Oaksford & Chater, 2010). Conditional reasoning is a key process of human mind. Permitted by propositions containing the connector "*If*", it allows human beings to think about hypotheses and suppositions. Accordingly, it underpins scientific reasoning (Kuhn, 2011), but also our capacity to think about causal relations (Kushsnir & Gopnik, 2007), to comply with social rules (Harris & Nunez, 1996; Light, Blaye, Gilly, & Girotto, 1989), to understand inducements such as promises and threats (Newstead, Ellis, Evans, & Dennis, 1997), and even to think in a counterfactual way ("*If only I had* ...", Beck & Riggs, 2014). Thus, it is not surprising that the origins and development of conditional reasoning were a matter of debate for the "old" paradigm. Whereas some authors assumed that the basic logical rules governing conditional reasoning such as Modus Ponens were based on mapping the *If* of the natural language to some innate concept of contingency (Braine, 1990), others assumed that these rules could be acquired through learning processes (Falmagne, 1990). Subsequent views of the development of conditional reasoning have assumed that it is provoked by an age-related increase in world knowledge and working memory capacities permitting the construction of richer mental model representations with age (Barrouillet & Lecas, 1998, 1999; Markovits & Barrouillet, 2002). More recently, the role of different levels of divergent thinking has been emphasized in the evocation by children and adolescents of the different possibilities compatible with conditionals involving different contents (Markovits, 2014).

Departing from the formerly prevailing extensional approach, the new paradigm assumes that the meaning of a natural language conditional *If p then q* is probabilistic in nature. More precisely, it is assumed that the probability of the conditional is the conditional probability, $P(q|p)$, in such a way that $P(\textit{if } p \textit{ then } q) = P(q|p)$. This formal position is so important for the new paradigm theoreticians that, following Edington (1995), they call it *the Equation*. Empirical evidence supporting this proposal is based on a probabilistic truth table task (hereafter, the *probability task*) in which participants are asked to assess the probability of an *If p then q* conditional from the probabilities of the four truth-table possibilities *p* & *q*, *p* & *not-q*, *not-p* & *q*, *not-p* & *not-q*. Several studies observed that a majority of adults judge the probability of the conditional as the conditional probability $P(q|p)$, that is the probability of *p* & *q* divided by the summed probabilities of *p* & *q* and *p* & *not-q* (Evans, Handley, & Over, 2003; Fugard, Pfeifer, Mayerfofer, & Kleiter, 2011; Oberauer & Wilhelm, 2003; Over, Hadjichristidis, Evans, Handley, & Sloman, 2007).

However, contrary to the traditional psychology of reasoning, new paradigm theoreticians seem unconcerned by development. For example, there is no mention of developmental questions in the recent special issue of the journal *Thinking & Reasoning* devoted to basic and applied perspectives for the new paradigm psychology of reasoning (Elqayam, Bonnefon, & Over, 2013). In the same way, although dual-process theories of reasoning have been successfully used to account for the development of reasoning (Barrouillet, 2011; Brainerd & Reyna, 2001; Gauffroy & Barrouillet, 2009; Klaczynski & Cottrell, 2004; Klaczynski & Felmban, 2014; Markovits, 2014; Reyna & Brainerd, 2011), Evans and Stanovich (2013) do not even evoke developmental issues in their last review on dual-process theories. Thus, the new paradigm remains silent about the question of the origins of *the Equation* and its possible evolution with age. In the following, we will try to derive developmental predictions from one of the most coherent theoretical frameworks pertaining to the new paradigm, namely Evans' (2007) suppositional theory of conditional along with the heuristic-analytic approach (Evans, 2006) as its algorithmic counterpart. These predictions will be compared to those that can be derived from our own revised mental model theory of conditional concerning its probability (Barrouillet, Gauffroy, & Lecas, 2008; Gauffroy & Barrouillet, 2009, 2014b).