NEUROPSYCHOLOGIA

Neuropsychologia 42 (2004) 926–938

www.elsevier.com/locate/neuropsychologia

Inductive reasoning and implicit memory: evidence from intact and impaired memory systems

Luisa Girelli [a,*], Carlo Semenza [b], Margarete Delazer [c]

[a] Dipartimento di Psicologia, Università degli studi di Milano-Bicocca, Edifico U6, Piazza dell' Ateneo Nuovo 1, Milan 20126, Italy
[b] Dipartimento di Psicologia, Università degli studi di Trieste, Trieste, Italy
[c] Universitätsklinik für Neurologie Innsbruck, Innsbruck, Italy

Received 31 May 2002; received in revised form 25 November 2003; accepted 28 November 2003

Abstract

In this study, we modified a classic problem solving task, number series completion, in order to explore the contribution of implicit memory to inductive reasoning. Participants were required to complete number series sharing the same underlying algorithm (e.g., +2), differing in both constituent elements (e.g., 2 4 6 8 versus 5 7 9 11) and correct answers (e.g., 10 versus 13). In Experiment 1, reliable priming effects emerged, whether primes and targets were separated by four or ten fillers. Experiment 2 provided direct evidence that the observed facilitation arises at central stages of problem solving, namely the identification of the algorithm and its subsequent extrapolation. The observation of analogous priming effects in a severely amnesic patient strongly supports the hypothesis that the facilitation in number series completion was largely determined by implicit memory processes. These findings demonstrate that the influence of implicit processes extends to higher level cognitive domain such as induction reasoning.

Keywords: Number series; Arithmetic reasoning; Amnesia; Priming

1. Introduction

Inductive reasoning, defined as the process of inferring a general rule by inspection of specific instances, is regarded to be a critical constituent of human intelligence (Spearman, 1923; Thurstone, 1938). Research by cognitive psychologists demonstrated that inductive reasoning is essential in problem solving, in the development of expertise and in learning (Bisanz, Bisanz, & Korpan, 1994; Pellegrino & Glaser, 1982). In particular, rule induction has been shown to underlie a variety of activities such as concept formation (Simon & Lea, 1974), reading comprehension (Greeno, 1978), and effective instruction (Norman, Genter, & Stevens, 1976).

Typical examples of inductive reasoning tasks are series completion problems that require noting similar relationships across instances (Holzman, Pellegrino, & Glaser, 1983; Kotovsky & Simon, 1973; Simon & Kotovsky, 1963). In the completion of letter or number series, such as A C E G or 2 4 8 16, a general rule, which defines the relations among the constituent elements, has to be identified and subsequently applied to continue the series. Letter series and number series offer the opportunity to create a universe of items and to determine item difficulty on an a priori basis (Quereshi & Seitz, 1993); moreover, they seem rather sensitive indices of problem solving abilities (Holzman et al., 1983). For this reason, tasks of series completion gained wide application in both educational and psychological assessments (Langdon & Warrington, 1995; Thorndike, Hagen, & Sattler, 1986).

Solution of series completion problems is a complex process and elaborate theoretical frameworks have been proposed to model the cognitive steps involved (Holzman et al., 1983; Kotovsky & Simon, 1973; Simon & Kotovsky, 1963). Overall, four basic components of series completion are depicted by cognitive models. The first component, *relations detection*, requires the subject to scan the series and to advance hypotheses about the way in which one element of the series is related to the adjacent one. Relations between elements may be simple or complex, they may involve a single arithmetic operation (such as addition or subtraction) or more than one operation (such as multiplication and subtraction). The second component is the *discovery of periodicity*. The period length of a series defines the number of elements that completes one cycle: simple series have a period length of 1 (such as 2 5 8 11—rule +3), where the same relation applies to each following element, more complex

* Corresponding author. Tel.: +39-02-6448-6722; fax: +39-02-6448-6706.
E-mail address: luisa.girelli@unimib.it (L. Girelli).

0028-3932/$ – see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2003.11.016

series have longer period lengths (such as 2 4 3 5—rule +2 − 1). The third component consists in the *completion of the pattern description*. When the period length of a series is discovered, the identification of the relations between the elements composing a cycle allows one to formulate the rule describing the sequence. This rule is used in the final processing stage, the *extrapolation of the sequence* where the subject has to: (a) assess to which position within a period the answer will correspond, (b) isolate the part of the rule that applies to this position, and, finally, (c) apply this part of the rule in computing the answer (this applies to complex series only, while series with period length 1 may be answered simply by applying the rule).

Among the characteristics which potentially influence performance are the content of the series, its complexity, the type of arithmetic operation involved, and the magnitude of the arithmetic operations within the series (Holzman et al., 1983).

Indeed, it is generally assumed that the demand on arithmetical abilities is a relevant variable in series completion. In particular, the participants' expertise in calculation as well as their amount of memorized arithmetic knowledge seem to influence not only reaction times and accuracy but also strategy choice (Le Fevre & Bisanz, 1986).

Apart from calculation abilities, several distinct memory processes contribute to numerical problem solving. It is generally assumed that working memory capacity strongly correlates with reasoning abilities (Kotovsky & Simon, 1973); the impact of working memory load, however, varies with age and experience of the problem solver, being stronger for children than for adults (Holzman et al., 1983). With growing expertise, adults handle complex information more efficiently and increasingly rely on knowledge stored in long-term memory, such as multiplication tables, calculation procedures, or informal, but proved, heuristics (Holzman et al., 1983; Quereshi & Smith, 1998).

Besides working memory and semantic memory, episodic memory also contributes to problem solving abilities. Lovett and Anderson (1994) defined problem solving memory as "an episodic memory trace that includes various features of a previous problem solving experience (e.g., the problem statement, steps taken in the solution, operators used, and mistakes made)" (Lovett & Anderson, 1994, p. 366). Overall, one may assume that both semantic memory and episodic memory increase experience and basic knowledge thus minimizing processing demands on working memory in inductive reasoning.

While the influence of explicit memory has gained wide interest in cognitive research, relatively few studies have investigated the role of implicit memory processes in problem solving (Lovett & Anderson, 1994; Schunn & Dunbar, 1996). Implicit memory refers to any effect of past events, not consciously recollected, on experience, thought, or action. Dissociations between explicit and implicit memory have been repeatedly described in normal subjects as well as in amnesic patients, where implicit memory functions were often found to be preserved (Milner, Corkin, & Teuber, 1968; Schacter, 1987; Shimamura, 1986).

One of the most extensively studied implicit memory process is that of priming, in which exposure to a piece of information whether a word, an object, or a concept, facilitates its subsequent processing (Tulving & Schacter, 1990). Priming occurs in both perceptual tasks and conceptual tasks (Srinivas & Roediger, 1990), and it may concern very different functional levels as, for example, auditory (Schacter et al., 1994) and visual recognition (Cermak, Talbot, Chandler, Talbot, & Wolbarst, 1985), lexical access (Stanners, Neiser, Hernon, & Hall, 1979), or semantic processing (Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995).

Although less commonly investigated, conceptual priming has been used to analyze text comprehension (Seifert, McKoon, Abelson, & Ratcliff, 1986) and, more relevant to our study, problem solving abilities (Schunn & Dunbar, 1996; White, 1988). Overall, in comparison to the extensive literature on priming word production and recognition, relatively few studies have investigated priming effects in arithmetic. Moreover, these studies were mainly concerned with the cognitive architecture of arithmetic processing rather than the role of implicit memory in numerical tasks (Campbell, 1991; Campbell & Tarling, 1996).

Priming has been extensively exploited to study preserved memory functions in amnesia. Amnesic patients exhibit preserved priming effects in a variety of tasks: among them, word stem completion (Warrington & Weiskrantz, 1974), free association of word pairs (Graf & Schacter, 1985), lexical decision (Moscovitch, 1982), semantic category generation (Keane et al., 1995), and simple arithmetic (Delazer, Ewen, & Benke, 1997). Although preserved priming effects in amnesia are subject to some boundary conditions (Shimamura, 1986), the dissociation between explicit memory performance and priming is generally regarded as evidence for the existence of independent memory systems (Tulving & Schacter, 1990; but see Ostergaard, 1999).

The present study is motivated by results of previous investigations which demonstrated reliable priming effects in number series completion (Delazer & Benke, 1999; Delazer & Girelli, 2000; Delazer, Girelli, & Benke, 1999). In these studies, a priming paradigm was adopted which required subjects to complete number series—*primes* -; the corresponding *targets* consisted of different numbers, but shared with the prime the same underlying algorithm (e.g., prime: 1 4 7, target: 2 5 8). Thus, primes and targets had different perceptual features, required different arithmetic computations (prime: 7 + 3, target: 8 + 3), and different verbal answers (prime: *ten*, target: *eleven*). This experimental design allowed us to exclude facilitation of verbal output, of arithmetic fact retrieval, and of perceptual processes as sources of potential reaction time saving in answering targets.

Delazer and Benke (1999) reported an amnesic patient who showed priming effects in number series completion comparable to those of healthy individuals. But