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Involvement of shared resources in time judgment and sequence reasoning tasks

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ABSTRACT

Previous research suggests that time perception is supported by the same attentional resources involved in sequence processing. The present experiment was designed to clarify this connection by examining the relation between timing and reasoning tasks that involved either sequencing or non-sequencing judgments. For the timing task, subjects produced a series of 5-s intervals. For the reasoning tasks, subjects judged whether pairs of statements describing common actions either (a) were presented in the correct temporal order (sequencing), or (b) described similar actions or objects (similarity). Subjects performed the timing and reasoning tasks both separately and concurrently in a series of 3-minute trials. Comparisons of single-task and dual-task performance assessed interference patterns between concurrent tasks. Both reasoning tasks interfered with timing by making temporal productions longer and more variable. Timing had differential effects on the two reasoning tasks. Concurrent timing caused sequencing judgments to become slower, less accurate, and less sensitive relative to sequencing-only conditions. In contrast, similarity judgments were either unaffected or affected to a lesser degree by the concurrent timing task. These results support the notion that timing and sequencing are closely related processes that rely on the same set of cognitive resources or mechanisms.

1. Introduction

Recent research on the cognitive psychology of time reflects a growing recognition of the influential role of attentional processes in shaping temporal perception. Investigations of expectancy and perceived duration (Boltz, 1993; Fortin & Massé, 2000; Grondin & Rammsayer, 2003; Macar, 2002), directed attention to temporal events (Enns, Brehaut, & Shore, 1999; Mattes & Ulrich, 1998), and neural networks underlying attentional and temporal processing (Coull & Nobre, 1998; Harrington, Haaland, & Knight, 1998; Macar et al., 2002) all show a close connection between timing and attention. A great deal of research has approached the issue from an attentional resource perspective. Much of this research involves the dual-task paradigm, in which subjects are required to perform simultaneous temporal and nontemporal tasks. This methodology has uncovered what is probably the most robust finding in the timing literature, the *interference effect* (for reviews, see Brown, 1997, 2008, 2010). The interference effect refers to a disruption in timing performance produced by a concurrent nontemporal distractor task. Relative to timing-only single-task conditions, dual-task conditions cause time judgments to become shorter, more variable, and/or more inaccurate. This basic pattern has been observed with a variety of time judgment methods, temporal intervals, and distractor tasks. Moreover, increasing the difficulty level of the distractor tasks generally leads to a progressively greater disruption in timing performance. All these results imply that keeping track of time is a demanding cognitive task that consumes limited attentional resources, and when those resources are diverted away by another task, timing performance suffers (Brown & West, 1990; Hicks, Miller, Gaes, & Bierman, 1977; Zakay, 1989).

A subset of studies on the interference effect has also examined performance on the distractor task. This approach is informed by the idea that resource competition should lead to performance decrements on both concurrent tasks, i.e., a pattern of *bidirectional (mutual) interference* (Brown, 1997). In a review of 33 studies that reported timing and distractor performance under both single-task and dual-task conditions, Brown (2006) found that distractor tasks involving perceptual or lower-level cognitive processing (e.g., visual search, manual tracking, card sorting) interfered with timing, but were themselves unaffected by a concurrent timing task. In contrast, bidirectional interference occurred between timing and distractor tasks associated with higher-level executive cognitive functions, such as working memory, mental arithmetic, and reading tasks. These results were interpreted to mean that timing is an executive task that is reliant on specialized attentional resources dedicated to executive functions (see also Brown, 2008). Subsequent research has shown that a variety of executive tasks tend to produce bidirectional interference with concurrent timing (Brown, 2006; Brown, Collier, & Night, in press; Brown & Merchant, 2007; Ogden, Salominaite, Jones, Fisk, & Montgomery, 2011; Rattat, 2010).

Executive functions are those cognitive processes that serve to monitor, direct, and control thinking and behavior (Phillips, 1997; Royall &

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Mahurin, 1996; Stuss & Alexander, 2000). Some of the major executive functions include planning, reasoning, attentional switching, and memory updating (Banich, 2009; Logan, 1985; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Executive functions are critical for such processes as integrating information from different sources, coordinating multiple tasks, and inhibiting responses to distractions (Baddeley, 1993; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Logie, Cocchini, Dela Sala, & Baddeley, 2004). One basic executive function, sequencing, would appear to be particularly relevant to timing (Brown & Merchant, 2007). Conceptually, sequencing and time estimation are closely related. Sequencing involves ordering a succession of objects, actions, or events in a series. In a similar manner, timing typically involves segmenting an event sequence into smaller units (Liverence & Scholl, 2012; Poynter, 1989; Poynter & Homa, 1983) or perceived changes (Block, 1982; Brown, 1995; Fraisse, 1963; Gibson, 1975). A common example is *chronometric counting* (e.g., "Mississippi-1, Mississippi-2…"), wherein one tries to pace counts to mark the number of seconds in an interval (see Grondin, Ouellet, & Roussel, 2004; Hinton & Rao, 2004). Given that sequencing and timing both involve temporal processing, it is reasonable to assume that a common set of attentional resources support both tasks (Brown & Merchant, 2007).

Several dual-task studies are consistent with this hypothesized link between timing and sequencing. In one study (Fortin & Massé, 1999, exp. 1), subjects performed a memory search task while they simultaneously attempted to produce a 2-s interval. In one condition, they simply judged whether a probe letter matched any of the items in the memory set, whereas in another condition, they judged whether the probe matched and whether its indicated position within the memory set sequence was correct. The results showed that longer temporal productions were associated with the sequence judgment condition. Because longer productions correspond to a shortening of perceived time (see Doob, 1971, pp. 27–29; Fraisse, 1978, pp. 215–217; Zakay, 1993), these results indicate that sequence processing led to the classic interference effect. In a modification of the task, Fortin, Champagne, and Poirier (2007, exp. 1) had subjects produce a 2.7 s interval while they also performed a memory search task in which a sequence of letters appeared on a screen one at a time followed by a probe letter. In a spatial version of the task, subjects judged whether the probe had appeared in a particular location; in a temporal version, they judged whether the probe had appeared in a particular point in the letter sequence. The results showed that increasing the size of the memory set lengthened productions in the temporal task but had no effect in the spatial task. Brown (2006) combined a serial production task in which subjects produced a continuous series of 5-s intervals with a random number generation (RNG) task that required subjects to verbalize a sequence of numbers in a random order. These tasks were performed both separately and concurrently. The data showed that the RNG task caused temporal productions to become longer and more variable, and the timing task caused the number sequence to become less random. This pattern of bidirectional interference implies that the two tasks vie for the same attentional resources. Brown and Merchant (2007) used similar methodology in two experiments involving sequence reasoning and sequence monitoring tasks. In the sequence reasoning task, subjects verified a series of statements describing the ordering of pairs of letters (e.g., *A follows B—AB*); in the sequence monitoring task, subjects had to monitor a familiar event sequence (either an alphabetic sequence of letters or an alphanumeric sequence of letter–number pairs) and detect omissions in the series. Dual-task conditions involving concurrent serial temporal production revealed a strong bidirectional interference effect in each case, with sequencing interfering with timing performance and timing interfering with sequencing performance.

2. Experiment

The purpose of the present research is to build upon and extend these findings. One limitation of the Brown and Merchant (2007) experiments is that all the distractor tasks involved sequencing. It is conceivable that some aspect of the tasks other than sequencing could be responsible for the bidirectional pattern of interference that was observed. For example, the tasks also involved reasoning, comprehension, updating, and possibly other executive components. A better design would be to compare directly sequencing and non-sequencing versions of the same task. This procedure would allow for a more clear-cut evaluation of the relation between sequencing and timing. To this end, subjects in the present experiment performed reasoning tasks requiring them to make comparative judgments concerning pairs of statements describing common actions. In one instance, the judgments involved the proper sequencing of the action statements; in another instance, judgments concerned the similarity of the action statements.

The experimental design allows certain predictions to be specified. First, both reasoning tasks should interfere with concurrent timing performance, which would conform to the interference effect. In the case of temporal productions, this interference effect should be manifested as longer (and/or more variable) temporal production responses. The critical issue is whether timing interferes with reasoning performance. Given that both versions of the distractor task involve reasoning, and reasoning is widely regarded as a basic executive function, then both tasks may invoke executive resources. Because timing is dependent upon executive resources, both reasoning tasks may produce bidirectional interference. However, the close connection between timing and sequencing suggests that the sequencing task may place stronger demands on executive resources relative to the similarity task. Therefore, it is reasonable to expect that the timing-plus-sequencing condition would produce a greater degree of bidirectional interference compared with the timing-plus-similarity condition. That is, dual-task conditions should lead to a stronger performance decrement on the timing task, the sequencing task, or both tasks. Such findings would strengthen the proposed relationship between timing and sequencing.

3. Methods

3.1. Subjects

Forty-five students (15 males, 30 females) enrolled in General Psychology classes participated in the experiment in return for extra course credit. The average age of the students was 24.9 years.

3.2. Apparatus and stimuli

A desktop PC equipped with a 5-button Serial Response Box (Model 200A; Psychology Software Tools, Inc.) was used to present stimuli and record responses. Programming for the experiment utilized MEL Professional V2.01 software (Psychology Software Tools, Inc.).

The stimuli consisted of 248 pairs of statements describing familiar actions. Each statement was 1 to 4 words in length. The statement pairs were configured to be used for either similarity judgments or sequencing judgments. Half of the similarity pairs described related objects, actions, or things (e.g., *throw a basketball—toss stone into pool*; *brush teeth—go to dentist*), and half described unrelated actions (e.g., *fly a kite—make popcorn*; *write a poem—paint house*). The related and unrelated statement pairs were presented in a random order. The sequencing judgments involved scripts, stereotyped sequences of actions that occur in familiar situations (Abelson, 1981; Schank & Abelson, 1977). In this instance, the statement pairs formed 2-item scripts that were either in the correct or incorrect temporal order (for similar methodology, see also Allain, Le Gall, Etcharry-Bouyx, Aubin, & Emile, 1999; Crozier et al., 1999). Examples of items in the correct order included *break your arm—go to doctor*, and *put on socks—put on shoes*; items in the incorrect order included *receive a medal—perform heroic act*, and *take a drink—unscrew the cap*. The correct and incorrect scripts were presented in a random order.