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Time perception and temporal order memory

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ABSTRACT

The purpose of this research was to investigate the relation between the attentional resources underlying time perception and temporal order memory. Subjects made judgments about temporal attributes associated with a series of wordlists. Each word was displayed for 1.4 s, and the lists contained 10 words (14 s total), 15 words (21 s total), or 20 words (28 s total). Subjects judged either the list duration, the temporal order of the words, or both duration and temporal order. In addition, there were three mental workload conditions: control (no additional task requirements), and two mental arithmetic tasks (subtract 3 or subtract 7 from a series of random numbers). The results showed a pattern of bidirectional interference between timing and temporal order: the concurrent temporal order task interfered with duration judgments, and the concurrent timing task interfered with temporal order judgments. Bidirectional interference also occurred between the mental workload task and both duration judgments and temporal order judgments. The results indicate that duration and temporal order are closely related temporal attributes, and suggest that the processing of these attributes relies on a common set of executive attentional resources.

"Temporal judgments require an ordered memory representation of the event sequence under concern and this requires at least a partial retrieval of the order of the constituent events" (Michon & Jackson, 1984, p. 303).

1. Introduction

This research concerns the nature of temporal information. Our interest centers on the relationship between perceived duration and temporal order memory (also known as serial order memory). Are judgments of duration and judgments of temporal order essentially equivalent in some sense, or are they different? Conceptually, it seems appropriate to place various temporal attributes together into the same general category. Attributes such as *duration* (the temporal extent of an interval), *order* (the sequencing of a series of events), *successiveness and simultaneity* (the temporal relation between two or more events), and *change* (as indicated by a shifting or transformation of stimulus events) all involve temporal information processing. An especially close connection would seem to exist between duration and order or sequence processing (Brown & Merchant, 2007). Monitoring the duration of events typically involves segmenting an interval into an ordered series of smaller units, as in generating counts or rhythmic sequences (Grondin, Meilleur-Wells, & Lachance, 1999; Grondin, Ouellet, & Roussel, 2004; Guay & Wilberg, 1983; Poynter, 1989; Poynter & Homa, 1983). Similarly, ordering a sequence may involve establishing explicit temporal relations between the component events, an operation that relies fundamentally on timing processes. Many theoretical accounts of serial order memory emphasize the role of timing processes, postulating that item order is represented by placing the items along a temporal dimension (e.g., Brown, Morin, & Lewandowsky, 2006; Brown, Preece, & Hulme, 2000; Farrell & McLaughlin, 2007; Lewandowsky, Brown, Wright, & Nimmo, 2006; Lewandowsky, Nimmo, & Brown, 2008). It follows that the perception of these temporal attributes would share common cognitive mechanisms or processes.

We approach this topic by focusing on the role of attentional resources in temporal processing. If duration and order are closely related attributes, then one may expect that manipulations of attentional processing would produce comparable effects both in duration judgments and in temporal order judgments. One basic issue is whether a pattern of bidirectional (i.e., mutual) interference occurs when duration and ordering tasks are performed together, which would imply that both tasks rely on the same set of attentional resources. In the sections that follow, we review the research bearing on these issues.

1.1. Relation between duration and order processing

Research on the relation between duration and order is limited. Although there exists a well-established literature on duration judgments and a substantial body of work on temporal order judgments, research in these different areas has tended to develop independently. However, a small number of studies employing diverse methodologies have

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examined the relationship between these temporal attributes, and this research points to a close connection between duration and order.

In one experiment (Elvevag, Brown, McCormack, Vousden, & Goldberg, 2004), schizophrenic patients and control subjects performed a line length judgment task, a timing task in which they judged the duration of a series of 333 to 2333 ms tones, and a temporal order task in which they judged the position of a probe letter within a 7-letter sequence. The results showed that both groups were equally accurate at judging line lengths, but the patients were less accurate than the controls in their judgments of duration and temporal order. Elvevag et al. (2004) argued that duration and order tasks rely on temporal processing resources, and that the poor performance of the patients on these tasks supports a *temporal deficit hypothesis* of schizophrenia. Farrell (2008, exp.1) examined the relation between memory for order and rhythm timing. Lists of 6 digits were presented with irregular intervals separating the digits. Some trials included grouping instructions in which subjects were asked to perceive the 6 digits as being composed of two groups of 3 digits each. Following list presentation, a cue prompted subjects to either recall the digits in order or tap on a button to reproduce the rhythm of the digit sequence. The results showed that grouped lists lead to more accurate serial recall and more accurate rhythm reproduction, leading Farrell (2008) to conclude that there was a "common basis for timing and order information in short-term memory" (p. 136).

Brown, Vousden, and McCormack (2009) devised a series of experiments to examine the relation between (a) recalling the serial order of items as a function of their temporal distance from the time of recall, and (b) judging the same temporal distance intervals in a duration discrimination task. Overall, serial position curves on the memory tasks paralleled serial position curves on the duration discrimination tasks. For example, in one study (exp. 1) 7 letters were presented sequentially followed by a probe letter; the task was to judge the serial position of the probe. The results showed a strong recency effect (memory of the last 4 items) and a smaller primacy effect (memory of the first 3 items). This pattern was duplicated in a timing task (exp. 2), in which subjects judged the durations of 7 tones (ranging from 333 to 2333 ms) that represented the temporal distances of the items in the previous experiment. Timing performance was most accurate for the shorter intervals (corresponding recency in exp. 1) and next most accurate for the longer intervals (corresponding to primacy). These results support the idea that timing is an important component of memory for serial order.

1.2. Effects of mental workload on duration and order processing

Mental workload refers to the amount of mental effort or attentional resources needed to perform a task (O'Donnell & Eggemeier, 1986). In the duration judgment literature, mental workload has been used to demonstrate what is known as the *interference effect*. The interference effect refers to a disruption in timing that occurs when subjects are asked to keep track of time and perform a concurrent distractor task during the interval (for summaries of this work, see Block, Hancock, & Zakay, 2010; Brown, 1997, 2008, 2010). Compared with control conditions without any concurrent task, dual-task conditions typically lead to greater error in duration judgments. This error in timing may be in the form of underestimation error, absolute error, or increased variability in duration judgment responses. Many theorists (e.g., Brown & West, 1990; Hicks, Miller, Gaes, & Bierman, 1977; Zakay, 1989) attribute the interference effect to a diversion of attentional resources away from temporal processing. This view is supported by studies employing various techniques designed to manipulate attentiveness to the passage of time. In general, the less attention directed to time, the greater the error in duration judgments (Brown, 2008). All this research establishes time perception as an attentional task that is very sensitive to resource allocation.

There is also evidence for a similar interference effect occurring with temporal order judgments. This work bears on a debate as to whether temporal order information is automatically encoded or whether it requires intentional, controlled processing. Initially, theorists had proposed that the order information contained in a sequence of items was extracted automatically when that sequence was processed (Hasher & Zacks, 1979). This encoding was thought to be automatic and unintentional, using few (if any) attentional resources. However, a number of subsequent empirical studies have contradicted this notion (Auday, Kelminson, & Cross, 1991; Jackson, 1985; Jackson & Michon, 1984; Marshall, Chen, & Jeter, 1989; Michon & Jackson, 1984; Tzeng, Lee, & Wetzel, 1979; Zacks, Hasher, Alba, Sanft, & Rose, 1984). This research shows that encoding temporal order information is a deliberative, capacity-consuming process. For example, there is an effect of intention. Temporal order judgments are more accurate when subjects are instructed to pay attention to the ordering of the event sequence (e.g., Naveh-Benjamin, 1990a, 1990b). In one experiment (Correa, Sanabria, Spence, Tudela, & Lupianez, 2006), subjects judged the temporal order of two lights whose onsets were separated by 10 to 110 ms. A cue indicating whether the lights would appear sooner (400 ms) or later (1400 ms) in the following interval directed subject's attention to different parts of the interval. The results showed that valid cues lead to more accurate judgments and smaller JNDs (Just Noticeable Differences) relative to invalid cues. These effects are analogous to comparisons of prospective (intentional) versus retrospective (incidental) duration judgments, which show that prospective judgments are generally longer and more accurate than retrospective judgments (Block & Zakay, 1997).

A critical finding is that concurrent distractor tasks such as shadowing (Healy, 1975, 1977), articulatory suppression (Alloway, Kerr, & Langheinrich, 2010; Crowder, 1978; Jones, Farrand, Stuart, & Morris, 1995), and manual tapping (Alloway et al., 2010) act to disrupt temporal order memory. Naveh-Benjamin (1990a, exp. 2) had subjects attend to the temporal order of words in a list and perform a concurrent arithmetic task. The results showed that the more demanding the arithmetic task, the greater the impairment in temporal order judgments. Attentional allocation is an explicit element in some contemporary theories of temporal order memory. The computational model known as SIMPLE conceives of memory items represented in a multidimensional space, with one dimension representing time (Brown, Neath, & Chater, 2007; Lewandowsky et al., 2006). SIMPLE includes a parameter representing the "attentional weight" given to the temporal dimension. As more attention is devoted to time, there is a corresponding reduction in the amount of attention devoted to other dimensions, and vice versa. Thus, workload studies of both perceived duration and temporal order memory produce similar results. Both types of tasks are resource-dependent, are sensitive to resource allocation, and are susceptible to interference from concurrent distractor tasks.

1.3. Bidirectional interference in duration and order processing

The interfering effect of concurrent distractor tasks is an important issue in the time perception literature. Resource theory (Navon & Gopher, 1979, 1980; Wickens, 1984) posits that if two tasks rely upon the same pool of attentional resources, then the simultaneous performance of both tasks should suffer (producing a pattern of bidirectional interference) due to resource competition. In contrast, if the two tasks rely on different resource pools, or if the resource overlap between them is only partial, then interference is expected to be either nonexistent or unidirectional, with one task showing interference but the other task being unaffected (e.g., Navon & Gopher, 1980; Tsang, Shaner, & Vidulich, 1995; Wickens, 1980). Therefore, interference patterns between concurrent timing and distractor tasks may reveal the nature of the attentional resources that support duration processing (Brown, 2008). Distractor tasks involving executive cognitive functions tend to produce bidirectional interference patterns with timing, whereas non-executive distractor tasks produce unidirectional interference (that is, they interfere with timing, but timing does not interfere with them); see Brown (2006) for a review. Executive functions are cognitive