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Judging the contact-times of multiple objects: Evidence for asymmetric interference

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ABSTRACT

The accuracy of time-to-contact (TTC) judgments for single approaching objects is well researched, however, close to nothing is known about our ability to make simultaneous TTC judgments for two or more objects. Such complex judgments are required in many everyday situations, for instance when crossing a multi-lane street or when engaged in multi-player ball games. We used a prediction-motion paradigm in which participants simultaneously estimated the absolute TTC of two objects, and compared the performance to a standard single-object condition. Results showed that the order of arrival of the two objects determined the accuracy of the TTC estimates: Estimation of the first-arriving object was unaffected by the added complexity compared to the one-object condition, whereas the TTC of the second-arriving object was systematically overestimated. This result has broad implications for complex everyday situations. We suggest that it is akin to effects observed in experiments on the psychological refractory period (PRP) and that the proactive interference of the first-arriving object indicates a bottleneck or capacity sharing at the central stage.

1. Introduction

Since David Lee's (e.g., 1976) seminal work, time-to-contact (TTC, that is the time remaining before an object reaches the observer or a specific point of interception) has been taken to be directly available to observers. The optical variable specifying TTC has been shown to be critical in numerous everyday tasks, such as interceptive actions (e.g., DeLucia, 2004; Peper, Bootsma, Mestre, & Bakker, 1994; Tresilian, 2005; Tresilian & Houseman, 2005; Tyldesley & Whiting, 1975). The accuracy of TTC perception has been assessed at length for single approaching objects (for a summary see Hecht & Savelsbergh, 2004). However, close to nothing is known about observers' ability to make simultaneous TTC judgments for two or more objects. Such judgments are required in many everyday situations, such as when crossing a multi-lane street or in multi-player ball games. A current theory that assumes the direct availability of TTC information would not predict any problems induced by a second or third approaching object. To investigate potential effects of added objects, the present study put observers in a position to judge the TTC of two simultaneously moving objects. We first describe the prediction-motion paradigm we used and then introduce the issue of multiple-object judgment before reporting our study.

The prediction-motion (PM) paradigm has been employed as a rather direct method to assess observers' absolute TTC judgments (e.g., Schiff & Detwiler, 1979). A moving object is occluded by a visible or invisible occluder some time (here referred to as *extrapolation time*) before it reaches the observer or a specified target. The observer is required to make a simple response (e.g., press a button) at the time the object would have reached the target, had it continued its trajectory. The main aim of a PM task is to determine which visual information is used by participants to judge or predict TTC, through careful manipulation of variables related to the object's motion (e.g., velocity, extrapolation distance and/or duration). It is generally found that participants are able to perform the task but that they underestimate TTC for longer extrapolation times and overestimate it for shorter extrapolations. The transition point between under- and overestimations is approximately at 1 s of extrapolation (e.g., Manser & Hancock, 1996; Schiff & Detwiler, 1979; Oberfeld & Hecht, 2008).

Most PM studies have used single objects as stimuli. To our knowledge, simultaneous TTC judgments on *multiple* objects have not been reported. One PM study that came close is that of Novak (1998). She presented multiple approaching objects but observers were only asked to judge one object. First, they saw one to eight objects approaching a finish line. Then, the target object was indicated by a visual cue after all objects had disappeared from the screen but before they would have reached the finish line. The observers may have made several TTC estimates and then dropped all but the relevant estimate. However, as they eventually produced only one single PM estimate (for the target object) they may also have used a different strategy.

Other studies that presented multiple objects always used a relative-judgment paradigm. In such tasks, observers had to indicate

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which of two or more objects would arrive first at a designated goal (e.g., DeLucia & Novak, 1997; Todd, 1981). Here again, observers may have computed and compared multiple TTC estimates, but they were only asked for one decision. The fundamental difference between such a relative-judgment task and a multiple-object PM task is that in the former, participants might misestimate the TTC of both objects in absolute terms (e.g., estimate a TTC of 0.5 s as being of 1 s) but could still give the correct answer, as long as the perceived order of arrivals was preserved. In contrast, in a multiple-object PM task, the *absolute* accuracy of TTC judgments is assessed. We expected observers to have a hard time to simultaneously produce two absolute TTC estimates if cognitive processing is involved. Indeed, it is assumed that a particular resource can only or mainly be used by one task at a time (Borst, Taatgen, & van Rijn, 2010). Thus, no interference occurs in dual tasks as long as the tasks require different resource (e.g., walking and talking). However, as soon as a particular resource is shared (e.g., writing and talking), that resource will behave as a bottleneck and delay the execution of the combined process (Borst, Taatgen, & van Rijn, 2010). Such dual task interference (cf. Pashler, 1994) is commonplace, but may not generalize to performance in more basic TTC tasks that could be based on a simple optical variable.

When estimating the TTC of two objects moving toward an interception point in a PM task, and comparing those results to a one-object condition, three outcomes are possible.

(1) *Parallel TTC processing with unlimited resources*: If TTC is judged directly and in parallel as implied by the initial concept (see Lee, 1976), we would observe no differences in TTC estimation as a function of the number of objects to be judged. Both the constant error (CE) corresponding to the difference between the estimated TTC of the object and its actual TTC, and the variable error (VE) reflecting the variability of TTC estimations, should remain unchanged. This would imply that observers are able to access and process the TTC of both objects in a completely parallel fashion without any interference between the two concurrent estimations.

(2) *Proactive interference*: Resource limitations may affect the additional objects but not the first one. This would correspond to an effect that Telford (1931) first highlighted and termed psychological refractory period (PRP). In a typical PRP experiment, two stimuli, each requiring a response, are presented one after another with temporal overlap between the two tasks. The experimenter manipulates the stimulus onset asynchrony (SOA), that is, the temporal delay between the presentations of these two stimuli. The usual finding is that for short SOAs (e.g., <100 ms), the response time to stimulus 2 (RT2) is delayed by several hundreds of milliseconds relative to a situation where the second task is presented alone. In contrast, the response time to stimulus 1 (RT1) remains broadly unaffected. However, the delay in RT2 is removed when the SOA is increased to several hundred milliseconds. One hypothesis that has received good empirical support (e.g., Maquestiaux, Laguë-Beauvais, Ruthruff, & Bherer, 2008; Lien, Ruthruff, & Johnston, 2006; Pashler, 1994) is the central bottleneck model (but see Navon & Miller, 2002, and Tombu & Jolicoeur, 2003). This model states that tasks are divided in three distinct processing stages: pre-central stage (e.g., stimulus identification), central stage (e.g., response selection), and post-central stage (e.g., response execution). While the pre-central and post-central stages are assumed to be conducted in parallel with any stage of the other task, this is not the case for the central stage that proceeds on only one task at a time. Hence, the central stage of the second task cannot start before the full completion of the central stage of the first task, thus delaying the response to the second stimulus (see Fig. 1). This model would thus assume a delayed answer for the second object, while the TTC estimation for the first object would remain unchanged.

(3) *Mutual interference*: The introduction of other objects may lead to a modification of the TTC estimation for *both* objects. According to a central capacity sharing model (e.g., Tombu & Jolicoeur, 2003, 2005), the central stage of information processing is capacity limited. Both TTC estimates could be performed in parallel, but the resources have to be split among the two tasks. Hence, the duration of the central stage would be increased for both tasks (Fig. 2). In our example, this increased processing time would lead to an increase in the TTC estimation for both approaching objects.

To summarize, on the basis of the existing literature on dual tasks, three distinct patterns of results can be predicted for the concurrent estimation of two TTCs. We designed an experiment to decide between these hypotheses. In a prediction-motion task, participants judged the TTCs of two objects approaching a target line with different

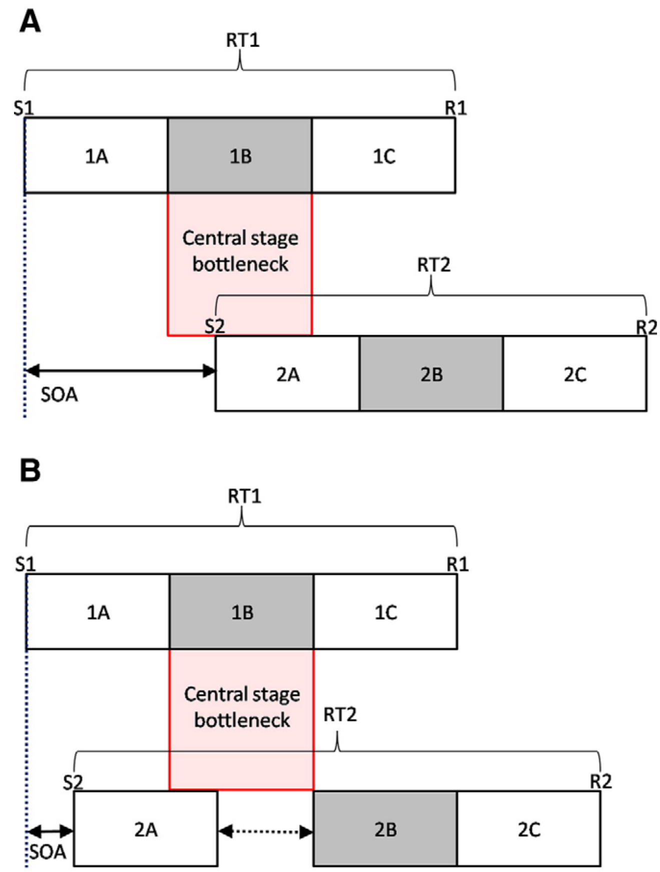

Fig. 1. PRP paradigm. Each task is divided into three distinct processing stages, pre-central stage (A), central stage (B) and post-central stage (C). Stages A and C are assumed to be realized in parallel with any other stage of the other task, while the 2B cannot start before the full completion of 1B. Hence, for long SOA (A panel), stage 1B is ended before stage 2B may begin. As a consequence, 2B can start immediately after the end of 2A, and RT2 is unaffected by the first task. However, for short SOA (B panel), stages 1B and 2B would overlap, what lead 2B to be delayed until the completion of 1B. RT2 is thus increased by this waiting period called bottleneck delay.

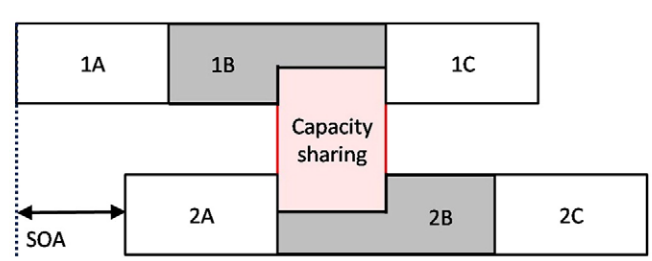

Fig. 2. Whereas the A and C stages are capacity free, the B stage is capacity limited for its part. Hence, for short SOA, an overlap of the B stages of the two tasks would require people to share processing capacity among tasks, and there would be thus less capacity for each individual task. As a consequence, performance in both tasks would be impaired.