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# Introspective reports of reaction times in dual-tasks reflect experienced difficulty rather than timing of cognitive processes

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ABSTRACT

Reports of introspective reaction times (iRTs) have been used to investigate conscious awareness during dual-task situations. Previous studies showed that dual-task costs in RTs (the psychological refractory period, PRP, effect) are not reflected in participants' introspective reports. This finding has been attributed to conscious awareness of Task 2 being delayed while Task 1 is centrally processed. Here, we test this *Temporal* model and compare it to an alternative that assumes participants base their iRTs on experienced difficulty. We collected iRTs and difficulty estimates after each trial of a PRP paradigm in which the perceptual difficulty of either Task 2 (Experiment 1) or Task 1 (Experiment 2) was manipulated. Our results largely support the difficulty-based account, suggesting that in a dual-task situation, iRTs do not reflect timing of cognitive processes but are strongly influenced by the experience of difficulty.



## 1. Introduction

The ability to introspect accurately about the time it takes to complete a task is important for successfully monitoring and controlling one's behavior in demanding situations (i.e. behaving metacognitively; Zimmerman, 2001). Furthermore, research into the accuracy of introspection has the potential to provide insights into current debates in consciousness (Smithies & Stoljar, 2012), for example regarding the link between attention and consciousness. While some theorists consider attention as a prerequisite for conscious awareness (Dehaene & Changeux, 2011; Dehaene, Kerszberg, & Changeux, 1998; Shallice & Burgess, 1996), others regard it merely as a confound (Kentridge, Nijboer, & Heywood, 2008).

Dual-task paradigms are especially useful for investigating the role of attention in conscious awareness because the temporal demands on attention vary. Two previous studies (Corallo, Sackur, Dehaene, & Sigman, 2008; Marti, Sackur, Sigman, & Dehaene, 2010) exploited this advantage by using an introspective version of a well-known dual-task paradigm – the psychological refractory period (PRP) paradigm. In the PRP paradigm, two stimuli (S1 and S2) are presented with a variable interval (stimulus onset asynchrony, SOA) and participants must respond to each task as quickly as possible. Responses to the second task are typically slower when the two stimuli are presented at short as compared to long SOAs, an effect called the PRP effect. It is proposed that each task is composed of (at least) three processing stages – a perceptual, a central and a motor stage. The PRP effect is said to be explained by a central processing bottleneck, in which only one task can be centrally processed at a time (McCann & Johnston, 1992; Pashler, 1994; Welford, 1952). Importantly, the perceptual and motor stages of one task can proceed in parallel with any stage of the other task, while the two central stages must be processed serially.

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Thus, at short SOAs the central and motor stages of Task 2 are delayed until the end of the Task 1 central stage (see Fig. 1). This processing delay for Task 2 is called the slack time.

Corallo et al. (2008) and later Marti et al. (2010) combined this classic PRP paradigm with a methodology named quantified introspection, in which participants gave estimates of their own reaction times for each task after every trial of a PRP experiment. They indicated their reaction time estimates (named introspective RTs, or iRTs) on a visual analogue scale (VAS). In these studies, it was found that participants failed to report the PRP effect in their reaction times. That is, while there was an objective PRP effect on RT2, participant's reports of their RT2 (iRT2s) were unaffected by SOA. Thus, participants appeared to be unaware of the dual-task cost on response speed for the second task. Marti et al. (2010) explained these findings by invoking "a single hypothesis: in a dual-task setting, introspection is tied up by the first task and cannot focus on the second target until decision on the first target is resolved" (p. 311). Thus, they support the idea that conscious awareness requires not only perceptual processes but also central (attentional) processes (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Del Cul, Baillet, & Dehaene, 2007; Sergent, Baillet, & Dehaene, 2005). Specifically, they posit that participants cannot be consciously aware of the second stimulus while they are centrally processing Task 1. Therefore, conscious awareness of the second stimulus is delayed at short SOAs, as it is linked to the end of the Task 1 central stage (see dotted lines in Fig. 1). This interpretation of the apparent unawareness of the PRP effect is based on the assumption that iRTs reflect accurate estimates of the time between conscious awareness of the stimulus and the related response. Therefore, we refer to this model as the *Temporal* model.

In order to test this Temporal model, Marti et al. (2010) asked their participants for estimates of RT1, RT2, SOA, and the slack or free time (i.e. the time between their decision on Task 1 and S2 onset) at the end of each trial. In addition to replicating the iRT results of Corallo et al. (2008), they found that the SOA was overestimated by about 250 ms when the two stimuli were presented simultaneously (i.e. at a SOA of 0 ms). This, as well as the finding that SOA estimates were non-linear across objective SOAs, is consistent with the assumption that the conscious awareness of the second stimulus is delayed at short SOAs while Task 1 is centrally processed. However, Corallo et al. (2008) found a similar overestimation of SOAs when participants only estimated the SOA without responding to the stimuli. Thus, overestimation of short SOAs may reflect a central tendency in time estimates (i.e. Vierordt's law; Bausenhart, Dyjas, & Ulrich, 2014; Lejeune & Wearden, 2009) rather than a delay of conscious awareness of S2. Marti et al. (2010) also found that while the objective slack/free time becomes negative at short SOAs (as S2 is presented before the end of Task 1 central stage), participants' estimates remained close to zero, supporting the idea that participants are not aware of S2 onset until the end of the Task 1 central stage. However, these slack/free time estimates may also be influenced by central tendency. While this result is especially difficult to interpret because there is no objective measure of the end of Task 1 central stage, the authors found that at short SOAs the slack/free time estimates did not significantly correlate with a measure that was intended to reflect objective slack/free time (the difference between RT1 and SOA). In summary, although Marti et al. (2010) provide some compelling evidence in support of the Temporal model, their data are not unequivocal and some key predictions of the model are missing. The most consistent data in support of Marti et al.'s (2010) idea that conscious awareness of S2 is delayed while Task 1 is centrally processed is the lack of a SOA effect on iRT2 in both Corallo et al. (2008) and Marti et al. (2010).

However, other explanations can also account for this null effect of SOA on iRT2 – for instance, participants might not base their iRTs on temporal information, but rather on the difficulty they experience in each task. In the PRP task, according to the central bottleneck model, RT2s are longer at short than long SOAs because central processing of the second task must wait for the central stage of Task 1 to be completed, and not because the task is more difficult. Indeed, Task 2 always remains

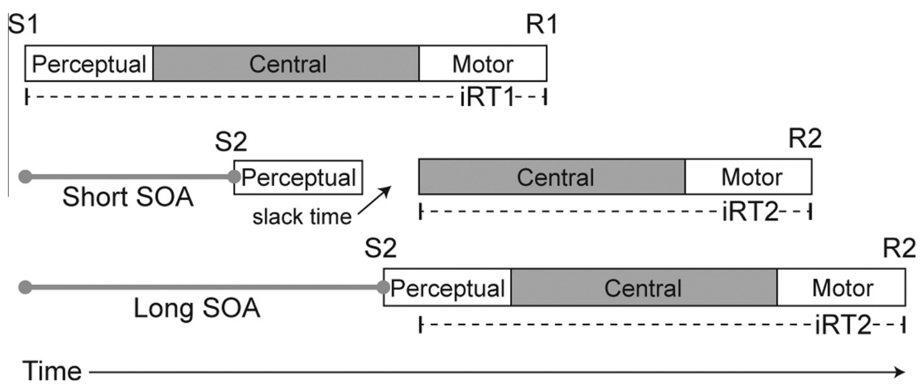


**Fig. 1.** Illustration of how introspective reaction times (iRTs, represented by the dotted lines) are produced according to the Temporal model, an example of both a short and a long SOA. iRT1 is composed of the Task 1 perceptual, central and motor stages. Participants are not consciously aware of the second stimulus while they are centrally processing Task 1. Therefore, the length of SOA determines which Task 2 stages are included in iRT2. At short SOAs, when Task 2 perceptual stage is completed before the end of Task 1 central stage, iRT2 contains only Task 2 central and motor stages. When SOA is such that there is some overlap between Task 2 perceptual stage and Task 1 central stage ('Long SOA' in this figure), iRT2 is composed of part of Task 2 perceptual stage, and all of Task 2 central and motor stages. At very long SOAs, when Task 1 central stage is completed before the second stimulus is presented, iRT2 is composed of Task 2 perceptual, central and motor stages.