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Are spatial responses to visuospatial stimuli and spoken responses to auditory letters ideomotor-compatible tasks? Examination of set-size effects on dual-task interference

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ABSTRACT

Previous studies have paired a visual–manual Task 1 with an auditory–vocal Task 2 to evaluate whether the psychological refractory period (PRP) effect is eliminated with two ideomotor-compatible tasks (for which stimuli resemble the response feedback). The present study varied the number of stimulus-response alternatives for Task 1 in three experiments to determine whether set-size and PRP effects were absent, as would be expected if the tasks bypass limited-capacity response-selection processes. In Experiments 1 and 2, the visual–manual task was used as Task 1, with lever-movement and keypress responses, respectively. In Experiment 3, the auditory–vocal task was used as Task 1 and the visual–manual task as Task 2. A significant lengthening of reaction time for 4 vs. 2 alternatives was found for the visual–manual Task 1 and the Task 2 PRP effect in Experiments 1 and 2, suggesting that the visual–manual task is not ideomotor compatible. Neither effect of set size was significant for the auditory–vocal Task 1 in Experiment 3, but there was still a Task 2 PRP effect. Our results imply that neither version of the visual–manual task is ideomotor compatible; other considerations suggest that the auditory–vocal task may also still require response selection.

1. Introduction

In a typical experiment studying the psychological refractory period (PRP) effect, subjects are to identify two stimuli (S1 and S2) presented in temporal proximity, making a separate response (R1 and R2) to each. The stimuli and responses for the tasks (T1 and T2) are often presented in different sensory modalities, to minimize physical interference. When S1 and S2 are presented in close succession, reaction time (RT) to S2 (RT2) increases as the time between S1 and S2 onsets (stimulus onset asynchrony, or SOA) decreases (for reviews, see Lien & Proctor, 2002; Pashler, 1994). The PRP effect is measured by subtracting RT2 at long SOAs from RT2 at short SOAs.

The PRP effect is a robust phenomenon that has been found for many tasks (simple RT: Frith & Done, 1986; Pashler & Johnson, 1989; go/no-go RT: Bertelson & Tisseyre, 1969; Smith, 1967; choice RT: Fagot & Pashler, 1992; McCann & Johnston, 1992). Several explanations of the PRP effect have been proposed, with most attributing it to limited capacity of a central-processing stage involved in response selection. According to central bottleneck models, response selection cannot occur concurrently for T1 and T2 (e.g., Pashler, 1994; Welford, 1952; see Fig. 1). Thus, if selection of R1 begins first, selection of R2 cannot start until R1 is selected. According to central capacity-sharing models, response selection can be performed concurrently for T1 and T2, but the limited processing capacity must be divided between the tasks (Navon & Miller, 2002; Tombu & Jolicœur, 2005). At short SOAs, selection of R2 is usually given lower priority than selection of R1, resulting in lengthening of RT2. The capacity-sharing model becomes the bottleneck model if the capacity is allocated entirely to T1 and then to T2. Despite the different views of response selection, both the central bottleneck model and the capacity-sharing model predict that RT2 is prolonged when T1 and T2 demand central resources at nearly the same time (i.e., short SOAs).

Several studies have attempted to find conditions in which central response-selection resources can be bypassed and the PRP effect eliminated (see Lien, Ruthruff, & Johnston, 2006). The idea behind these attempts is that if the capacity limitation for processing the two tasks is at the response-selection stage, then it should be possible to achieve perfect timesharing of the tasks by minimizing or eliminating response-selection demands. Many recent studies have attempted to bypass the capacity limitations by automatizing response selection through extended practice (e.g., Hazeltine, Teague, & Ivry, 2002; Van Selst, Ruthruff, & Johnston, 1999). The PRP effect is typically reduced with extended practice

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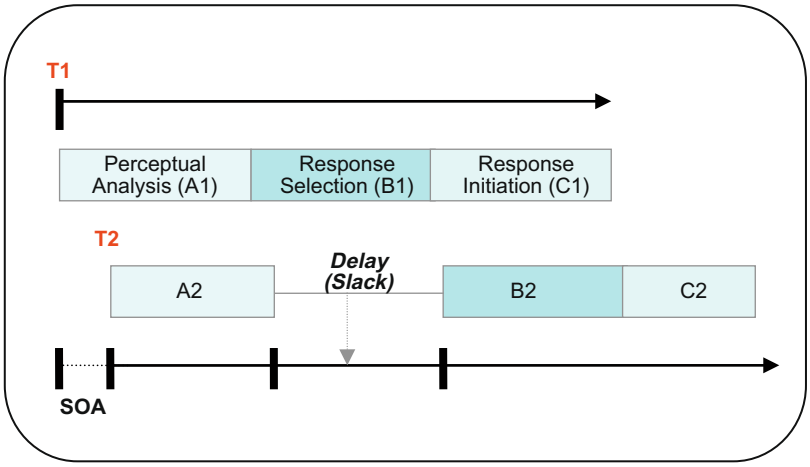

Fig. 1. Pashler's response-selection bottleneck model for dual task performance. T1 is Task 1, T2 is Task 2, and SOA is stimulus onset asynchrony.

and, for a few subjects, eliminated under certain conditions. There has been disagreement, though, as to whether even in cases for which there is little or no PRP effect the limited-capacity mechanism has been eliminated (e.g., Schumacher et al., 2001) or is just latent due to short RT1 (e.g., Ruthruff, Johnston, & Van Selst, 2001).

Another method used to try to eliminate the PRP effect, in this case with little practice, is to use tasks of extremely high compatibility between stimulus and response for T1 and T2 (e.g., Brebner, 1977; Greenwald, 2003; Greenwald & Shulman, 1973). Greenwald (1972) referred to such tasks as ideomotor (IM) compatible and distinguished them from other high compatibility tasks, basing this distinction on ideomotor theory. According to Greenwald (1972, p. 52),

> Ideomotor theory proposes that responses are centrally coded by representations of their sensory feedback. Accordingly, it ought to be possible to select a response very directly, perhaps totally bypassing any limited-capacity process, by presenting a stimulus that closely resembles the response's sensory feedback. This should occur, for example, when a word is said in response to hearing it said. The dimension denoting the extent to which a stimulus corresponds to sensory feedback from its required response will be referred to as "ideomotor compatibility".

Greenwald and Shulman (1973) tested four groups of participants with different combinations of IM-compatible and non-IM-compatible visual–manual tasks for T1and auditory–vocal tasks for T2 to test the hypothesis that IM-compatible tasks bypass the limited-capacity response-selection process. T1 required a left-right joystick movement corresponding to location information provided by a stimulus, which was a left or right pointing arrow (presented in a corresponding left or right position) in the IM-compatible version and the word "left" or "right" in the non-IM-compatible version. For T2, the stimulus was the auditory letter *A* or *B*, and the response was vocalization of "a" or "b" in the IM-compatible version and "1" or "2" in the non- IM-compatible version. In their Experiment 2, for which the S1-S2 SOA was 0, 100, 200, or 1,000 ms, the PRP effect was largest when neither T1 nor T2 was IM-compatible, reduced when one task was IM-compatible and the other was not, and absent when both tasks were IM-compatible. Based on this latter finding, Greenwald and Shulman concluded that the limited-capacity mechanism that translates between a stimulus and response is indeed bypassed and "is not needed when a task is ideomotor compatible" (p. 70).

However, tasks similar to the IM-compatible tasks used in Greenwald and Shulman (1973) Experiment 2 often show a PRP effect. Of the existing experiments using manual responses to positioned arrows and naming responses to letters, all others show at least some evidence of a PRP effect (see Shin, Cho, Lien, & Proctor, 2007). Greenwald (2003), Greenwald (2004), Greenwald (2005) and Lien and colleagues (Lien, McCann, Ruthruff, & Proctor, 2005; Lien, Proctor, & Allen, 2002; Lien, Proctor, & Ruthruff, 2003) have debated whether IM compatibility allows the limited-capacity response-selection mechanism to be bypassed. Lien et al. have argued that IM-compatible tasks require an act of response selection like any other task, although it occurs quicker and more efficiently (see Hommel, 1998, and Paelecke & Kunde, 2007, for similar views). Greenwald has maintained that IM-compatible tasks allow direct response selection, but only under restricted conditions in which instructions and task structure emphasize speed and simultaneity of responding.

Another possibility, which has yet to be considered in detail, is that at least one of the two tasks in these studies is not truly IM compatible. Recollect that Greenwald and Shulman (1973) found clear PRP effects when only one task was classified as IM compatible, which would not be expected if the IM-compatible task bypasses the response-selection bottleneck. Rather, the intermediate level of PRP effect for those conditions to the effects obtained when neither task is IM-compatible or both are IM-compatible is more consistent with the possibility that all tasks require the limited-capacity response mechanism, with IM-compatible tasks requiring less capacity than tasks that are not IM-compatible.

Greenwald and Shulman (1973) mentioned the possibility that one of their "IM-compatible" tasks might not truly be IM-compatible in a section of their General Discussion, titled *Problems in the Definition of Ideomotor Compatibility*, where they stated:

> In the present research IM compatibility was operationalized as (*a*) repeating (speaking) a heard word, or (*b*) giving a spatial (switch movement) response to a spatial visual cue (positioned arrow). Task *a* clearly conforms to the conceptual definition of IM compatibility but, in the case of Task *b*, it is necessary to assume that spatiality of a visual positional cue "resembles" the spatial component of kinesthetic and visual feedback from movement. The reader probably shares the somewhat uncomfortable feeling of the authors that, had the results not turned out as expected, it might have been more convenient to criticize this resemblance assumption than to criticize the conception of IM-compatibility. (Greenwald & Shulman, 1973, p. 76.)

The possibility that the visual–manual task is not IM compatible may indeed afford an explanation why many studies show a PRP effect when that task is paired with the letter-naming task, which