Acta Psychologica 142 (2013) 332–342

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Working memory capacity and dual-task interference in picture naming

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ARTICLE INFO

Article history:
Received 23 May 2012
Received in revised form 9 January 2013
Accepted 12 January 2013
Available online 16 February 2013

PsycINFO classification:
2340 Cognitive Processes

Keywords:
Dual-task interference
Naming
Picture–word interference
Psychological refractory period
Operation-span task
Working memory

ABSTRACT

Researchers have found no agreement on whether dual-task interference in language performance, such as dual-task interference from tone discrimination on picture naming, reflects passive queuing or active scheduling of processes for each task. According to a passive-queuing account, while a central response-selection bottleneck is occupied by the tone discrimination task, picture naming is held in a passive queue until the bottleneck is freed. In contrast, according to an active-scheduling account, participants determine the order in which the tasks proceed, monitor progress on the tasks, suspend picture naming and hold it in working memory, and determine when to resume picture naming. Here, we report a study that assessed the relative merits of the queuing and scheduling accounts by examining whether the magnitude of dual-task interference in picture naming is associated with individual differences in the capacity of monitoring and updating of working memory representations, as assessed by the operation-span task. We observed that the updating/monitoring ability correlated with the speed of picture naming and with the magnitude of the interference from tone discrimination on picture naming. These results lend support to the active-scheduling account of dual-task interference in picture naming.

1. Introduction

Speakers are typically able to quickly and accurately access words in long-term memory. Lexical access in spoken word production has been extensively studied using the picture–word interference (PWI) paradigm, in which speakers name pictures while trying to ignore spoken or written distractor words. For example, they say "dog" to a pictured dog combined with the written word *cat* (i.e., a word from the same semantic category, here animals; the semantic condition) or the word *tree* (the unrelated condition). Previous research has shown that mean response time (RT) is longer for semantically related picture–word stimuli relative to unrelated stimuli, an effect called *semantic interference* (e.g., Damian & Martin, 1999; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989). The semantic interference effect is only obtained when speakers have to select a word to name the picture, but not when a manual response to the picture is required (Schriefers, Meyer, & Levelt, 1990), which suggests that the effect arises during lexical selection for word production. Given that the semantic effect is one of interference rather than facilitation, lexical selection has been taken to be a competitive process (e.g., Abdel Rahman & Melinger, 2009; Hantsch, Jescheniak, & Schriefers, 2005; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992, 2003; Starreveld & La Heij, 1996). This account of semantic interference has been computationally implemented in a number of models of word production, including the model of Starreveld and La Heij (1996) and WEAVER++ (Levelt et al., 1999; Piai, Roelofs, & Schriefers, 2011; Roelofs, 1992, 2003, 2007, 2008a,b,c).

The assumption of a lexical response-selection locus of the semantic interference effect was recently challenged by two dual-task studies (Ayora et al., 2011; Dell'Acqua, Job, Peressotti, & Pascali, 2007). These studies revealed that the semantic interference effect may be absent when participants perform picture naming in the context of a tone discrimination task requiring a manual response. According to Dell'Acqua et al. and Ayora et al., response selection constitutes a structural processing bottleneck in dual-task performance (cf. Ferreira & Pashler, 2002). Therefore, response selection in the tone discrimination task precludes concurrent response selection in picture naming. While the central response-selection bottleneck is occupied by the tone discrimination task, picture naming is held in a passive queue until the bottleneck is freed, henceforth the *passive queuing account* (cf. Adcock, Constable, Gore, & Goldman-Rakic, 2000; Bunge, Klingberg, Jacobsen, & Gabrieli, 2000; Dux et al., 2009; Jiang, Saxe, & Kanwisher, 2004; Pashler, 1984, 1994, 1998; Pashler & Johnston, 1989). If the semantic interference effect arises before response selection in picture naming (e.g., during perceptual and conceptual processing of the picture), the effect may be absorbed while response selection in the tone discrimination task is taking place and picture naming waits in queue. Consequently, the semantic interference effect will disappear in concurrent task performance, as empirically observed by Dell'Acqua et al. and

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0001-6918/$ – see front matter
http://dx.doi.org/10.1016/j.actpsy.2013.01.006

Ayora et al. In contrast, if the semantic interference effect arises in lexical response selection (e.g., Abdel Rahman & Melinger, 2009; Hantsch et al., 2005; Levelt et al., 1999; Roelofs, 1992, 2003; Starreveld & La Heij, 1996), the effect should not have been absorbed according to the response-selection bottleneck account (Pashler, 1994, 1998; Pashler & Johnston, 1989), contrary to what Dell'Acqua et al. and Ayora et al. observed.

However, although very influential, the assumption of a structural response-selection bottleneck is debatable (e.g., Fan et al., 2012; Hübner & Lehle, 2007; Israel & Cohen, 2011; Kahneman, 1973; Karlin & Kestenbaum, 1968; Lehle & Hübner, 2009; Leonhard & Ulrich, 2011; Meyer & Kieras, 1997a,b; Miller, Ulrich, & Rolke, 2009; Navon & Miller, 2002; Pannebakker et al., 2011; Schumacher et al., 1999, 2001; Schvaneveldt, 1969; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006; Szameitat, Schubert, Müller, & von Cramon, 2002; Tombu & Jolicœur, 2003). According to alternative accounts of dual-task performance, response selection for two tasks may occur in parallel depending on the strategic choice of participants concerning the amount of overlap between tasks (cf. Logan & Gordon, 2001; Meyer & Kieras, 1997a,b; Navon & Miller, 2002; Tombu & Jolicœur, 2003). Under one such strategic account, henceforth the *active scheduling account* (cf. Kondo et al., 2004; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997a,b; Szameitat et al., 2006, 2002), participants determine the order of the tasks, monitor progress on the tasks, suspend picture naming before or after response selection (depending on the amount of overlap allowed between tasks) and hold it in working memory, and determine when to resume picture naming (Piai et al., 2011; Roelofs, 2007, 2008a; Roelofs & Piai, 2011). If response selection in the tone discrimination task temporally overlaps with response selection in picture naming, semantic interference arising during response selection in picture naming may be resolved while response selection in the tone discrimination task is in progress. As a consequence, the semantic interference effect will disappear in concurrent task performance, as empirically observed by Dell'Acqua et al. and Ayora et al.

An important difference between the passive queuing and active scheduling accounts concerns the ability of monitoring and updating of working memory, often referred to as *working memory capacity* (e.g., Conway et al., 2005; Kane & Engle, 2002; Miyake et al., 2000). This ability is central to the active scheduling account (Kondo et al., 2004; Logan & Gordon, 2001; Meyer & Kieras, 1997a,b; Szameitat et al., 2006, 2002) but not to the passive queuing account (Adcock et al., 2000; Bunge et al., 2000; Dux et al., 2009; Jiang et al., 2004; Pashler, 1984, 1994, 1998; Pashler & Johnston, 1989). This implies that individual differences in working memory capacity should affect dual-task performance under the active scheduling account, but not under the passive queuing account. In the present article, we report an experiment that assessed whether dual-task interference from tone discrimination on picture naming depends on individual differences in working memory capacity.

The remainder of the article is organised as follows. First, we describe the findings of Dell'Acqua et al. (2007) and Ayora et al. (2011), and the queuing and scheduling accounts in more detail. Next, we derive predictions concerning the influence of working memory capacity on dual-task performance and report a dual-task experiment, involving tone discrimination and PWI tasks, designed to test these predictions.

1.1. Passive queuing and active scheduling accounts

In their studies of picture naming during dual-task performance, Dell'Acqua et al. (2007) and Ayora et al. (2011) employed the widely used psychological refractory period (PRP) procedure, in which participants have to make two different responses to corresponding stimuli (Tasks 1 and 2), with the common instruction that the Task 1 response should precede the Task 2 response. The stimuli are presented with certain stimulus onset asynchronies (SOAs), which usually range from 0 to 1000 ms. A typical finding is that Task 2 response time (RT2) is longer at short (e.g., 0 ms) than at long SOAs (e.g., 1000 ms), reflecting dual-task interference. In the studies of Dell'Acqua et al. and Ayora et al., participants performed a manual tone discrimination task (Task 1) and a PWI task (Task 2, picture naming while ignoring written distractor words) with varying SOAs. In the experiment of Dell'Acqua et al., the tones preceded the picture–word stimuli by SOAs of 100, 350 or 1000 ms. Dell'Acqua et al. observed that the semantic interference effect was much smaller at the 350-ms SOA than at the 1000-ms SOA and that the effect was absent at the 100-ms SOA. These findings were replicated by Ayora et al. using the SOAs of 100 and 1000 ms. These results suggest that, at the short SOA of 100 ms, the semantic interference from the picture–word stimuli was resolved while performing the tone discrimination task.

Following (Pashler, 1984, 1994, 1998; Ferreira & Pashler, 2002; Pashler & Johnston, 1989), Dell'Acqua et al. and Ayora et al. assumed that dual-task interference arises from a structural response-selection bottleneck. According to this passive queuing account, response selection in the tone discrimination task precludes concurrent response selection in picture naming. Dell'Acqua et al. argued that, if semantic interference in picture naming arises in response selection, then the semantic interference and SOA effects should be additive, that is, the magnitude of the semantic interference effect should not differ between long and short SOAs, contrary to what they empirically observed. Therefore, under the assumption of a response-selection bottleneck, the finding that the semantic interference effect disappears at short SOAs in dual-task performance suggests that the locus of the semantic interference effect is prior to the response selection stage.

Other accounts of PRP performance assume no such structural response-selection bottleneck, but maintain that simultaneous selection of two responses in dual-task performance is possible depending on a strategic choice regarding the amount of parallelism allowed between Task 1 and Task 2 (cf. Kahneman, 1973; Kondo et al., 2004; Logan & Gordon, 2001; Meyer & Kieras, 1997a,b; Navon & Miller, 2002; Tombu & Jolicœur, 2003). The assumption that dual-task performance is not constrained by a structural response-selection bottleneck is supported by several findings (e.g., Fan et al., 2012; Hübner & Lehle, 2007; Israel & Cohen, 2011; Kahneman, 1973; Karlin & Kestenbaum, 1968; Lehle & Hübner, 2009; Leonhard & Ulrich, 2011; Logan & Gordon, 2001; Meyer & Kieras, 1997a,b; Navon & Miller, 2002; Pannebakker et al., 2011; Schvaneveldt, 1969; Szameitat et al., 2006, 2002; Tombu & Jolicœur, 2003). For example, there is evidence that the magnitude of dual-task interference can be eliminated with practice (e.g., Schumacher et al., 1999, 2001, but see Ruthruff, Van Selst, Johnston, & Remington, 2006; Van Selst, Ruthruff, & Johnston, 1999) or by increasing the number of short SOAs in an experimental block of trials (Miller et al., 2009). The malleability of dual-task interference should not be observed under a structural response-selection bottleneck.

Various studies have suggested that an executive control system operates during dual-task performance in order to coordinate or supervise processing (e.g., Fan et al., 2012; Kondo et al., 2004; Leonhard & Ulrich, 2011; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997a,b; Schumacher et al., 1999, 2001; Szameitat et al., 2006, 2002). Such an account "assumes that PRP phenomena result from scheduling and control strategies enacted by a central executive, whereas RSB [response-selection bottleneck] theory says nothing about such strategies and explains PRP phenomena without them" (Logan & Gordon, 2001, p. 395). Under an active scheduling account of concurrent tone discrimination and picture naming, participants strategically postpone particular stages of picture–word processing until particular stages of tone processing have been finished (e.g., Lamers & Roelofs, 2011; Piai et al., 2011; Roelofs, 2007, 2008a; Roelofs & Piai, 2011). To this end, participants set a point during Task 2 performance at which processing is strategically suspended, which is typically before or after response selection in Task 2. Moreover, they set a point during Task 1 performance at which Task 2 processing is resumed, which is