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Exceptions to the PRP Effect? A Comparison of Prepared and Unconditioned Reflexes

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Psychological research has documented again and again marked performance decrements whenever humans perform 2 or more tasks at the same time. In fact, the available evidence seems to suggest that any type of behavior is subject to such limitations. The present experiments employed the psychological refractory period (PRP) paradigm to identify a clear exception to this rule: Unconditioned reflexes do escape dual-task interference, whereas intended simple responses, so called “prepared reflexes,” do not. Beyond this empirical novelty, we discuss the findings in broader terms of human action control. In particular, we suggest that the (non)susceptibility to dual-task interference may provide a clear empirical delineation between goal-directed behavior (i.e., actions) and other, not goal-directed behavior.

Keywords: dual-task, PRP, reflex, prepared reflex, behavior, action

In real life one will hardly if ever find a situation where one is not engaged in more than one task at the same time. And likely everybody has realized all too often that performance suffers the more we try to do concurrently. Consequently, the investigation of such multitasking situations has a longstanding tradition in cognitive psychology. As often two tasks have been combined, the most common term is that of “dual-tasking.” Of particular interest to the field is the question of whether there are exceptions to dual-task interference, i.e., to performance decrements in at least one of the two tasks. Early demonstrations of perfect performance in either task (e.g., Spelke, Hirst, & Neisser, 1976) have been criticized on various grounds (see, e.g., Cowan, 1997). For example, the use of tasks requiring continuous performance does not allow exclusion of a switch-and-buffer strategy (e.g., Pashler & Johnston, 1998). This has led to a shift toward using discrete tasks and to experimentally varying the time-overlap of two tasks.

In the following paragraph we give a brief overview of paradigms for studying dual-task interference plus a summary on the search for exceptions to it. We then continue by considering research on unconditioned reflexes and provide an overview of the present study.

Doing More Than One Thing at Once: Dual-Tasking and the PRP Paradigm

Basically, there are two approaches to studying the costs of performing two tasks at the same time. In the classical dual-task paradigm, performance is measured for each task in separation (single-task) and when both tasks are performed simultaneously (dual-task). Typically, the respective stimuli are presented at the same time, i.e., with a stimulus onset asynchrony (SOA) of zero. Performance differences between single- and dual-task conditions are taken to indicate dual-task costs. In contrast, in the psychological refractory period (PRP) paradigm (Telford, 1931), the two stimuli are presented with a varying amount of time in between them (thus a varying SOA), and this procedure experimentally varies the time-overlap of both tasks. Typical findings in the PRP paradigm are (a) that response times (RTs) to the first stimulus do not depend on the SOA, whereas (b) RTs to the second stimulus sharply increase with a decreasing SOA, i.e., with increases in task-overlap. The latter finding is commonly referred to as the *PRP effect*. These performance decrements in Task 2 are also taken to indicate some sort of dual-task interference. Several models have been proposed to explain these findings, ranging from bottleneck models with structural (Pashler, 1994) or strategic limitations (Meyer & Kieras, 1997) to capacity sharing models (Tomblin & Jolicoeur, 2003). Either way, these models propose that one stage of processing cannot proceed in parallel with the same stage of a concurrent task without suffering from performance decrements. Most often this particular stage is identified as the central stage of response selection. According to bottleneck models, only one such central stage can run at any time (see Figure 1), whereas, according to capacity sharing models, parallel processing is possible though less efficient. According to bottleneck models, at short SOAs central processing of Task 2 is delayed until after Task 1 central processing has finished. Hence, an idle time—called the *cognitive slack*—occurs in Task 2 processing and prolongs RTs. In contrast, at sufficiently long SOAs no such cognitive slack occurs and RTs are accordingly shorter.

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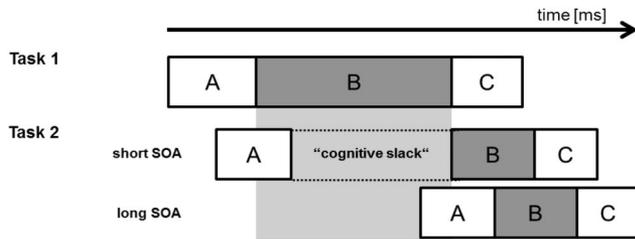


Figure 1. Illustration of the central bottleneck model (e.g., Pashler, 1994). Stages A and C refer to perceptual/precentral and motor/postcentral processing stages, respectively, and can run in parallel with other stages. Central stages B, however, are subject to a bottleneck and that of Task 2 must await the end of the Task 1 central bottleneck stage. At short stimulus onset asynchronies (SOAs), this gives rise to an idle time (the “cognitive slack”), leading to prolonged response times in comparison with long SOAs.

Many different tasks have been used to demonstrate dual-task costs in general and the PRP effect in particular and both approaches yielded robust and highly replicable results. From a theoretical perspective, however, it is clearly interesting to look for situations where dual-task costs and PRP effects do *not* emerge. Such findings may help to determine what the processing constraints and the bottleneck are actually about. For the classical approach, there are studies showing that considerable practice can eliminate dual-task costs and yield performance comparable to a single-task condition (Hazeltine, Teague, & Ivry, 2002; Schumacher et al., 2001; but see Tombu & Jolicoeur, 2004). In contrast, the PRP effect seems to be very pertinacious and unwilling to disappear (for an overview, see Lien, Ruthruff, & Johnston, 2006). Related to the just mentioned results from the classical dual-task approach, several studies have been performed to test whether PRP effects can be overcome eventually following extensive training and some promising cases have been reported (e.g., Van Selst, Ruthruff, & Johnston, 1999). Later studies, however, have revisited these results and demonstrated that the PRP effect was still evident under proper conditions (e.g., Ruthruff, Johnston, Van Selst, Whitsell, & Remington, 2003). Indeed, even the very same participants that showed no dual-task costs in Experiment 1 of Schumacher et al. (2001), did show a pronounced PRP effect in their Experiment 2 (but see Ruthruff, Hazeltine, & Remington, 2006, for opposing findings). Concerns have been expressed that the PRP paradigm creates the observed performance decrements by its methodological peculiarities (e.g., the successive stimulus presentation) instead of reflecting true dual-task interference.

A very influential proposal for exceptions to dual-task costs and the PRP effect was made by Greenwald (1970, 1972), who suggested that ideomotor compatible tasks do not create a PRP effect because they do not entail the critical response selection stage. Ideomotor compatible tasks are those using stimuli that resemble the effects resulting from the required responses, for example responding with a left/right movement to a left/right arrow. Indeed, such ideomotor compatible tasks appeared to be immune to the PRP effect (Greenwald & Shulman, 1973). However, these results were difficult to replicate later on (Lien, Proctor, & Allen, 2002) and led to an intense discussion about their validity about a decade ago (Greenwald, 2003, 2004, 2005; Lien, McCann, Ruthruff, & Proctor, 2005; Lien, Proctor, & Ruthruff, 2003). A recent study

was devoted to this issue again and has shown absent dual-task costs when two ideomotor-compatible tasks were used, and the stimuli were presented simultaneously—a PRP effect was nonetheless reported (Halvorson, Ebner, & Hazeltine, 2013). In sum then, it appears that an absent PRP effect may be obtained only under very specific conditions and that the bottleneck is usually not bypassed.

Finally, some special and putatively encapsulated response systems have been investigated, for example, grasping movements controlled by the dorsal visual pathway. However, they were susceptible to dual-task costs (Singhal, Culham, Chinellato, & Goodale, 2007) and showed a clear PRP effect as well (Janczyk, Franz, & Kunde, 2010; Janczyk & Kunde, 2010; Kunde, Landgraf, Paelecke, & Kiesel, 2007). Of particular interest for the present study are eye-movements. Pashler, Carrier, and Hoffman (1993) investigated saccades toward a (peripheral) target location (Experiments 1 and 2) or to a direction cued by a central, symbolic stimulus (Experiments 3 and 4). In the latter case, signs of a typical PRP effect emerged and were attributed to a neural pathway involving the frontal eye fields. In contrast, for the former kind of saccades, only a small (but still visible) PRP effect was observed. Pashler et al. argued that these eye movements were susceptible to dual-task interference (see also Huestegge & Koch, 2009), but perhaps did not entail a central bottleneck. They further went on to suggest that they rely on a pathway including the superior colliculi, “generally regarded as critical in ‘reflexive’ eye movements” (Pashler et al., 1993, p. 78).

Summarized briefly, none of these approaches have provided compelling evidence for an exception to the PRP effect to date. Hence, a still unanswered question is, “Is there any human behavior that would not yield a PRP effect?” To provide an answer we rely on a different type of ocular response by comparing intended and reflexive eye blinks, which have to date not been investigated in a dual-task or PRP setting.

Unconditioned Reflexes as an Exception to the PRP Effect?

A close examination of the literature shows that all previous studies in the PRP paradigm share at least one characteristic: The tasks they used required the participants’ consent to show the desired behavior, which most often consist of an observable motor output such as pressing a response key (or at least to perform a required mental operation). What if we used a task where the participants cannot avoid showing some form of motor output?

The most straightforward response of this kind is the unconditioned reflex, and particularly well investigated in single-task situations are reflexive eye blinks. Can such reflexes be expected to be an exception to the PRP effect? Admittedly, a positive answer to this question fits with the naive concept of reflexes in everyday speech, but research has shown that reflexes are less automatic and resistant to top-down modulations than previously believed. In fact, reflex latencies are not constant, but depend—similar to RTs—on factors such as stimulus intensity. This has already been suggested by Exner (1874), although admittedly based on less controlled experiments. Moreover, Hilgard’s (1933) early work showed that a stimulus too weak to elicit a startle reaction can, in fact, modulate the magnitude of the eye blink component elicited briefly thereafter. Commonly, the first stimulus

is called the lead stimulus, and the interval from its onset to the onset of the startle eliciting stimulus is termed the lead interval. Obviously, the lead interval in the startle modification literature is similar to the SOA in the PRP literature, although typically no response is required to the lead stimulus, while this response is crucial in most studies using the PRP paradigm (to call for the critical response selection stage of processing). A robust finding is that with a short lead interval the reflex is usually inhibited (or, more precisely, the eye blink amplitude is decreased), while with longer lead intervals it is facilitated (although commonly only when lead and eliciting stimulus are of the same modality; see Filion, Dawson, & Schell, 1993, 1998; Graham, 1975). More interestingly for our purposes, not only the magnitude, but also the latency, of reflexive eye blinks was found to vary with experimental factors (Anthony & Graham, 1985; Hackley & Graham, 1983, 1987). For example, eye blinks are speeded if the reflex-eliciting stimulus is attended compared to when it is not, indicating “that an obligatory, automatic process can be modified by voluntary attention” (Hackley & Graham, 1987, p. 422). Anthony and Graham (1985) reported a similar finding when the modality of a reflex-eliciting stimulus and concurrent stimulation (the “foreground”) matched, although others pointed out that these effects were due to the emotional content (positive vs. negative) and its match with the reflex’s classification (appetitive vs. defensive), rather than being attentional in nature (Bradley, Cuthbert, & Lang, 1990; Lang, Bradley, & Cuthbert, 1990). Additionally, the finding that a simultaneously presented reflex-eliciting stimulus speeds voluntary responses (Valls-Solé et al., 1995) suggests some commonalities of voluntary and reflexive behavior, most likely in subcortical motor circuits required for behavior execution (Valls-Solé, Kumru, & Kofler, 2008). And, last but not least, it has been suggested that manipulations such as “foreperiod duration can have similar consequences for the latency of reflexive and voluntary reactions” (Hackley & Boelhouwer, 1997, p. 220). In sum, it is not entirely clear whether unconditioned reflexes remain completely unaffected by ongoing cognitive operations in a dual-task setting and variations in latencies could indeed result in a PRP effect in the present context. Yet they also present themselves as a good candidate for a clear exception to dual-task interference and the otherwise notoriously persisting PRP effect.

The Present Experiments: Unconditioned Versus Prepared Reflexes

Of importance to the present study is that behavioral expressions that are at first glance very similar in terms of their overt observable movement can have different reasons: For example, a simple eye blink can be part of an unconditioned reflex. In this case, afferent information is projected via the *superior colliculus* or the *nucleus ruber* to the *formatio reticularis* and further to the reflex center in the brain stem. From there, efferent information triggers the contraction of the *m. orbicularis oculi*. However, an eye blink can also be performed spontaneously if a person “decides to briefly close the eyes” for any reason, or as an instructed response to an external stimulus (admittedly most often in the psychological laboratory). If there was only one stimulus and the appropriate response to it was an eye blink, this would be a simple response task in technical terms. Woodworth (1938) coined such simple responses *prepared reflexes*.¹ He did so to emphasize the apparent

automaticity of such stimulus-triggered motor-responses, once the “sensorium” was appropriately prepared in advance. Although the term provides a nice frame for comparing such prepared with unconditioned reflexes (as we did here), we shall see that based on the present research the term is also somewhat misleading.

We report three experiments that examine simple eye blinks within the PRP paradigm. In Experiment 1, eye blinks were performed as a simple and intended response to an imperative tone (i.e., as a prepared reflex). In this case, we expect to see a typical PRP effect. The critical question relates to Experiments 2 and 3, where the eye blink is elicited by a slight air puff below the participants’ eye. As a consequence, the superficially same observable motor behavior as in Experiment 1 is now performed as an unconditioned reflex, and likely the participants will not be able to avoid showing this motor output. In all experiments, participants will not have extensive training with the PRP situation. Still, the question of interest is whether we observe a similar PRP effect for eye blinks. Apart from the empirical novelty of absent PRP effects without extensive training, such result is of clear theoretical importance. If release from response selection (i.e., automaticity in the PRP sense) was only a theoretical possibility, but never actually being shown, this would severely limit the plausibility of the whole approach.

Experiment 1: Eye Blinks as Prepared Reflexes

Participants were to perform two tasks in a PRP setup. Task 1 required a manual response to a visual stimulus, and Task 2 demanded for intended eye blinks as a simple response to an imperative tone stimulus in 50% of the trials. As simple responses have been shown earlier to produce PRP effects (e.g., Karlin & Kestenbaum, 1968; Schubert, 1999) we expected a PRP effect in this case, although eye blinks are a fairly easy-to-produce motor output.

Method

Participants. Eight naïve subjects from the Würzburg (Germany) area (mean age: 23.0 years, five female) volunteered in this experiment. Written informed consent was obtained prior to the experiment.

Apparatus and stimuli. A standard PC was used for controlling experimental procedures. Further, participants wore custom-built goggles used to register eye blinks online (see below). Stimuli

¹ The concept of the prepared reflex has seen a recent revival in cognitive psychology following an influential article by Hommel (2000; see also Cohen-Kadosh & Meiran, 2007; de Jong, 1995; Verleger, Jaskowski, & Wascher, 2005). It seems that this modern formulation is mainly concerned with choice-reaction tasks: Intentional processes configure the cognitive system with different S-R rules; once an appropriate stimulus occurs, no further intentional processing is necessary. Woodworth (1938), however, drawing on earlier work by Exner (1873, 1879), was only concerned with simple responses and he argued that participants prepare for perceiving a particular stimulus (i.e., the “sensorium” is tuned to this expected input via intentional mechanisms) such that its occurrence allows for an immediate and direct response without any further intentional processes. It is also important to note that the “preparation” always follows a specific instruction, thus there is no connotation with “preparedness” as used to describe innate and naturally prepared responses to particular stimuli (Garcia & Koelling, 1966; Seligman, 1970).

for Task 1 (S1) were the letters H and S, presented in white against a black background on a 17-in. (43.18-cm) CRT screen. Responses (R1) were given via external custom-built response keys with the right index- and middle-finger. The stimulus in Task 2 (S2) was a sinusoidal tone (900 Hz, 50 ms) presented via loudspeakers, and participants were to respond to S2 with an eye blink (R2). The goggles contained two diodes (one emitting infrared light, the other registering its reflection) to detect if participants had their eyes closed and to provide respective online error feedback. Additionally, two passive 12/6-mm electrodes were placed above and below the right eye for vertical electrooculographic (vEOG) recording of eye blinks. A BrainVision Quickamp device amplified the signal that was recorded at 500 Hz (lowpass-filtered online at 100 Hz).

Procedure. Each trial began with the presentation of a fixation cross (500 ms). Following a blank screen (500 ms) S1 set on and S2 sounded after an SOA of 100, 300, or 1,000 ms. However, as simple responses performed on every trial can inflate PRP effects (Schubert, 1999), this was only the case in randomly determined 50% of the trials (thus the occurrence of S2 was not predictable). A trial was canceled after 2,000 ms without R1. If necessary, error messages (wrong response to S1, eye blink without S2) were presented for 1,000 ms. During the following inter-trial interval (3,000 ms) participants were allowed to show spontaneous eye blinks.

Each block comprised 24 trials. In 12 of them S2 was presented (two repetitions of six trial types, resulting from orthogonal combinations of two S1 and three SOAs). In the other 12 trials S2 was absent (six repetitions of two S1). Each participant ran through seven blocks, of which the first was considered training and thus was unanalyzed. Prior to each block, the goggles were calibrated to ensure optimal registration of eye closure for error feedback. Experimental sessions were run individually in a dimmed experimental room and took about 30 min. Written instructions highlighted fast responses while keeping the error level low. The experimenter stayed in the room to monitor the vEOG signal. The mapping of S1 to R1 was counterbalanced across participants.

Data treatment and analyses. Response times in Task 1 (RT1) were measured from S1 onset until the respective key press. The vEOG data were screened offline and trials with multiple blinks or other disturbances (e.g., eye blinks during the baseline) were rejected. For subsequent analyses, the remaining data were filtered offline (lowpass: 30 Hz, Notch-filter: 47.5–52.5 Hz) and peak amplitude was identified using Matlab scripts. Based on this, time to peak amplitude (from S2 onset) was determined and response times in Task 2 (RT2) were derived in a backward search starting from peak amplitude until the first time point where five consecutive data points were below 1% of the trial's peak amplitude on a single-trial basis (exploratory analyses showed that various other criteria did not alter the overall picture of the data, although in particular for Experiment 2 the patterns of significance changed sometimes but not did the descriptive pattern of RT2). Only RT2s between 100 and 1,000 ms were considered valid, and participants' median values of the dependent variables² were then submitted to separate repeated-measures analyses of variance (ANOVAs) with the three-level factor SOA (100 vs. 300 vs. 1,000 ms). Percentages of errors in Task 2 were only analyzed as a function of SOA for trials where S2 was present (i.e., most errors imply that S2 was present, but the goggles did not register an

appropriate eye blink). Task 1 data were submitted to repeated-measures ANOVAs with the four-level factor SOA (100 vs. 300 vs. 1,000 ms vs. S2 absent). Throughout this article, a significance level of $\alpha = .05$ was adopted and, if necessary, Greenhouse-Geisser corrections were applied. In these cases we report uncorrected degrees of freedom, supplemented by the ϵ estimate.

Results

Descriptive statistics of the dependent variables are summarized in Table 1 (Task 1: RT1 and percentage of errors [PE]; Task 2: RT2, PE, amplitude, time to amplitude).

Task 2. RT2s decreased with an increasing SOA, thus a PRP effect, $F(2, 14) = 14.78, p = .005, \eta_p^2 = .68, \epsilon = .53$. The vEOG data are illustrated in Figure 2.³ Descriptively, the amplitude was higher with the long compared to the two shorter SOAs, and the respective effect of SOA was significant, $F(2, 14) = 5.70, p = .015, \eta_p^2 = .45$. Time to amplitude significantly decreased with an increasing SOA, $F(2, 14) = 15.87, p = .005, \eta_p^2 = .69, \epsilon = .51$. PEs were slightly larger at the long SOA, but the effect of SOA was far from significance, $F(2, 14) = 0.49, p = .624, \eta_p^2 = .07$.⁴ Blinks without S2 occurred in 1.5% of the trials.

Task 1. RT1s were slightly longer at the shortest SOA compared to the longer SOAs and the condition without S2, $F(3, 21) = 7.76, p = .001, \eta_p^2 = .53$. PEs were low and did not differ between conditions, $F(3, 21) = 0.45, p = .624, \eta_p^2 = .06, \epsilon = .59$.

Discussion

Experiment 1 was a PRP experiment where Task 2 demanded a simple eye blink in response to an auditory stimulus that was too weak to elicit a blink reflex on its own. The results reflect the typical finding and RT2 showed a PRP effect. Thus, as long as eye blinks require the participants' consent to be executed, they are susceptible to dual-task interference from an unrelated Task 1. In the following experiments, we investigate the superficially same overt motor behavior as an unconditioned reflex.

Experiment 2: Eye Blinks as Unconditioned Reflexes

Having established a PRP effect for intended eye blinks, we were now interested in an unconditioned reflex's susceptibility to dual-task interference. Thus far, the search for exceptions to the PRP effect has proven difficult and findings controversial (Lien et

² In PRP research, outlier elimination according to some criterion and the subsequent use of means of the dependent variables (typically this is RT) is more common. In this study, we strived to keep as many trials as possible for data analyses; thus, we did not apply an outlier screening procedure but used individuals' median values instead.

³ One may wonder why the data in Table 1 differs from what can be judged from Figure 2. It is important to realize that the analyzed parameters (RT, amplitude, time to amplitude) were extracted for each trial. The depicted vEOG data, however, presents means of trials and participants. Due to the onset variability within and between participants, the amplitude of the means must be smaller than the mean of the extracted amplitudes, a problem also known in ERP research. For the subsequent Experiments 2 and 3, the values match quite well as there was almost no onset variability.

⁴ The high error rate of 7.3% (cf. Table 1) was due to one particular participant. Excluding this participant from analyses gave PEs of 3.0, 3.6, and 3.0, respectively, for the three SOA levels, $F(2, 12) = 0.09, p = .917, \eta_p^2 = .01$.

Table 1
Means of Dependent Variables of Experiments 1 and 2

Variable	Experiment 1 SOA (ms)				Experiment 2 SOA (ms)			
	100	300	1,000	Without S2	100	300	1,000	Without S2
RT1 (ms)	431	395	394	396	407	410	407	400
PE1	1.0	2.1	2.1	1.4	7.1	1.9	1.6	2.8
RT2 (ms)	529	421	329		68	64	68	
PE2	6.2	7.3	8.3		9.9	7.1	9.6	
Amp (μ V)	616	601	636		298	318	371	
Time to Amp (ms)	660	541	449		134	133	139	

Note. SOA = stimulus onset asynchrony; S2 = Task 2 stimulus; RT = response time; PE = percentage errors; Amp = amplitude.

al., 2006; see introduction), and we reasoned above that the common characteristic of all relevant studies is that the tasks required participants' consent to give the desired responses—as in our Experiment 1. Unconditioned reflexes, however, do not require such consent and thus can be viewed as a good candidate for an exception to the PRP effect, although there is also clear evidence that characteristics of reflexive eye blinks (RT, amplitude) vary with ongoing cognitive and emotional processing (Anthony & Graham, 1985; Filion et al., 1993, 1998; Hackley & Graham, 1987; see introduction).

Method

Sixteen naïve undergraduate students (mean age: 22.0 years, 11 female) participated in this experiment for course credit. Written informed consent was obtained prior to the experiment. Similar to Experiment 1, the data were screened offline for valid trials. In particular, trials were rejected where the peak was not unambiguously attributable to the elicited reflex. Three participants were excluded from analyses because not enough trials were left after this screening.

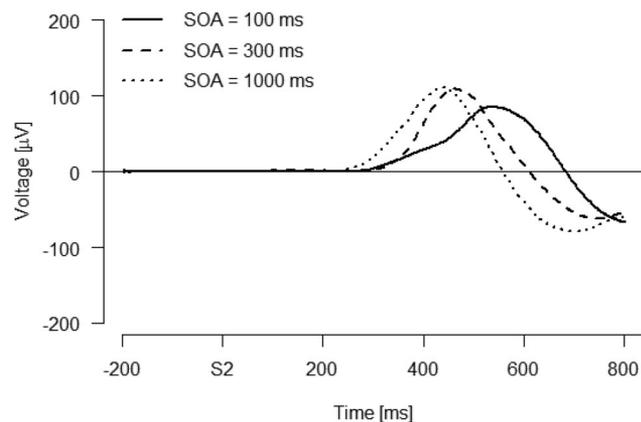


Figure 2. Illustration of the vertical electrooculographic (vEOG) data for eye blinks in response to an auditory stimulus (Experiment 1) as a function of stimulus onset asynchrony (SOA; S2 = Stimulus 2 onset). Note that, due to onset variability within and between participants, the plot does not reflect the extracted and analyzed parameters as given in Table 1, especially concerning mean peak amplitudes.

The only change to Experiment 1 relates to S2: The tone was now accompanied by a slight air puff just below the participants' left eye. Hence, the eye blink was elicited as an unconditioned reflex. Note that the tone had no particular meaning in this experiment. We opted for presenting it, however, to keep differences to Experiment 1 as minimal as possible, and the air puff and the additional stimulus were always presented together. For reasons of comparability, an additional stimulus was also presented together with the air puff in the subsequent Experiment 3. In this experiment the additional stimulus was visual, but Experiments 2 and 3 yielded essentially the same results. In comparison to Experiment 1, the addition of the air puff is indeed the critical S2 manipulation. The goggles (see Method section of Experiment 1) contained a small opening via that the air puff was applied. The air puff was about 110 ms long and arrived with a constant delay of about 30 ms after the experimental program triggered its application. Participants were urged to not exhibit spontaneous eye blinks following the fixation cross but to wait for the intertrial interval. RTs between 20 and 120 ms were considered valid.

Results

Descriptive statistics for the dependent variables are summarized in Table 1.

Task 2. As would be expected, RT2s were much faster than in Experiment 1. Although their descriptive pattern did not follow a PRP effect (i.e., faster RTs at longer SOAs), the effect of SOA was significant, $F(2, 24) = 3.63, p = .042, \eta_p^2 = .23$. The difference in RT2 between the shortest and the longest SOA amounted to 0.2 ms with a 95% confidence interval of $[-3.8; 4.2]$. The vEOG data are illustrated in Figure 3. Amplitude increased across SOAs, $F(2, 24) = 5.79, p = .009, \eta_p^2 = .33$, as did time to amplitude, $F(2, 24) = 7.77, p = .003, \eta_p^2 = .39$. PEs did not vary significantly with SOA, $F(2, 24) = 0.40, p = .577, \eta_p^2 = .03, \epsilon = .60$. Blinks without S2 occurred in 9.9% of the trials.

Additionally, RTs were submitted to a mixed ANOVA with SOA as a repeated measure and experiment (1 vs. 2) as a between-subjects factor. First, RT2s were obviously faster for Experiment 2, $F(1, 19) = 108.62, p < .001, \eta_p^2 = .85$, and overall SOA exerted a significant effect, $F(2, 38) = 24.83, p < .001, \eta_p^2 = .57, \epsilon = .53$. Critically, the interaction was significant as well, $F(2, 38) = 24.62, p < .001, \eta_p^2 = .56$.

Task 1. RT1s did not show any systematic variation across conditions, $F(3, 36) = 0.12, p = .777, \eta_p^2 = .01, \epsilon = .40$. PEs were

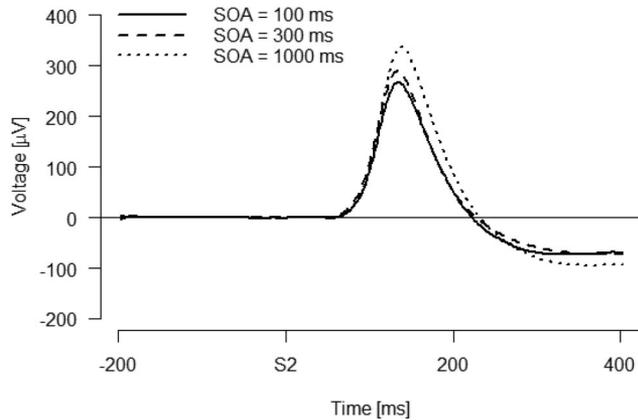


Figure 3. Illustration of the vertical electrooculographic (vEOG) data for reflexive eye blinks (Experiment 2) as a function of stimulus onset asynchrony (SOA; S2 = Stimulus 2 onset).

highest at the short SOA of 100 ms, yielding a significant effect, $F(3, 36) = 4.41, p = .042, \eta_p^2 = .27, \epsilon = .45$. Furthermore, we submitted RTs to a mixed ANOVA with SOA as a repeated measure and experiment (1 vs. 2) as a between-subjects factor. No effect reached significance, SOA: $F(3, 57) = 1.37, p = .264, \eta_p^2 = .07, \epsilon = .47$, experiment: $F(1, 19) = 0.01, p = .934, \eta_p^2 < .01$, interaction: $F(3, 57) = 1.28, p = .289, \eta_p^2 = .06$.

Discussion

The results from Experiment 2 are straightforward: Reflexive eye blinks did not show a PRP effect; hence, no interference from an unrelated concurrent task was observed. It should be noted that we draw this conclusion despite a significant effect of SOA. Yet the changes of RT2 with SOA are not compatible with any dual-task costs as RT2 did not differ for the shortest and the longest SOA. The RT2 pattern might suggest a form of conditioning instead, if one considers S1 a neutral stimulus (becoming a conditioned stimulus [CS]) and S2 an unconditioned stimulus (US).⁵ Trace conditioning of eye blinks is best at time windows of about 300–500 ms, hence in the range of our middle SOA. This might have speeded RTs if a conditioned response (CR) is produced with a good timing precision immediately before the US would occur (Boneau, 1958). This account faces problems on its own, however. Whereas differences in conditioning result when the CS–US interval is varied block-wise or between-participants, the SOA (to use the PRP terminology) varied randomly from trial to trial in the present experiment. Without additional assumptions it is not easy to see why the CR should be generated in response to the CS more quickly at one specific of the equally probable time points of the US. On top of that, the robustness of the RT2 pattern is somewhat questionable in itself, since it failed to replicate in Experiment 3 and in another control experiment (see General Discussion), in which conditioning should have happened to at least the same degree as in Experiment 2.

Experiment 3: The Latent Bottleneck Account

Experiments 1 and 2 allowed a direct comparison, as the only difference was the addition of the reflex-eliciting air puff as S2 in

Experiment 2. The consequences of this were massive: The clear PRP effect of Experiment 1 was absent in Experiment 2. This comparability, however, comes with some methodological drawbacks that complicate a clear interpretation of absent PRP effects (see also Lien et al., 2006).

In particular, situations without overlapping central stages at short SOAs may arise if (precentral and) central stages are sufficiently short. As a consequence, no PRP effect will be observed even though both tasks do entail capacity-limited central stages. This situation has been termed a *latent bottleneck*. Consider, for example, the study by Van Selst et al. (1999). Following extensive training, one of their participants did not show any signs of a PRP effect. In a follow-up article, the hypothesis was tested that merely non-overlapping, but still existing, central stages were responsible for this result (Ruthruff et al., 2003). Indeed, with manipulations that encouraged an overlap of central stages, the PRP effect re-emerged.

The particular situation for our Experiment 2 is illustrated in Figure 4a. Given the very short reflexive RTs and thus—if existing—the very short central stage, it is possible that even for the shortest SOA processing of the Task 2 central stage might have been finished before that of Task 1 has even started. Consequently, no PRP effect would be observed. To circumvent this issue we introduced two major changes in Experiment 3. First, Task 1 entailed three stimuli and responses to prolong its central stage. Second, we used five SOAs and the shortest SOA was 250 ms (compared to 100 ms in the previous experiments). These measures were taken to increase the probability that the two central stages overlap, what in turn would produce a PRP effect (see Figure 4b for an illustration).

Method

Twenty-four new naïve undergraduate students (mean age: 21.5 years, 18 female) participated for course credit. Written informed consent was obtained prior to the experiment. Four participants were excluded from analyses because not enough trials were left after the screening procedure.

Several changes apply in comparison to Experiment 2. First, S1 were now three tones (300, 600, and 900 Hz; 50 ms). R1 was given via key presses with the right index-, middle-, and ring-finger. Second, five different SOAs (250, 300, 350, 400, and 1,000 ms) were employed to promote overlapping central stages (see Figure 4b for an illustration). Finally, the tone that accompanied S2 was replaced with a visually presented stimulus, a centrally presented “O.” As a result of these changes, each block now comprised 30 trials. In 15 of them, S2 was presented (resulting from combining three S1 and five SOAs); in the remaining 15 trials, S2 was absent (five repetitions of three S1). We also increased block number to nine, the first of which was considered training. To prevent loss of too much data due to Task 1 errors, participants ran through at least one practice block of 30 trials where only Task 1 was applied before the actual experiment. This practice block was repeated at the experimenter’s discretion if a participant made too many errors.

⁵ We thank a reviewer for directing our attention to this point.

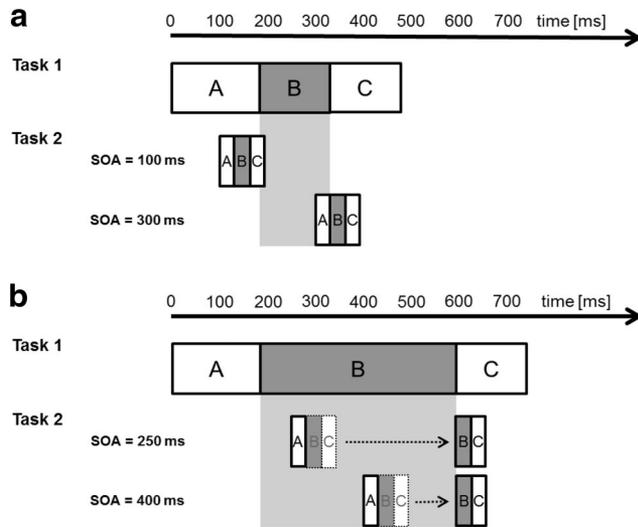


Figure 4. Illustration of the latent bottleneck hypothesis. a. With sufficiently short central stages in Task 2, situations are possible where both tasks indeed entail central stages, yet they do not overlap in time and thus no psychological refractory period (PRP) effect emerges. b. In Experiment 3 we used a longer Task 1 central stage, and the shortest stimulus onset asynchrony (SOA) was now 250 ms (instead of 100 ms in Experiments 1 and 2). These changes were made to promote overlapping central stages that—if existent—would need to be deferred until after Task 1 central processing has been finished (indicated by the dotted arrows).

Results

Descriptive statistics for the dependent variables are summarized in Table 2.

Task 2. RT2s showed no systematic pattern across SOAs, $F(4, 76) = 0.52$, $p = .590$, $\eta_p^2 = .03$, $\varepsilon = .47$. The difference in RT2 at the shortest and the longest SOA amounted to 0.6 ms with a 95% confidence interval of $[-6.9; 7.8]$. As can be seen in Figure 5, amplitude again increased across SOAs, $F(4, 76) = 11.38$, $p < .001$, $\eta_p^2 = .37$, and this was also true for time to amplitude, $F(4, 76) = 13.32$, $p < .001$, $\eta_p^2 = .41$. PEs did not vary, $F(4, 76) = 1.18$, $p = .312$, $\eta_p^2 = .06$, $\varepsilon = .42$, and blinks without S2 occurred in 11.8% of the trials.

Task 1. RT1s were not affected by SOA, $F(5, 95) = 0.56$, $p = .734$, $\eta_p^2 = .03$. Overall, PEs decreased across SOAs when S2 was

present and were smaller when S2 was absent, $F(5, 95) = 9.94$, $p < .001$, $\eta_p^2 = .34$.

Discussion

The results of Experiment 3 confirm those of Experiment 2: Despite the changes introduced in the experiment as means to avoid a possible latent bottleneck, no signs of a PRP effect were observed. In other words, although overlapping central stages were likely, RT2 was completely unaffected by the SOA manipulation. On the other hand, amplitude again increased with an increasing SOA, a finding to which we return in the General Discussion.

General Discussion

In the present study we took advantage of the fact that on surface the same overt motor behavior, an eye blink, can either (a) be demanded as a simple, intended response to an imperative stimulus (i.e., as a prepared reflex; Woodworth, 1938) or (b) result inevitably from a reflex-eliciting stimulus, thus as an unconditioned reflex. The main purpose was a comparison of the resulting dual-task costs in terms of the PRP effect in both cases.

The Effects of Dual-Tasking

To investigate dual-task interference for prepared and unconditioned reflexes, we employed the PRP paradigm (e.g., Pashler, 1994). Generally, RTs are considered the main dependent measure in such studies, and so we did here. When, as in Experiment 1, eye blinks were given as an intended response to an imperative stimulus, we observed a PRP effect: RTs were faster the less both tasks overlapped in time—a finding compatible with different theoretical models (Meyer & Kieras, 1997; Pashler, 1994; Tombu & Jolicoeur, 2003). This picture changed radically in Experiment 2, where the former stimulus was accompanied by a slight but reflex-eliciting air puff: RTs remained relatively constant across SOA levels. This finding was replicated in Experiment 3, where we took particular precaution to address alternative explanations in terms of a latent bottleneck (see Ruthruff et al., 2003). If unconditioned reflexes entailed a central stage, these results are not compatible with a structural bottleneck model (see Figure 1; Pashler, 1994). It may be argued that central processing indeed existed, yet it ran in parallel (Tombu & Jolicoeur, 2003). In this case, however, detrimental effects on Task 1 RTs should have shown up. In sum,

Table 2
Means of the Dependent Variables of Experiment 3

Variable	SOA (ms)					
	250	300	350	400	1,000	Without S2
RT1 (ms)	760	745	746	743	753	750
PE1	15.6	15.0	11.2	9.8	6.0	6.0
RT2 (ms)	71	69	72	71	71	
PE2	18.5	17.1	14.2	13.8	13.8	
Amp (μ V)	296	294	291	313	372	
Time to Amp (ms)	141	136	137	137	143	

Note. SOA = stimulus onset asynchrony; S2 = Task 2 stimulus; RT = response time; PE = percentage errors; Amp = amplitude.

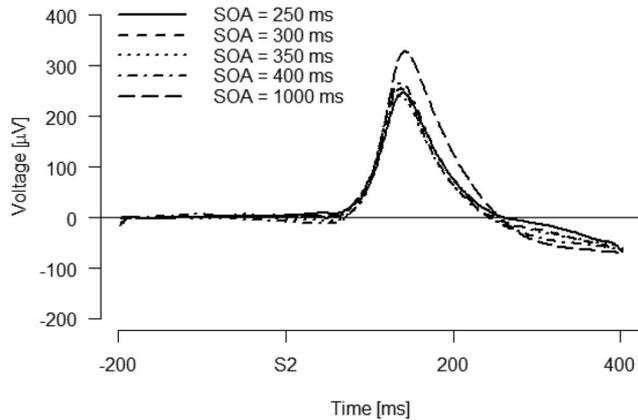


Figure 5. Illustration of the vEOG data for reflexive eye blinks (Experiment 3) as a function of stimulus onset asynchrony (SOA; S2 = Stimulus 2 onset).

Experiments 2 and 3 do present a very clear exception to the PRP effect and thus dual-task interference—reassuring that it is possible to find such exceptions. Purposefully, we have used the PRP paradigm in the present research as it has at times been criticized to boost dual-task costs merely due to experimental details, such as the successive stimulus presentation (e.g., Schumacher et al., 2001). Hence, using the PRP paradigm can be construed as a liberal approach to measuring dual-task interference—and still no sign thereof was evident in Experiments 2 and 3.

However, the magnitude of the reflexive eye blinks increased with an increasing SOA, i.e., with decreases in task overlap, in Experiments 2 and 3. This suggests that the strength of the investigated reflex suffered from dual-task interference. Conceivably, for defensive protection responses it makes sense that their latency is kept constant, although their strength may suffer to some degree from other ongoing cognitive activities. Albeit an interesting interpretation, there are alternatives. First, the Task 1 stimulus could be considered a lead stimulus. Considering the SOA of 300 ms a baseline, the short and long SOAs translate to short and long lead intervals. Given the evidence of eye blink amplitude inhibition and facilitation with short and long lead intervals (for summaries, see Filion et al., 1993, 1998; Graham, 1975), this reasoning easily accounts for this particular effect in the present study. Second, another viable interpretation is that the more time elapsed (i.e., the longer the SOA), the more participants might have experienced an urge to blink for merely physiological reasons (e.g., dry eyes), thereby driving the increase in amplitudes of our reflexive eye blinks artificially. To test whether the amplitude effect was due to the dual-task situation, we ran a control experiment that was similar to Experiment 2 but no response was required to the first stimulus ($n = 16$, mean age: 28.8 years, 15 female). Again, amplitude increased with SOA (324, 358, and 375 μV , for the SOAs of 100, 300, and 1,000 ms, respectively), $F(2, 30) = 5.62$, $p = .008$, $\eta_p^2 = .27$.⁶ A comparison with Experiment 2 yielded a significant main effect of SOA, $F(2, 54) = 11.15$, $p < .001$, $\eta_p^2 = .29$, but neither the main effect of experiment, $F(1, 27) = 0.05$, $p = .820$, $\eta_p^2 < .01$, nor the interaction was significant, $F(2, 54) = 0.98$, $p = .383$, $\eta_p^2 = .04$. These results argue against the amplitude effect as resulting from the dual-task situation.

There are also some doubts about the lead stimulus interpretation. Facilitation effects appear mostly to occur when attention is directed to the modality of the reflex-eliciting stimulus or if lead and eliciting stimuli are of the same modality—a situation not present in our experiments. Also, directing attention to the lead stimulus typically enhances its inhibitory effect (Hackley & Graham, 1987; McDowd, Filion, Harris, & Braff, 1993; see Filion et al., 1998, for a review). Conceivably, more attention to a putative lead stimulus (i.e., the Task 1 stimulus) was required in Experiment 2 than in the control experiment. The between-experiments analysis, however, did not suggest any differences. Which of the two alternative interpretations is eventually more appropriate cannot be decided safely on the basis of the present data. It is, however, important to note that the control experiment rules out the dual-task situation as the source of the amplitude effect.

The Broader Picture: Inferences From Interference

When adopting a broader theoretical perspective, the reported dissociation of differing susceptibility to dual-task interference, i.e., to the PRP effect, maps on an interesting theoretical difference. We have briefly suggested above that all previous PRP studies employed tasks that required the participants' consent to produce the desired behavior, i.e., participants needed to have an *intention* to perform the required behavior as a response (or to perform a required mental operation for successful task performance). In turn, intentional behavior, i.e., actions, is defined as goal-directed. A fruitful framework to study goal-directed behavior is offered by *ideomotor theory*, rooted in philosophical analyses of the 19th century (e.g., Harleß, 1861; Herbart, 1825; James, 1890/1981; for historical remarks, see Pfister & Janczyk, 2012, and Stock & Stock, 2004). Briefly, ideomotor theory states that actions can only be accessed and initiated by anticipating the sensorial consequences of the desired actions, i.e., the action effects or action goals (see Hommel, Müseler, Aschersleben, & Prinz, 2001; Kunde, 2001; Shin, Proctor, & Capaldi, 2010, for more details and empirical evidence for this assumption).

According to Prinz (1998), even rather simple responses to stimuli must be considered actions and thus be studied in the framework of ideomotor theory: The proprioceptive feedback when moving the finger to depress a response key or closing the eye lid is an action effect and its anticipation is the necessary precondition for selecting this motor output. Thus, the simple responses in Experiment 1 are actions carried out to achieve a goal. In contrast, unconditioned reflexes, as investigated in Experiments 2 and 3, are certainly *not* performed to achieve a self-chosen goal; they are performed without intention (if anything to achieve an evolutionary developed and preset goal).

It would follow then, that behavior is only susceptible to dual-task interference inasmuch it is based on intentions and goals and in fact this fits nicely with other recent studies from our lab. For example, Paelecke and Kunde (2007) have shown the processes of effect anticipation to coincide with what has been called the central stage of response selection in models such as Pashler's (1994).

⁶ RTs were 73, 69, and 71 ms (for the SOAs of 100, 300, and 1,000 ms, respectively) and the main effect of SOA was not significant, $F(2, 30) = 0.97$, $p = .356$, $\eta_p^2 = .06$, $\epsilon = .62$. This finding also suggests that conditioning did not play an important role in Experiment 2.

Also in line with this reasoning are recent findings regarding specific dual-task interference (Müsseler & Wühr, 2002). Specific interference means that the actual size of dual-task costs depends on the overlap between stimulus and response characteristics of both tasks (in addition to unspecific costs that are caused by any dual-task setting). We have studied different ways through which an action's contingent effects may influence different types of interference phenomena. For example, the well-known advantage of homologous finger combinations can be reversed if non-homologous finger combinations produce identical visual effects, while homologous combinations produce different visual effects (Janczyk, Skirde, Weigelt, & Kunde, 2009). A similar importance of effects, rather than of structural/body-related characteristics, has been observed for the interplay of manual and mental rotations (Janczyk, Pfister, Crognale, & Kunde, 2012) and the backward crosstalk effect (Janczyk, Pfister, Hommel, & Kunde, 2013). In other words, the amount of dual-task interference appeared in all these studies to depend on the commensurability of the currently pursued action goals.

A critical note on the term "prepared reflex" (Hommel, 2000; Woodworth, 1938) is due, however. There is, of course, some similarity between a real reflex and a prepared reflex in that both are shown in response to a specific stimulus. Apart from that, even the two kinds of eye blinks investigated here differ strikingly on closer observation regarding their shapes, their latencies, their amplitudes, and so on (compare Figures 2 and 3). Moreover, it is true that once a prepared reflex (or an S-R rule) is instantiated, the mere occurrence of a relevant stimulus might yield some automatic or non-intended activation of response-related codes. In turn, this gives rise to phenomena such as the well-known flanker effect (see Hommel, 2000). *Execution* of a response, however, is not automatic in the sense that it does not require central resources: While a prepared reflex suffers from unspecific dual-task interference, a real reflex does not. Thus, although the term prepared reflex may have some metaphorical merit, it should nevertheless be used with some caution.

Conclusions

Although virtually absent dual-task costs after extended training have been demonstrated several times (Hazeltine et al., 2002; Schumacher et al., 2001), the PRP effect proved quite resistant to many attempts of its elimination (see Lien et al., 2006, for an overview). Here we show that in principle it is possible to observe absent PRP effects—even without training. This is good news to attention, dual-task, and PRP researchers as these results demonstrate that automaticity (in the sense of absent central processing stages) is not only a theoretical claim. Its existence as an empirical phenomenon renders the theoretical framework plausible.

Future research should move upward in the behavioral hierarchy. For example, an interesting case is that of conditioned reflexes: Previous studies have focused on the conditioning phase (e.g., Papka, Ivry, & Woodruff-Pak, 1995), yet it is unknown to which extent the execution of conditioned reflexes suffers from interference. Investigating these cases in terms of their susceptibility to dual-task interference could be a promising path toward establishing distinctions between different classes of behavior.

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