DIFFERENCES BETWEEN REACTION TIME TO STIMULUS ONSET AND OFFSET: EVIDENCE FOR POST-PERCEPTUAL EFFECTS

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Reaction time to stimuli offset is usually longer than to stimuli onset (offset disadvantage). According to V. Di Lollo et al. (2000), such disadvantage arises from the need to suppress the automatically arisen response to stimulus onset that necessarily precedes the offset. If such is the case, one expects the onset–offset difference to decrease as the delay between stimulus onset and offset (i.e. foreperiod) increases. Results of the first experiment confirmed this hypothesis. A potential confounding factor was identified, however, related to different sensory consequences after response (i.e. light offset vs. light onset in the reaction time to stimulus onset and offset tasks, respectively). We thus reasoned that, besides suppression, the action effect could influence the results. Results of the second experiment in which the sensory consequences were equalized confirmed the role of the action effect and suggest that, when such effect is removed, suppression plays a little role in offset disadvantage.

Key words: *reaction time, stimulus onset, stimulus offset*

Reacting quickly and efficiently to abrupt stimuli in the environment is essential for adapted behavior and survival. Although the disappearance of a stimulus is often as informative as an appearance, it is well established that reaction time (RT) to a stimulus offset is longer than RT to the same stimulus onset. For very brief stimuli, this lengthening has been interpreted as being due to the visual persistence effect (Briggs and Kinsbourne, 1972; Di Lollo, 1980). This explanation, however, does not hold for longer stimulus durations (Di Lollo et al., 2000). Plain sensory effects, i.e. a very early difference in the encoding speed (evidence from the cellular level comes from animal studies, e.g., Bair et al., 2002), are unlikely, since visual P1 (Servière et al., 1977) and auditory N1 (Hari et al., 1987; Pratt et al., 2008) event-related potentials have been reported to occur earlier for stimuli offset, indicating that stimulus encoding is likely not responsible for a delayed response.

An alternative interpretation was put forward by V. Di Lollo et al. (2000): they proposed that stimulus onset tends to trigger response tendencies automatically, which then needs to be suppressed. This view is supported by data obtained in conflict tasks. P. Wuhr and W. Kunde (2006) compared the Simon effect to stimulus onset and offset. In this task, subjects must issue a right or left hand response as a function of the color of a lateralized stimulus: when the position of the stimulus and response correspond, RT is faster and the error rate lower than when they do not correspond. This is generally interpreted as reflecting an automatic activation of the ipsilateral hand by stimulus position. Interestingly, P. Wuhr and W. Kunde (2006) reported that the Simon effect was stronger for stimulus onset than offset, suggesting that automatic response activation was larger for stimulus onset than for stimulus offset, supporting the idea of V. Di Lollo et al. (2000). Importantly, such response capture is often considered to be short-lived and quickly decay after stimulus onset, either spontaneously (Hommel, 1993 b, 1994) or under active suppression (Burle et al., 2002; Ridderinkhof, 2002; van den Wildenberg et al., 2010 for a review). We thus reasoned that if the offset disadvantage is due to the necessity to suppress the response activated by the stimulus onset, this disadvantage should decrease as the duration between stimulus onset and offset increases. We thus introduced a delay of varying duration between a warning signal (i.e. the offset or onset of stimulation acted as a warning stimulus in RT to stimulus onset and offset tasks, respectively) and the imperative signal (respectively, onset or offset of the stimulation). During this delay, called "foreperiod" (FP), it has been reported that cortico-spinal excitability decreases shortly after the warning signal, but that for a long FP this decrease has disappeared at the time of the imperative stimulus (Davranche et al., 2007; Hasbroucq et al., 1999), reflecting an increase of the inhibition of the cortico-spinal pathway during FP, which prevents from an erroneous premature responding (Davranche et al., 2007). If the offset disadvantage is due to the necessity to suppress the response automatically triggered by stimulus onset, one expects the onset–offset difference to decrease as the FP increases.

Experiment I

Method

Participants

Twelve 28.8 ± 1.9 years old subjects with a normal or corrected-to-normal visual acuity took part in the experiment. The gender was counterbalanced – we tested 6 women and 6 men.

Procedure

Each subject performed two tasks: either reacting to stimulus onset (white light emitting diode (LED) onset) or to stimulus offset (white LED offset). The use of LED allows ensuring a perfect, sub-millisecond timing for both onset and offset. The order of the tasks was counterbalanced among the subjects. A subject was asked to press the response button as fast as possible after light onset (RT to stimulus onset task) or offset (RT to stimulus offset task). A white LED 1.5 cm in diameter was placed on a grey panel (width 19.8 cm, height 9.7 cm) at a 53 cm distance in front of a subject's eyes. Whatever the task, the trial started with a warning stimulus (offset of LED from the previous trial in RT to stimulus onset tasks or onset of LED in the current trial in RT to stimulus offset tasks, see below) that lasted

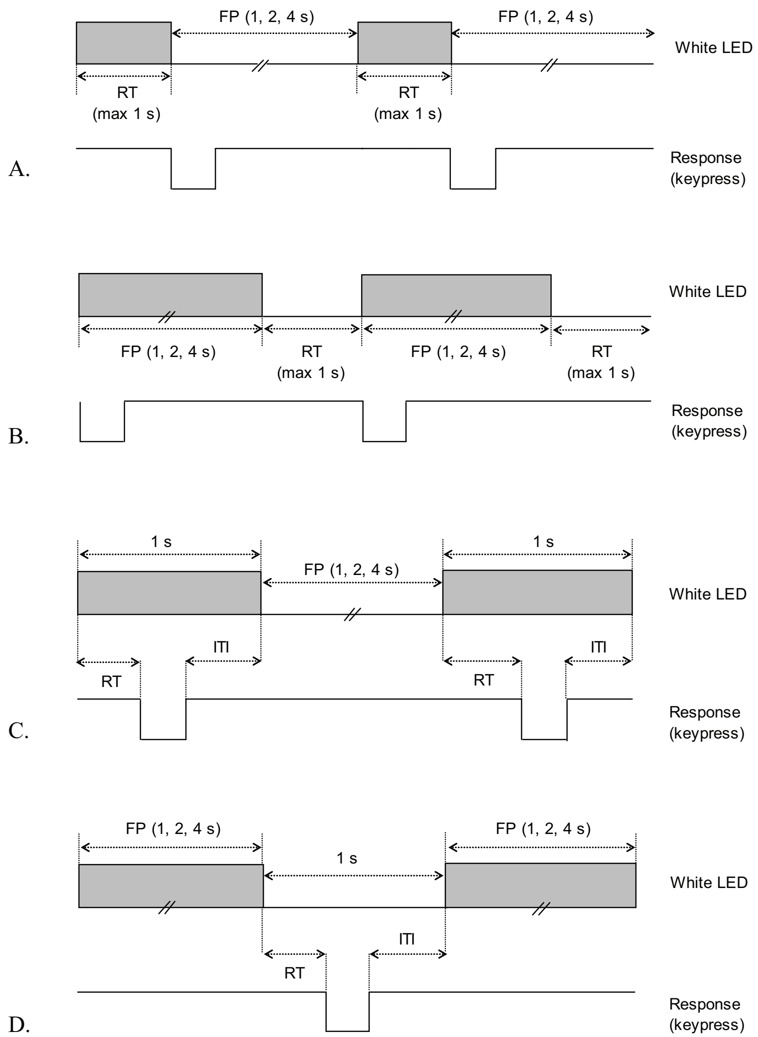

Figure 1. ***A – reaction time to stimulus onset task in Experiment 1; B – reaction time to stimulus offset task in Experiment 1; C – reaction time to stimulus onset task in Experiment 2; D – reaction time to stimulus offset task in Experiment 2. FP – foreperiod; RT – reaction time; ITI – intertrial interval; LED – light emitting diode***

1000, 2000 or 4000 ms. This interval will be called "foreperiod" (FP). At the end of the FP, an imperative stimulus (onset or offset of the white LED) was presented, to which subjects had to react as fast as possible (see Figures 1A and 1B). A participant had 1 s to respond. Immediately after a subject's response, the imperative signal was removed and replaced by the warning signal which initiates the FP of a new trial. FP is thus defined as the response–stimulus interval. Each block consisted on 63 trials, each FP being repeated 21 times in random order. For the onset task, the warning signal was the extinction of the white LED, and the imperative signal was its onset (see Figure 1A), while the roles were inverted for the offset task (see Figure 1B). Each task comprised 5 blocks run consecutively. Before each series of blocks from the same task, a practice block was performed. Each block was followed by a short 1–2-minute break. LED and the response button were connected to the same computer (Xeon CPU 2.0 GHz, 2 GB RAM) and controlled through the parallel port to ensure a perfect timing. The experimental program was written in the C programming language based on the T-Scope library (Stevens et al., 2006). The total duration of the experiment was about one hour.

Results

4.58% of trials, identified as anticipations (response before stimulus) or misses (including insufficient response force to close the response switch), were excluded from the subsequent analysis (limits were chosen according to Di Lollo et al. (2000)).

The results were analyzed by the repeated measures analysis of variance (ANOVA) which revealed a clear effect of the task ($F(1, 11) = 16.6$, $p < 0.01$), of FP ($F(2, 22) = 12.6$, $p < 0.001$) and a clear task–FP interaction ($F(2, 22) = 10.0$, $p < 0.001$), but gender was not a statistically significant factor ($F(1, 10) < 1$). Even if ANOVA revealed a significant effect of the task order ($F(1, 10) = 5.04$, $p = 0.049$), there was no interaction between task order and task ($F(1, 10) < 1$). The task effect was thus maximal (71 ms) for the shortest FP (1000 ms) and decreased with increasing FP (40 ms at 2000 ms FP and 32 ms at 4000 ms FP, see Figure 2).

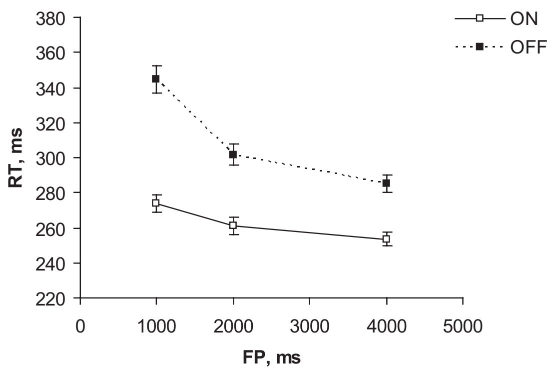

Figure 2. ***Reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod of the current trial. Error bars define the 95% confidence interval of the mean. N (number of subjects) = 12***

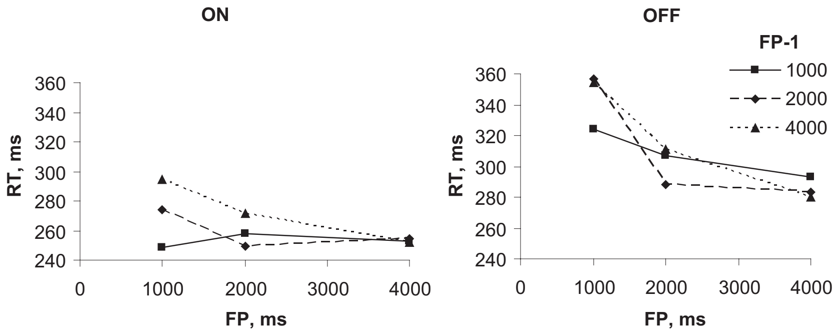

Figure 3. ***Sequential effects in reaction time to stimulus onset (ON) and offset (OFF) tasks. RT – reaction time; FP – foreperiod of the current trial; FP-1 – foreperiod of the preceding trial. N (number of subjects) = 12***

Besides the main analysis, the FP effect is known to largely depend on the duration of the previous FP, and this dependence is asymmetric (Niemi and Naatanen, 1981, for a review): RT in the current trial of short FP usually slower when preceded by a longer FP, but the influence of preceding FP decreases with current FP increasing. Repeated measures ANOVA revealed a clear effect of the preceding FP (F (2, 22) = 10.33, p < 0.001) and the classical sequential effect qualified by the interaction between the current and the preceding FP (F (4, 44) = 18.64, p < 0.001). However, the interaction between the sequential effect and the task was not statistically significant (F (4, 44) = 1.13, p = 0.35, see Figure 3).

Discussion

We have reasoned that if the offset disadvantage comes from the need to suppress the response activated by stimulus onset, the onset–offset difference should decrease as the time between onset and offset increases, which corresponds to the FP duration. The interaction between FP and the task shows that while the offset disadvantage is very large for a short FP, it reduces as the FP duration lengthens. This fits with the idea that the onset of the warning signal tends to activate the response tendency which needs to be suppressed, since for a long FP the suppression is likely largely reduced at the time of the imperative signal. The further analysis of the experimental design, however, suggests a potential other factor affecting the pattern of results related to the so-called "action effect" principle (Hommel, 1993 a, 1996). It is well known that motor actions are also coded as a function of their expected sensory consequences (Hommel, 1993 a; 1996). For example, B. Hommel (1993 a) showed that when pressing the left key induces a right light onset, RT is longer than when pressing the left key induces a left light onset, demonstrating the action-effect compatibility. In the current design, in the onset condition, pressing the button induces an offset of the diode, while in the offset condition, a button press lights up the diode. It might well be that turning on a signal when pressing a button is less natural than turning it off after a key press. This might increase the offset disadvantage, especially for a short FP duration. In the second experiment, we thus removed this action effect by de-correlating the response–stimulus change and making the response non-contingent to different sensory effects.

Experiment II

Method

Participants

Twelve 28.6 ± 3.3 years old subjects (7 women and 5 men) with a normal or corrected-to-normal visual acuity participated in the experiment.

Procedure

The experimental task and procedure were the same as in the first experiment, except that participants' response did not remove the stimulus which stayed present for 1 s, whatever the RT (see Figure 1C and 1D). In order to signal that the response was given, a sound feedback was delivered. As in the first experiment, a participant had 1 s to respond, and after response the diode light was not turned off (in the onset task) or turned on (in the offset task) irrespective of RT. Hence, in both tasks, the key press was associated with the same action effect, namely a brief sound.

Results

1.34% of trials identified as anticipations or misses were excluded from the subsequent analysis.

Repeated measures ANOVA revealed a significant effect of the task ($F(1, 11) = 7.74$, $p < 0.05$) and FP ($F(2, 22) = 13.38$, $p < 0.001$), but not their interaction ($F(2, 22) = 1.44$, $p > 0.05$). Gender was not a significant factor ($F(1, 10) < 1$), as was also the task order ($F(1, 10) < 1$). RT to stimulus onset was shorter than to stimulus offset at all FPs (Figure 4).

Data on sequential effects are presented in Figure 5. Although the FP and task interaction in general was not significant ($F(2, 22) = 1.44$, $p > 0.05$), repeated measures ANOVA revealed a significant effect of a previous FP ($F(2, 22) = 22.61$, $p < 0.001$) and a classical sequential effect ($F(4, 44) = 32.18$, $p < 0.001$), but there was no significant interaction between the task and the sequential effect ($F(4, 44) = 0.26$, $p > 0.05$).

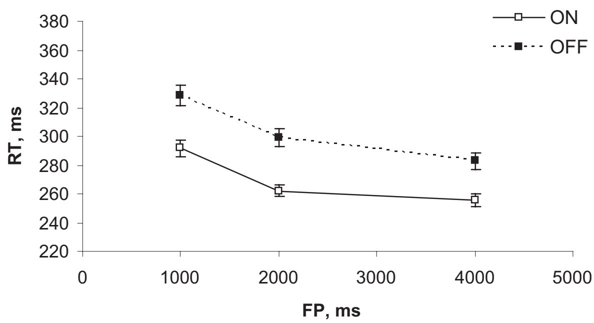

Figure 4. ***Reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod of the current trial. Error bars define the 95% confidence interval of the mean. N (number of subjects) = 12***

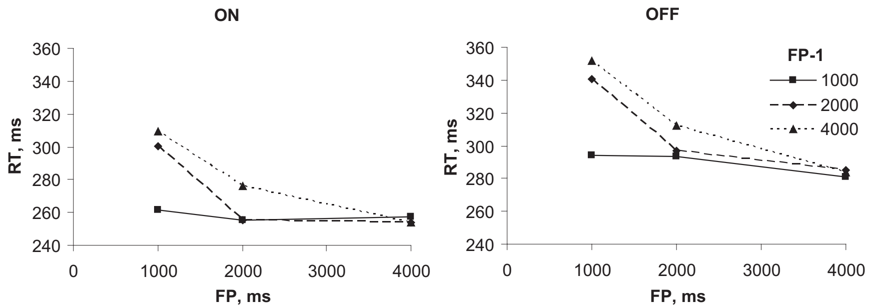

Figure 5. ***Sequential effects in reaction time to stimulus onset (ON) and offset (OFF) tasks. RT – reaction time; FP – foreperiod of the current trial; FP-1 – foreperiod of the preceding trial. N (number of subjects) = 12***

Discussion

Data of the second experiment are largely comparable with the first one, with a noticeable difference, however. The interaction between FP and the task disappeared in Experiment 2, so that the offset disadvantage became constant and independent of the FP. The interaction observed in the first experiment was, thus, at least to a large extent, due to the action effect induced by the onset of the diode co-occurring with button press in the offset condition. The consequences of these results for the interpretation of the offset disadvantage will now be discussed in the general discussion.

General Discussion and Conclusions

Both experiments in the present report replicate the traditional finding that onset RTs are faster than offset RTs. Given the stimulus durations used here, this effect cannot be due to visual persistence. V. Di Lollo et al. (2000) proposed that, in the task of RT to stimulus offset, stimulus onset automatically triggers the response, which has to be suppressed, resulting in a longer RT to stimulus offset than to stimulus onset. Since automatic activation is a short-lived process (Burle et al., 2002; Hommel, 1993 b; 1994; Ridderinkhof, 2002; van den Wildenberg et al., 2010), increasing the time between stimulus onset and offset should allow the suppression to be over at the time of the stimulus and hence reduce the offset disadvantage. This was studied by varying this interval, known as the foreperiod (FP).

The results of the first experiment support this view: a clear interaction was present between FP and the task, revealing that the offset disadvantage was the largest for a short FP and then decreased for longer ones. However, a closer analysis of the task revealed a potential confounding factor: in the offset task, button pressing was associated with an actual LED onset. This "action effect" might be unnatural for the participants (as compared with turning the LED off at button press), leading to an incompatible situation between an action and its sensory consequences (Hommel, 1993 a; 1996). Since resolving such an interference may take time, this could explain the larger offset disadvantage for short delays. We thus tested this hypothesis in the second experiment in which stimulus duration was independent of button press, the response being signalled by a sound inducing an identical action effect in both tasks. The results reveal a clear offset disadvantage, but no more interaction with FP. A comparison of the two experiments (see Figures 2 and 4) reveals remarkably similar RTs and the effect for the last two FP, indicating that in the first experiment the action effect indeed increased the offset disadvantage for the shortest FP.

The absence of interaction in the second experiment does not support the suppression idea of V. Di Lollo et al. (2000): giving a participant more time to suppress the potential response activation did not reduce the offset disadvantage, suggesting that suppression is not a key aspect. However, a large impact of action effect on the size of the offset disadvantage indicates a post-perceptual locus of this effect, likely at the response selection stage (Hommel, 1996). Having identified a post-perceptual locus of the offset disadvantage opens new perspectives and new questions that will be addressed in subsequent studies.

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PO SUVOKIMO VYKSTANČIŲ PROCESŲ ĮTAKA REAKCIJOS LAIKO Į STIMULO ĮJUNGIMĄ IR IŠJUNGIMĄ SKIRTUMAMS

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S a n t r a u k a

Reakcijos į stimulo išjungimą laikas nustatomas ilgesnis nei į stimulo įjungimą. Pasak V. Di Lollo ir bendraautorių (2000), reaguojant į stimulo išjungimą, pirmiausia automatiškai aktyvinamas atsakas į stimulo įjungimą, kuris turi būti nuslopintas. Tai lemia ilgesnį reakcijos į stimulo išjungimą nei į stimulo įjungimą laiką. Jeigu ši reakcijos laiko į stimulo išjungimą delsa iš tikrųjų priklauso nuo atsako į stimulo įjungimą slopinimo, tuomet galima tikėtis, kad šis slopinimas ilgėjant priešstimuliniam intervalui silpnės, taigi reakcijos laiko į stimulo atsiradimą ir išnykimą skirtumas – mažės. Pirmojo eksperimento rezultatai šią hipotezę patvirtino, tačiau, be atsako slopinimo, gautus reakcijos laiko skirtumus galėjo veikti ir skirtingi sensoriniai atsako padariniai skirtingose užduotyse (t. y. šviesos išjungimas reakcijos laiko į stimulo įjungimą užduotyje ir šviesos įjungimas reakcijos laiko į stimulo išjungimą užduotyje), taigi skirtingas veiksmo efektas. Šiai hipotezei patikrinti atlikome antrąjį eksperimentą, kuriame sulyginome sensorinius atsako padarinius abiejose užduotyse. Rezultatai patvirtino veiksmo efekto svarbą ir parodė, kad, sulyginus veiksmo efektą, atsako slopinimas turi mažai įtakos reakcijos laiko į stimulo išjungimą delsai.

Pagrindiniai žodžiai: reakcijos laikas, stimulo įjungimas, stimulo išjungimas.

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