

RESPONSE-RELATED FACTORS IN REACTION TIME TO STIMULUS ONSET AND OFFSET TASKS

Rugilė Sokolova

PhD Student
Department of Neurobiology and Biophysics
Faculty of Natural Sciences
Vilnius University
M. K. Čiurlionio 21/27
03101 Vilnius, Lithuania
E-mail: rugile.sokolova@gmail.com

Boris Burle

Senior Researcher, PhD
Laboratoire de Neurosciences Cognitives
Pôle 3C, Aix-Marseille Université, CNRS
3, place Victor-Hugo 13331 Marseille cedex 3,
France
E-mail: boris.burle@univ-provence.fr

Osvaldas Rukšėnas

Professor, PhD
Department of Neurobiology and Biophysics
Faculty of Natural Sciences
Vilnius University
M. K. Čiurlionio 21/27
03101 Vilnius, Lithuania
Tel: (+370 5) 2398 222
Fax: (+370 5) 2398 216
E-mail: osvaldas.ruksenas@gf.vu.lt

According to V. Di Lollo et al. (2000), the difference in reaction time to stimulus onset and offset is related to response suppression. By using electromyographic activity recording, in the first experiment we investigated whether both premotor and motor parts are affected by the task. Furthermore, in the second experiment, we investigated how other response-related factors, such as response type, could contribute to the difference between reaction time to stimulus onset and offset. In the first experiment, eleven subjects 29 ± 4.6 years old (six women and five men) performed reaction time tasks to stimulus onset and offset, and their response-related muscular activity was recorded. Sixteen 21.6 ± 1.5 years old subjects (eight women, eight men) participated in the second experiment, in which two types of response were required. The results have revealed that differences in the reaction time to stimulus onset and offset are independent of response type and are related to the premotor part of reaction time only.

Key words: reaction time, stimulus onset, stimulus offset

The adapting behavior in our environment requires a quick and efficient reaction to both the appearance and disappearance of stimuli. Despite the logical equivalent importance of stimuli onset and offset, it is well established that reaction time (RT) to the stimulus offset is longer than RT to

the stimulus onset. Although initially interpreted as a visual persistence effect (Briggs and Kinsbourne, 1972; Di Lollo, 1980), this explanation does not hold for longer stimulus durations (Di Lollo et al., 2000), and evidence for a post-perceptual locus has been provided (Di Lollo et al., 2000; Fisher

and Miller, 2008). For example, R. Fisher and J. Miller (2008), although in a different theoretical context, reported that response force was stronger for stimuli offset than to stimuli onset. Note, however, that force deployment, at least partially, occurs after response onset. Hence, this difference in force may not necessarily explain the chronometric difference classically reported. Recently, R. Sokolova et al. (2013) also provide arguments for the post-perceptual locus of the offset disadvantage: they have evidenced that the action effect (the expected sensory consequences of a motor action, see B. Hommel, 1993; 1996) plays a critical role in the size of the offset disadvantage. In the present report, we further explore the possible post-perceptual, motor-related effects. First, thanks to electromyographic (EMG) recordings of the muscles involved in the response, we fractioned the RT into the premotor time (from stimulus to EMG onset) and the motor time (from EMG onset to mechanical response) in order to directly chronometrically measure motor effects. In the second experiment, we investigated a possible stimulus-response mapping account of the offset disadvantage.

Experiment I

Method

Subjects

Eleven people (six women, five men) 29 ± 4.6 years old with a normal or corrected-to-normal visual acuity participated in the experiment. The experiment was performed in Laboratoire de Neurosciences Cognitives, Aix-Marseille University.

Procedure

Each subject performed two tasks – RT to stimulus onset (white light emitting diode – LED – onset) and RT to stimulus offset (white LED offset). Task primacy was counterbalanced among the subjects. LED (which has sub-millisecond time accuracy, e.g., L. Svilainis (2008)) with the diameter of 1.5 cm was placed on the center of a grey panel (width 19.8 cm, height 9.7 cm) in front of subject's eyes (at the same level as eyes) at a distance of 53 cm. LED was connected to a stimulus generating computer (Core 2 Duo CPU 3.0 GHz, 4 GB RAM) through a parallel port. The response button was made especially for the RT experiment, in which response with the thumb is required. The response button was attached to the board for stability and was connected to the same computer through the parallel port. The use of a parallel port ensures a sub-millisecond time accuracy (Stewart, 2006). The experimental program was written in the C programming language and was loaded in a T-Scope (Stevens et al., 2006). Each task comprised five blocks. Each block was followed by a short 1–2-minute break. One practice block was presented before each of two tasks. 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 white LED in the current trial in RT to stimulus offset tasks, see below) that lasted 1000, 2000 or 4000 ms. This interval will be termed “foreperiod” (FP). Each block consisted of 63 trials, each FP being repeated 21 times in a random order. At the end of the FP, an imperative stimulus (onset or offset of

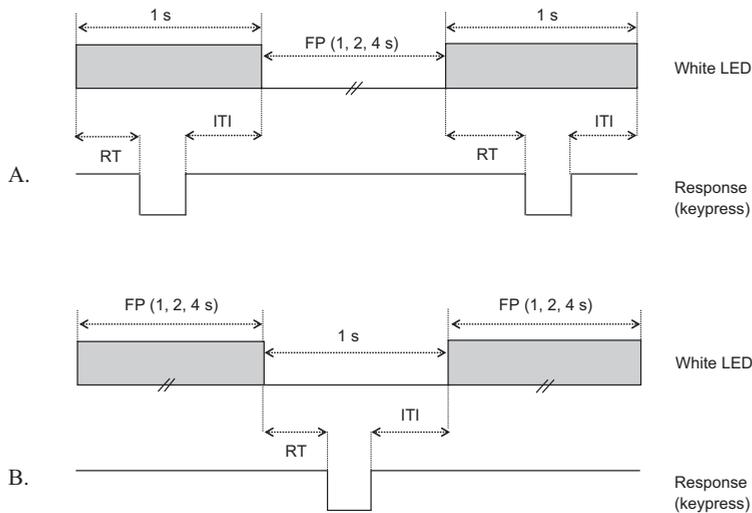


Figure 1. A – reaction time to stimulus onset task; B – reaction time to stimulus offset task. RT – reaction time; FP – foreperiod; ITI – intertrial interval; LED – light emitting diode

the white LED) was presented, to which subjects had to react as fast as possible (see Figure 1A and 1B). A subject had 1 s to respond. The subject's response did not remove the stimulus which stayed present until the end of 1 s, whatever RT duration (see Figure 1A and 1B). In order to signal that the response was given, a sound feedback was delivered. The period of time between RT and the end of 1 s was termed the intertrial interval. Hence, in both tasks, the key press was associated with the same action effect, namely a brief sound.

Electromyographic activity was recorded by means of Ag-AgCl flat Biosemi electrodes (11 mm width, 17 mm length, and 4.5 mm height) placed above the muscle flexor pollicis brevis of the thumb of a responding hand 2 cm apart. Electromyographic activity was continuously monitored (by means of BIOSEMI ActiveTwo system, Biosemi Inc., Amsterdam,

The Netherlands), amplified (BIOSEMI ActiveTwo), filtered (10 Hz to 1 kHz) and digitized online (BIOSEMI ActiveTwo, A/D rate 2 kHz) during each block. EMG facility was synchronized with the stimulus-generating computer through the parallel port, ensuring a sub-millisecond synchronization, but the EMG signal was saved in another computer (Pentium 4 CPU 2.8 GHz, 2 GB RAM).

EMG data analysis

Electromyographic data analysis was performed with a BrainVision Analyser (version 1.05, Brain Products, Germany). From the subsequent analysis, 17.35% of trials identified as anticipations (response before stimulus) or misses (including insufficient response force to close the response switch), were excluded. Additional 5.95% of trials were excluded because of an inappropriate EMG signal. On correct trials, the start of

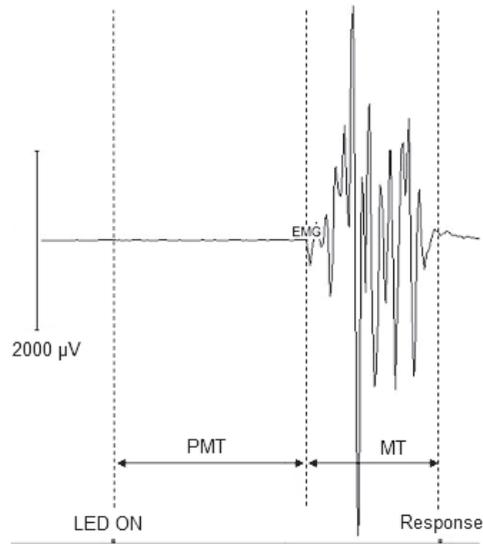


Figure 2. Example of electromyographic activity marking and reaction time partition into premotor (PMT) and motor (MT) time. EMG – electromyographic activity marker which marks the start of this activity; LED ON – light emitting diode switched on

EMG activity was determined visually and marked manually (Figure 2). This method was preferred to automatic ones because manual marking, although longer than the automatic procedure, is more precise (Hasbroucq et al., 2001; Van Boxtel et al., 1993).

Results

At the behavioral level, repeated measures ANOVA revealed a significant effect of the task $F(1, 10) = 12.68, p < 0.05$ and FP $F(2, 20) = 12.66, p < 0.05$, but the FP-task interaction was not statistically significant $F(2, 20) = 1.08, p = 0.36$. Gender was not a significant factor $F(1, 9) = 0.13, p = 0.73$, neither was the task priority $F(1, 9) = 0.25, p = 0.63$. The difference of RT to stimulus onset and offset was 20 ms at 1000 ms FP, 18 ms at 2000 ms FP, and 12 ms at 4000 ms FP (Figure 3).

We divided RT into premotor time (PMT) (Figure 4A) and motor time (MT) (Figure 4B) based on the start of electromyographic activity (Figure 2). Repeated measures ANOVA for PMT data revealed a significant effect of task $F(1, 10) = 23.91, p < 0.05$ and FP $F(2, 20) = 20.05, p < 0.05$, but their interaction was not statistically significant $F(2, 20) = 2.17, p = 0.14$. The difference between PMT to stimulus onset and offset was as follows: 22 ms at 1000 ms FP, 18 ms at 2000 ms FP, 13 ms at 4000 ms FP (Figure 4A).

Repeated measures ANOVA for MT data revealed no effect of the task $F(1, 10) = 0.09, p = 0.77$ and a marginal effect of FP $F(2, 20) = 2.85, p = 0.08$. Their interaction $F(2, 20) = 0.59, p = 0.57$ was far from significant. Task priority $F(1, 9) = 0.93, p = 0.36$ was not a statistically significant factor, either. Even if gender $F(1, 9) = 7.55, p <$

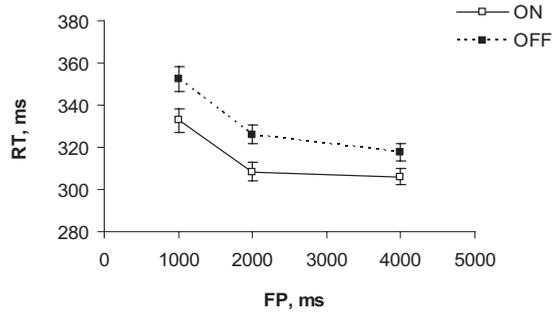
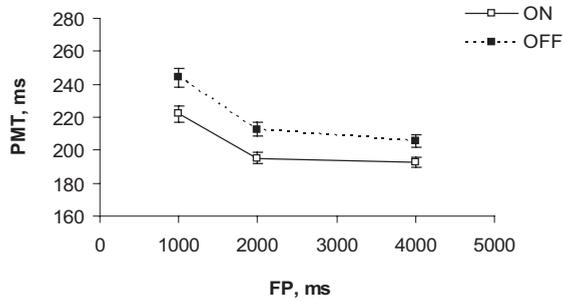
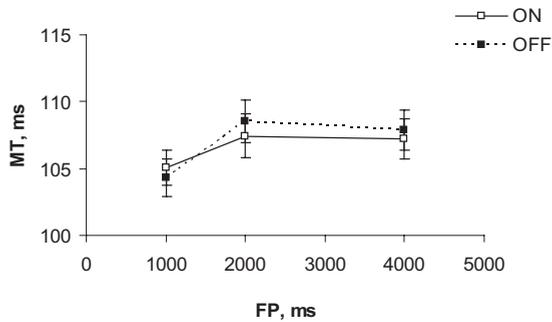


Figure 3. Behavioral simple reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod. Error bars define 95% confidence interval of the mean. N (number of subjects) = 11



A.



B.

Figure 4. Components of reaction time based on electromyographic activity recording. A – premotor time (PMT), B – motor time (MT). ON – reaction time to stimulus onset task; OFF – reaction time to stimulus offset task. Error bars define the 95% confidence interval of the mean. N (number of subjects) = 11

0.05) had a significant effect on MT (MT for men (96 ms) being shorter than for women (116 ms)), it was far from interacting with the task ($F(1, 9) = 0.0003, p = 0.99$).

Discussion

RT fractioning revealed no effect of the task on late motor components. With the same methodology, we have already reported small but reliable effects of other variables (for instance, motor preparation (Possamaï et al., 2002; Tandonnet et al., 2003)), thus this absence of the effect in current experiment is probably not a type II error. Since the later motor stages of RT are spared by the on-off effect, we move one step back in the information processing and explore a possible stimulus–response compatibility effect. Indeed, in the task of RT to stimulus onset subjects are required to give a press response to the onset of a stimulus, which is very natural, or, in other words, entails a highly compatible mapping between the stimulus and response. In the offset task, subjects must provide the same press response to a stimulus offset. It might be that this association is less natural, i.e. more incompatible. If so, we reasoned that some other type of response might be more compatible with stimulus offset. To test this hypothesis, in the second experiment, we asked the subjects to either press a response button at stimulus onset or offset, or to release a button for the same condition.

Experiment II

Method

Subjects

Sixteen 21.6 ± 1.5 years old subjects (8 women, 8 men) with a normal or corrected-to-normal visual acuity participated in the

experiment. The experiment was performed at the Department of Neurobiology and Biophysics of Vilnius University.

Procedure

Each subject performed two tasks – RT to stimulus onset (white LED onset) and RT to stimulus offset (white LED offset). The tasks, procedure, experimental setup were the same as in the first experiment, except that in this experiment there were two response types and no intertrial interval (no sound feedback). The stimulus, as well as response button were connected to the same computer (Intel Core 2, ~1600 Mhz, 2 GB RAM) through a parallel port; no EMG activity was recorded. As there were two types of response – button press and button release in this experiment, four tasks were composed: button press as a response to stimulus onset, button press as a response to stimulus offset, button release as a response to stimulus onset, button release as a response to stimulus offset. Each task comprised three blocks.

The tasks were counterbalanced according to the balanced Latin square (Edwards, 1951). Button press tasks were the same as in the first experiment, except that a subject's response removed the stimulus (see Figure 5A and 5B) – the LED was turned off (in the onset task) or turned on (in the offset task) after the response button had been pressed. In button release response tasks, subjects were instructed to continuously keep the response button pressed during the block and to release it just shortly when responding to stimulus onset (RT to stimulus onset task) or stimulus offset (RT to stimulus offset task). LED was turned off (in the onset task) or turned on (in the offset task) after the response button had been re-

leased. After a short release, the button had to be pressed again immediately and kept pressed until the next response (see Figure 5A and 5B). Subjects had 1 s to respond.

Results

1.07% of trials, identified as anticipations or misses, were excluded from the subsequent analysis (limits were chosen according to Di Lollo et al. (2000)).

Repeated measures ANOVA revealed a significant effect of response type ($F(1, 15) = 5.52, p < 0.05$), of task ($F(1, 15) = 57.76, p < 0.001$) and of FP ($F(2, 30) = 13.87, p < 0.001$), but neither the interaction between response type and task ($F(1, 15) = 0.06, p = 0.82$) nor between response type and FP ($F(2, 30) = 1.05, p = 0.36$) were significant. The task and FP interaction ($F(2, 30) = 13.08, p < 0.001$) was statistically significant. Gender was not a statistically

significant factor ($F(1, 14) = 1.8, p = 0.2$), nor did it interact with the task ($F(1, 14) = 0.93, p = 0.35$). RT to stimulus onset was faster than to stimulus offset at all FPs of response type (Figure 6).

Discussion

The present data replicate our previous findings (Sokolova et al., 2013), namely when the response of the subject is associated with stimulus removal (LED onset or offset, depending on the task), there is an interaction between FP and task, the onset–offset RT difference being larger for short FP, which suggests that the action effect (i.e. the expected sensory consequences of an action) plays an undeniable role in the difference between RT to stimulus onset and offset.

Although the response type affected the RT, it did not interact with the task. In other words, responding to a stimulus offset was

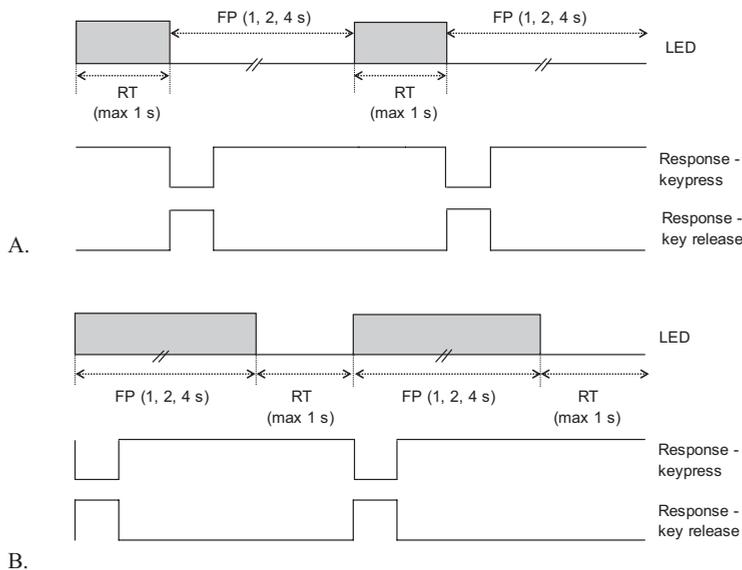


Figure 5. *A* – reaction time to stimulus onset task; *B* – reaction time to stimulus offset task. RT – reaction time; FP – foreperiod; LED – white light emitting diode; max – maximum

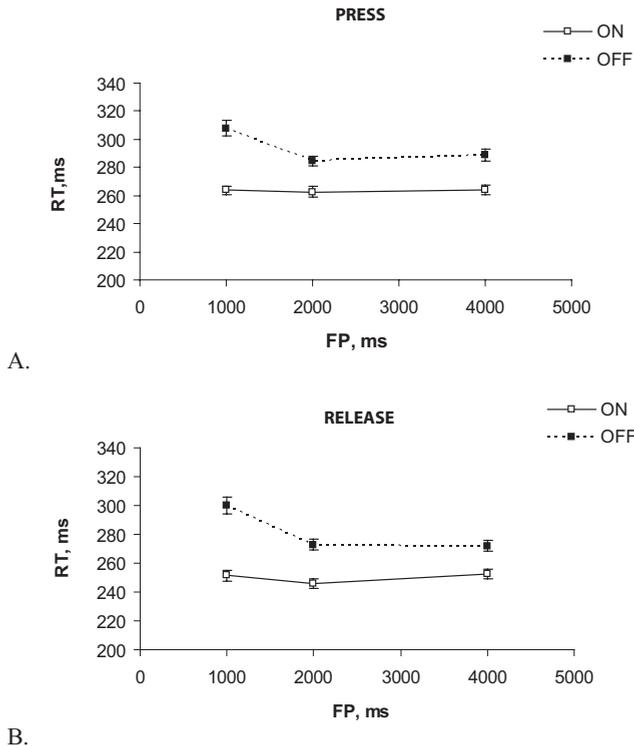


Figure 6. Reaction time to stimulus onset (ON) and offset (OFF) when responses were: A – button press and B – button release. RT – reaction time; FP – foreperiod. Error bars define the 95% confidence interval of the mean. N (number of subjects) = 16

not easier by releasing a button than by pressing it. This could be due to the fact that difference between RT to stimulus onset and offset does not occur at the response selection stage.

General discussion

The main goal of the first experiment was to investigate which part of RT – premotor, motor, or both – are affected by offset disadvantage. Activity recording of the response-related muscle – flexor pollicis brevis – during simple RT tasks to stimulus onset and offset enabled us to divide the behavioral RT into premotor time (time from stimulus – onset or offset – presentation to

the start of muscle activity) and motor time (time from the start of muscle activity to the mechanical response being recorded). This method is useful because it allows to locate the effect of experimental manipulation (Davranche et al., 2005), and it is possible to determine whether manipulation affects the part of RT before the electromyographic activity or after it, thus revealing whether it affects response execution and/or processes upstream (Botwinick and Thompson, 1966; Burle et al., 2002; Davranche et al., 2005; Hasbroucq et al., 1995; 2001; 2003; Pos-samaï et al., 2002). Our results replicate a faster behavioral RT to stimulus onset (Di Lollo et al., 2000). However, after partition

of RT into premotor and motor times, a statistically significantly faster RT to stimulus onset than to stimulus offset remained only in the premotor part. These results suggest that offset disadvantage is generated in the premotor part of RT. Keeping in mind the results from electrophysiological experiments (Hari et al., 1987; Pratt et al., 2008; Servière et al., 1977) which revealed sensory OFF potential latency to be shorter than the ON potential latency, it might be deduced that the locus of offset disadvantage is between the sensory part of the RT and the neuromuscular activity. All together, this suggests that the locus of offset disadvantage is post-perceptual, but pre-motoric.

In order to investigate whether offset disadvantage is related to the response-selection stage, to investigate the influence of the response type on RT to stimulus onset and offset differences we performed the second experiment, in which we used two types of response – button press and button release. We hypothesized that stimulus initiation could be more compatible with the initiation of response (button press), and stimulus cessation could be more compatible with response termination (button release), expecting a statistically significant task-response type interaction. Even if the response type was a statistically significant factor revealing the release RT being shorter for all foreperiods, no interaction showed up, indicating that the offset disadvantage is the same for press and release conditions. In other words, no compatibility effect was revealed. The reason for a shorter release RT than press RT might be due to different factors, including mechanical, button-related ones. However, importantly, such a bias would be the same for all foreperiods and for both tasks, and hence could not hinder a

possible interaction. This is consistent with the results of P. Wuhr and W. Kunde (2006), which showed no compatibility among the stimulus onset, offset, and response (button press or release) in the choice RT – Simon task. Our results revealed the same pattern in a simple RT task and with a stimulus, which is not changing its location, being in the centre of the field of view (what was opposite to the experiment of P. Wuhr and W. Kunde (2006)). L. Riggio et al. (2012), P. Wuhr and W. Kunde (2006) also showed the Simon effect not only in stimulus onset tasks, but also in stimulus offset tasks. P. Wuhr and W. Kunde (2006) demonstrated the Simon effect not only in the button press but also in the button release tasks. They suggested that the cognitive system encodes not only the location of stimulus onsets, but also the location of stimulus offsets. Our results suggest that the cognitive system might automatically encode the response in stimulus onset as well as in stimulus offset tasks, independently whether it is button press or button release, meaning that the response selection and its performance parts in these tasks do not differ. However, there could be an explanation why we did not get a compatibility between the stimulus and response. According to P. Wuhr and W. Kunde (2006), the stimulus offset task might be cognitively represented differently – as the terminating ongoing key press or as an initiating finger-lifting movement.

Moreover, RT remained statistically significantly faster to stimulus onset than RT to stimulus offset at all FPs in the first and second experiments in behavioral data and in PMT data of the EMG experiment as well. ANOVA in the second experiment revealed a statistically significant interaction between the task and FP, but as could be seen in the

button press data (Figure 6A) and the button release data (Figure 6B), the largest RT difference to stimulus onset and offset is at the shortest foreperiod of 1000 ms (button press condition 44 ms, button release condition 49 ms) and then it stabilizes at other foreperiods (button press condition: at 2000 ms – 22 ms, at 4000 ms – 25 ms; button release condition: at 2000 ms – 27 ms, at 4000 ms – 20 ms). This pattern of RT to stimulus onset and offset does not seem to be influenced by response type. The pattern remains similar in both the button press and the button release tasks. Such pattern of results is compatible with a stronger need for response suppression to stimulus onset in the stimulus offset task at the shortest FP (Di Lollo et al. 2000). Such interaction, however, is only present when a

subject's response is associated with stimulus removal, suggesting that action effect is critical for such a suppression to take place.

To summarize, our results have shown that the difference of RT to stimulus onset and offset is independent of the response type (button press or button release), i.e. it cannot be explained by (in)compatibility between stimulus onset and button press or between the offset of the stimulus and button release. Fractioning RT with respect to electromyographic activity revealed the effect of the task only in PMT, suggesting that the locus of the stimulus (onset or offset) manipulation is upstream from the neuromuscular activity. However, further studies are needed in order to determine better the locus of the RT difference to stimulus onset and offset.

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SU ATSAKU SUSIJĘ VEIKSNIAI REAKCIJOS LAIKO Į STIMULO ĮJUNGIMĄ IR IŠJUNGIMĄ UŽDUOTYSE

Rugilė Sokolova, Osvaldas Rukšėnas, Boris Burle

S a n t r a u k a

Pasak V. Di Lollo ir bendraautorių (2000), reakcijos laiko į stimulo įjungimą ir išjungimą skirtumai yra susiję su atsako slopinimu. Pirmajame eksperimente elektromiografijos metodu tyrėme, ar abi reakcijos laiko dalys – priešmotorinė ir motorinė – yra veikiamos užduoties. Antrajame eksperimente siekėme išsiaiškinti, kaip kiti su atsaku susiję veiksniai, pavyzdžiui, atsako tipas, galėtų veikti šiuos reakcijos laiko skirtumus. Pirmajame eksperimente dalyvavo vienuolika $29 \pm 4,6$ metų asmenų (šešios moterys ir penki vyrai), kurie atliko reakcijos laiko į stimulo

įjungimą ir išjungimą užduotis, tuo pačiu metu buvo registruojamas atsake dalyvaujančio raumens aktyvumas. Antrajame eksperimente, kuriame naudojome du atsako tipus, dalyvavo šešiolika $21,6 \pm 1,5$ metų žmonių (aštuonios moterys ir aštuoni vyrai). Rezultatai parodė, kad reakcijos laiko į stimulo įjungimą ir išjungimą skirtumai nepriklauso nuo atsako tipo, be to, šie skirtumai buvo susiję tik su priešmotorine reakcijos laiko dalimi.

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