VILNIUS UNIVERSITY

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FACTORS INFLUENCING DIFFERENCES BETWEEN REACTION TIME TO STIMULUS ONSET AND OFFSET

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Abbreviations

EMG – electromyographic, electromyography

FP – foreperiod

ITI – intertrial interval

LED – light emitting diode

MT – motor part of reaction time (motor time)

OFF – stimulus offset

ON – stimulus onset

PMT – premotor part of reaction time (premotor time)

RT – reaction time

RT_{OFF} – reaction time to stimulus offset

RT_{ON} – reaction time to stimulus onset

INTRODUCTION

Fast, effective and adequate reactions to sudden external stimuli are essential for living organisms to adapt in the environment and to survive. Stimulus onset and stimulus offset are relevant events, informing about the changes in the environment. One usually reacts to stimulus onset, which is a common environmental change. However stimulus offset is informative and important as well. Stimulus offset is relevant in pilot job while controlling aircrafts, where any offset of the indicator is extremely important, in the job of aircraft traffic guides, in medicine (instrument has to be withdrawn only when the sound is turned off during laparoscopic surgery), in music and language perception as well as production, in driving. Reactions to external stimuli are modeled and researched in laboratory conditions as well. Experiments with reaction time (RT) to various stimuli onset (ON) are usual. However experiments concerning stimulus offset (OFF) can provide interesting additional information about action formation, production as well as activity of the nervous system. OFF signal is relevant in researches concerning RT_{ON}-RT_{OFF} differences, visual persistence, duration perception, omission detection, language perception, gap detection. It is also important in clinical researches for diagnosing various disorders. For example, the amplitude of visual $P1_{OFF}$ event related potential is larger in Parkinson patients in comparison with healthy individuals (Bandini et al., 2001). Coherence decay of the visual steady-state response after stimulus offset is delayed in schizophrenia patients in comparison with healthy subjects (Clementz et al., 2004).

Researches of differences between RT_{ON} and RT_{OFF} can provide more information about the mechanisms of information coding, processing, interaction between stimulus and response, response formation. Usually RT_{ON} is revealed as shorter than RT_{OFF}. When stimuli are of very short duration (< 1 s) this RT_{ON}-RT_{OFF} difference is explained by the visual persistence (Briggs & Kinsbourne, 1972; Di Lollo, 1980). However for the stimuli of longer duration this explanation is no longer appropriate (Di Lollo et al., 2000).

Di Lollo et al. (2000) suggested another interpretation. According to this interpretation stimulus onset in RT_{OFF} task automatically activates processes of the response to stimulus onset. These processes have to be suppressed and this suppression determines longer RT_{OFF}. This view is supported from conflict tasks as well. Wühr & Kunde (2006) got larger Simon effect (which is usually described as the difference between RT when stimulus and response positions correspond and when they do not correspond with stimulus position being irrelevant to the task) in RT_{ON} task than in RT_{OFF} task. Longer RT in noncorresponding position is usually explained by the suppression of ipsilateral hand response activation to stimulus position (left or right) (Burle et al., 2002a). The results of Wühr & Kunde (2006) suggest that response activation was stronger in onset than in offset condition in accordance with the idea of Di Lollo et al. (2000). This response activation is usually short-lived and decreases soon after the stimulus presentation either spontaneously (Hommel, 1993b, 1994) or under active suppression (Burle et al., 2002a; Ridderinkhof, 2002; van den Wildenberg et al., 2010 review). Therefore, the RT_{ON}-RT_{OFF} difference should decrease with increasing time interval between the stimulus onset and offset (i.e. foreperiod, (FP)).

The other factor which could influence the RT_{ON}-RT_{OFF} difference is action effect, according to which actions are influenced by their sensory consequences (Hommel, 1993a, 1996). Hommel (1993a) showed action-effect compatibility by revealing longer RT when pressing left button switched on the right light than the left light. In the first experiment of the current research LED was turned off in stimulus onset task and turned on in stimulus offset task. Thus, both tasks had different action effects and this incompatibility could influence the results. Therefore, the second experiment was carried out in which action effect was equalized in both tasks.

Fisher & Miller (2008) showed that response force was larger in RT_{OFF} tasks than in RT_{ON} tasks, although in quite different theoretical context. They interpret that larger force in RT_{OFF} tasks is needed to overcome the suppression of the response, thus in accordance with the hypothesis of Di Lollo et al. (2000). Although the deployment of the response force occurs partly during the process of response, it does not necessarily explain the chronometric differences between the tasks. However, this in general suggests the possible involvement of not only premotor, but also motor processes. Furthermore, considering the results from the first two experiments, which revealed the role of response-related factors, the third experiment was performed, in which the influence of the task on the premotor and motor parts of RT was studied employing the method of electromyography (EMG).

Considering the results from the third experiment (that only premotor part of RT is affected by the task), the results from the first two experiments (showing the role of response-related factors) and keeping in mind Di Lollo et al. (2000) suggestion, as well as stimulus-response compatibility theory (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum et al., 1990; Proctor et al., 2002), according to which the stimulus can be more or less compatible with the response, it was hypothesized that response type could influence the RT_{ON}-RT_{OFF} difference. This would demonstrate the importance of the stage of response selection. In order to test this, the fourth experiment was performed, in which the influence of the response type was tested.

The novelty of this research is that the difference between reaction time to stimulus onset and offset was studied as a function of foreperiod, premotor and motor RT parts were compared between the reaction time to stimulus onset and offset tasks, the influence of the action effect and response type (in simple reaction time) on the differences between reaction time to stimulus onset and offset was studied.

The aim is to investigate the influence of response-related factors on the difference between reaction time to stimulus onset and offset.

Tasks:

- to test the influence of foreperiod on the difference between reaction time to stimulus onset and offset;
- to test the influence of the action effect on the difference between reaction time to stimulus onset and offset;
- to test if premotor and motor parts (according to electromyographic activity measurements) of reaction time differ between the reaction time to stimulus onset and offset;
- to test the influence of the response type on the difference between simple reaction time to stimulus onset and offset.

Statements to defend (or hypotheses):

1. The difference between the reaction time to stimulus onset and offset decreases as foreperiod increases.
2. Action effect influences the difference between the reaction time to stimulus onset and offset by increasing it as foreperiod decreases.
3. Not only premotor, but also motor parts of the reaction time differ between the tasks of reaction time to stimulus onset and offset.
4. Response type influences the difference between the simple reaction time to stimulus onset and offset – the difference is larger at button press than at button release condition.

1. THE FIRST EXPERIMENT

The task of the first experiment was to investigate influence of the foreperiod to the difference between the reaction time to stimulus onset and offset.

1.1. Methods

1.1.1. Subjects

The experiment was carried out at the Cognitive Neurosciences Laboratory, Aix-Marseille University, Marseilles, France. Twelve (28.8±1.9 years old) subjects with normal or corrected-to-normal visual acuity participated in the experiment. Gender was counterbalanced – 6 women and 6 men were tested.

1.1.2. Procedure

Each of the subjects performed two tasks: reaction time to stimulus (white LED) onset (RT_{ON}) and reaction time to stimulus (white LED) offset (RT_{OFF}). During the first task the subjects were asked to press the response button as soon as they see the onset of LED and in the second task – as soon as they see the offset of LED. RT_{ON} and RT_{OFF} tasks were presented in different blocks (ON task – in one block and OFF task – in another block). Order of the tasks was counterbalanced between the subjects. LED (which use ensures sub-millisecond timing accuracy (Svilainis, 2008)) was attached on the grey board in front of the subject's eyes with the distance of 53 cm. LED and the response button (which is pressed with the thumb and made especially for RT experiment) were connected to the Dell computer (Xeon CPU 2.0 GHz, 2 GB RAM) through the parallel port which ensures sub-millisecond timing accuracy (Stewart, 2006). Experiment was performed in a dim room, isolated from the external sounds. Experimental program was presented in the open-source T-Scope environment (Stevens, 2006). Each of the tasks started with the warning stimulus – i.e. LED onset or offset, marking the start of the foreperiod interval which lasted 1000, 2000 or 4000 ms (Olivier & Rival, 2002) (Fig. 1.1 A and B). In the RT_{ON} task, stimulus (LED light) offset from the previous trial marked the start of the foreperiod in the current trial and in the RT_{OFF} task foreperiod of the current trial started with the LED onset. Each of the FP was finished with the imperative stimulus (LED onset (in RT_{ON} task) or offset (in RT_{OFF} task)) to which the subject had to react as soon as possible by pressing the response button.

Subject had 1 s to respond. Instantly after the button press the imperative stimulus was replaced with the warning stimulus which marked the start of a FP in a new trial. Thus, response-stimulus interval was determined as FP.

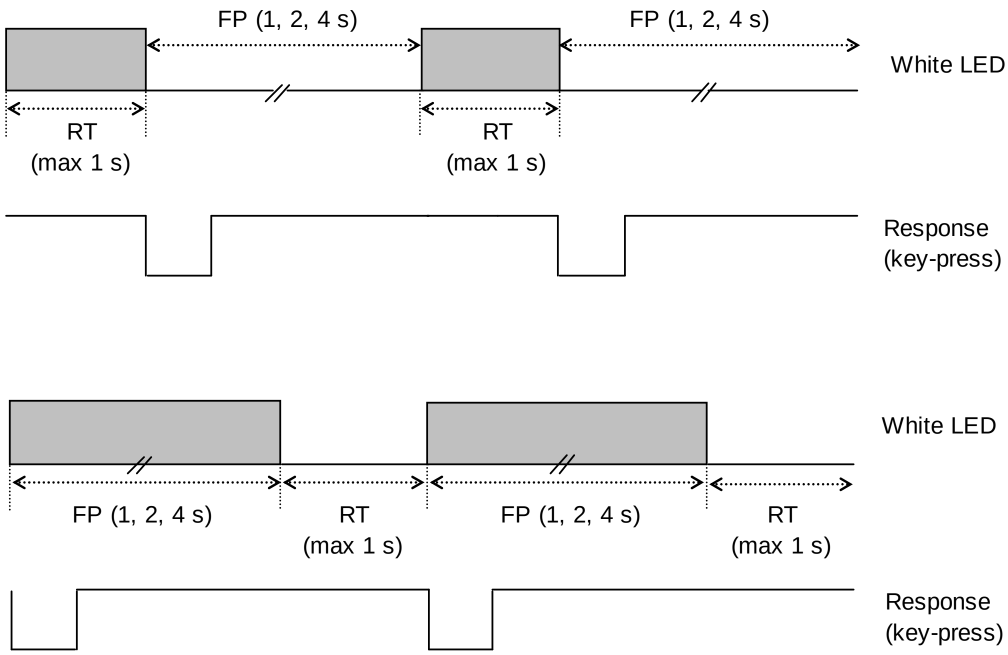


***Figure 1.1. A** – reaction time to stimulus onset task; **B** – reaction time to stimulus offset task. FP – foreperiod; RT – reaction time; LED – light emitting diode.*

Each block consisted of 63 trials with each foreperiod repeated 21 times in random order. Each of the tasks was comprised of the five blocks, performed consecutively with 1-2-minutes breaks after each of the blocks. One practice block was performed before each of the task. Half of the subjects performed five blocks with RT_{ON} task first, another half of the subjects – five blocks with RT_{OFF} task first. Duration of the whole experiment was about one hour.

1.1.3. Data analysis

Mean RTs, standard deviations, confidence intervals of the means in RT_{ON} and RT_{OFF} tasks at each of FPs were calculated for the each subject and generally. Results were analysed using repeated measures analysis of variance (ANOVA) in order to test the effect of the task (RT_{ON} and RT_{OFF}), FP (1000, 2000, 4000 ms), gender, task priority (onsets first, offsets first), as well as the effect of their interactions. RT between the tasks (ON and OFF) at different FPs and RT between the different FPs in the same task (RT_{ON}, RT_{OFF}) were compared with using planned comparisons method (Rutherford, 2011; Ruxton & Beauchamp, 2008). Pearson correlation coefficients calculated to test the correlation between ON and OFF RTs. Sequential effects analysis was performed.

1.2. Results

4.6% of trials, identified as anticipations (response before the stimulus) or misses (including insufficient response force to close the response switch), were excluded from the subsequent analysis. Limits for anticipations (100 ms and less) or misses (1000 ms and more) were chosen according to Di Lollo et al. (2000).

Mean RTs and standard deviations in RT_{ON} and RT_{OFF} tasks at each FP were calculated (Table 1.1).

Table 1.1. *Mean reaction times and standard deviations of the means.*

Task	FP, ms		
	1000	2000	4000
RT_{ON}, ms	274±90	261±87	254±71
$RT_{OFF,}$ ms	345±135	302±104	285±89
RT_{OFF} - RT_{ON}, ms	73.2±60.9	40.3±38.7	31.0±31.7

RT_{ON} – reaction time to stimulus onset, RT_{OFF} – reaction time to stimulus offset, OFF-ON – difference between reaction time to stimulus offset and onset, FP – foreperiod. N (number of subjects) = 12.

Repeated measures ANOVA 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 interaction between the task and FP ($F (2, 22) = 10.0$, $p < 0.001$). Thus, RT to stimulus onset was statistically significantly shorter than RT to stimulus offset and this difference depended on FP. Gender was not a statistically significant factor ($F (1, 10) < 1$), thus gender did not influence the RT. Gender-task interaction was not statistically significant also ($F (1, 10) = 0.47$, $p = 0.51$). Even if ANOVA revealed significant effect of the task priority ($F (1, 10) = 5.04$, p =

0.049), there was no interaction between the task priority and the task ($F(1, 10) = 0.03$, $p = 0.86$).

As ANOVA revealed significant interaction between the task and FP, planned comparisons (Rutherford, 2011; Ruxton & Beauchamp, 2008) were performed in order to check if RT_{ON}-RT_{OFF} difference was significant at different FPs. As the number of planned comparisons for one factor is equal to the number of factor levels minus one, and number of comparisons for two factors interaction is (p-1)(q-1) (where p ir q are the number of levels of each factors) (Rutherford, 2011; Ruxton & Beauchamp, 2008). Thus, for the current RT_{ON}-RT_{OFF} comparison at different FPs just two comparisons were possible. Since according to the hypothesis and experimental data the RT_{ON}-RT_{OFF} difference decreases with increasing FP, it was decided to test if the RT_{ON}-RT_{OFF} difference is still statistically significant at the shortest FP_{2000} and FP_{4000}. Contrast coefficients assigned were 1 and -1 for RT_{ON} and RT_{OFF} tasks respectively. Analysis revealed that RT_{ON}-RT_{OFF} difference was statistically significant at both FPs: at 2000 ms ($F(1, 11) = 12.99$, $p < 0.01$) and at 4000 ms ($F(1, 11) = 11.45$, $p < 0.01$). Two planned comparisons for comparing RTs between different FPs in the same task were also performed. In the first comparison contrast coefficients of 2; -1; -1 were assigned to FP_{1000}, FP_{2000} and FP_{4000} respectively. In the second comparison contrast coefficients of 1 and -1 were assigned to FP_{2000} and FP_{4000} respectively. Results in the onset task revealed that RT_{ON} at FP_{1000} did not differ from the mean RT_{ON} between FP_{2000} and FP_{4000} ($F(1, 11) = 4.14$, $p = 0.07$). RT_{ON} at FP_{2000} did not differ from RT_{ON} at FP_{4000} ($F(1, 11) = 2.07$, $p = 0.18$). Results in the offset task revealed that RT_{OFF} at FP_{1000} differed statistically significantly from the mean RT_{OFF} between FP_{2000} and FP_{4000} ($F(1, 11) = 16.49$, $p < 0.01$). RT_{OFF} at FP_{2000} differed statistically significantly from RT_{OFF} at FP_{4000} ($F(1, 11) = 7.97$, $p < 0.01$). The change of RT_{ON}-RT_{OFF} difference as FP increases can be seen in Figure 1.2.

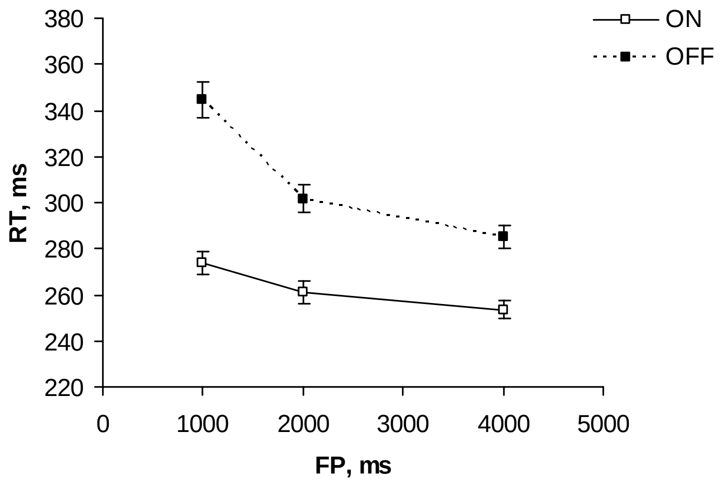


Figure 1.2. *Mean reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod of current trial. Error bars define 95% confidence interval of the mean. N (number of subjects) = 12.*

Correlation coefficients (with the mean correlation is 0.75) revealed that correlation between RT_{ON} and RT_{OFF} in different FPs is strong ($r > 0.7$). Thus, onset and offset are interrelated – RT_{OFF} increases as RT_{ON} increases.

It is also known that RT depends not only on the current FP, but on preceding FP also (Los, 2010; Niemi & Naatanen, 1981 for reviews): RT with current short FP is usually longer when preceding FP is longer than current, but the length of the preceding FP becomes irrelevant at the longest current FP because preparation is the best at the longest FPs. Repeated measures ANOVA revealed a clear effect of preceding FP ($F (2, 22) = 10.33$, $p < 0.001$) and classical sequential effect ($F (4, 44) = 18.64$, $p < 0.001$, see Figure 1.3), qualified by the interaction between the current and the preceding FP. However, the interaction between the sequential effect and the task was not statistically significant ($F (4, 44) = 1.13$, $p = 0.35$). Sequential effects can be seen in Figure 1.3.

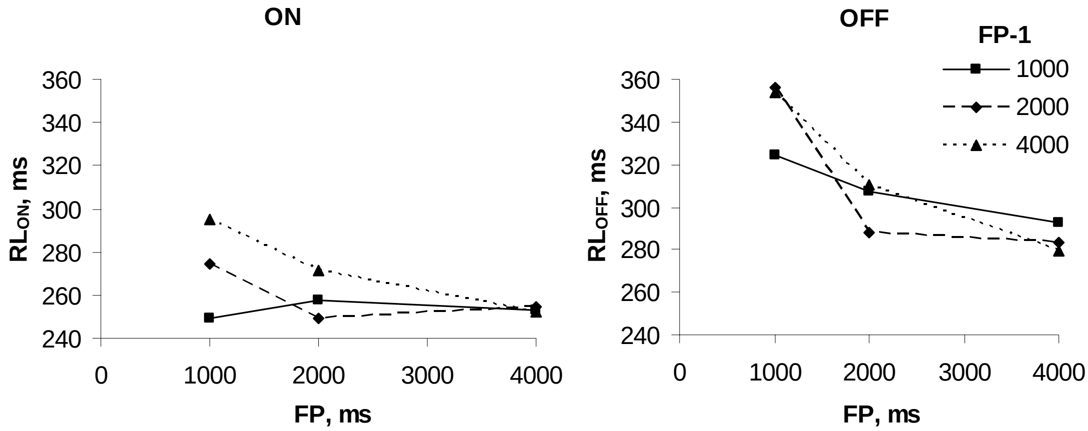


Figure 1.3. *Sequential effects in reaction time to stimulus onset (ON) and offset (OFF) tasks. RT – reaction time; FP – foreperiod of the current trial; FP-1 – foreperiod of the preceding trial. N (number of subjects) = 12.*

1.3. Discussion

Results revealed that RT_{ON} remains shorter than RT_{OFF} while FP increases. Shorter RT_{ON} than RT_{OFF} corresponds to the results of other authors as well (Briggs & Kinsbourne, 1972; Di Lollo et al., 2000; Fischer & Miller, 2008; Parker, 1980; Rolke et al., 2006; Wühr & Kunde, 2006). Sequential effects, gender or task priority did not influence the task.

According to the theory of Di Lollo et al. (2000) longer RT_{OFF} is produced by the suppression of the response to stimulus onset in stimulus offset task. Thus, it is expected that the RT_{ON}-RT_{OFF} difference decreases as the interval between the stimulus onset and offset increases. ANOVA and planned comparisons revealed significant task-foreperiod interaction demonstrating statistically significant change of RT_{ON}-RT_{OFF} difference depending on FP (the largest difference is at the shortest FP and decreases as FP increases, see Figure 1.2). RT_{OFF} changes more than RT_{ON} as FP increases. This is in accordance with the hypothesis of Di Lollo et al. (2000) that stimulus onset activates the response which has to be suppressed in stimulus offset task and the suppression decreases as FP increases.

The other factor, which could influence the RT_{ON}-RT_{OFF} difference, is action effect, according to which motor actions are influenced by the sensory consequences of the action (Elsner & Hommel, 2001; Hommel, 1993a, 1996; Kunde, 2001). As in the current experiment in RT_{ON} task button press turned the LED off, but in RT_{OFF} task – turned the LED on, thus action effect in both tasks was different. It is possible that turning the signal on while pressing the button is less compatible than turning it off while pressing the button. In order to show that the influence of the action effect was important in the first experiment, the second experiment was carried out in which action effect was equalized between the tasks.

2. THE SECOND EXPERIMENT

The task of the second experiment was to test the influence of the action effect to the difference between reaction time to stimulus onset and offset when the action effect was equalized in both tasks.

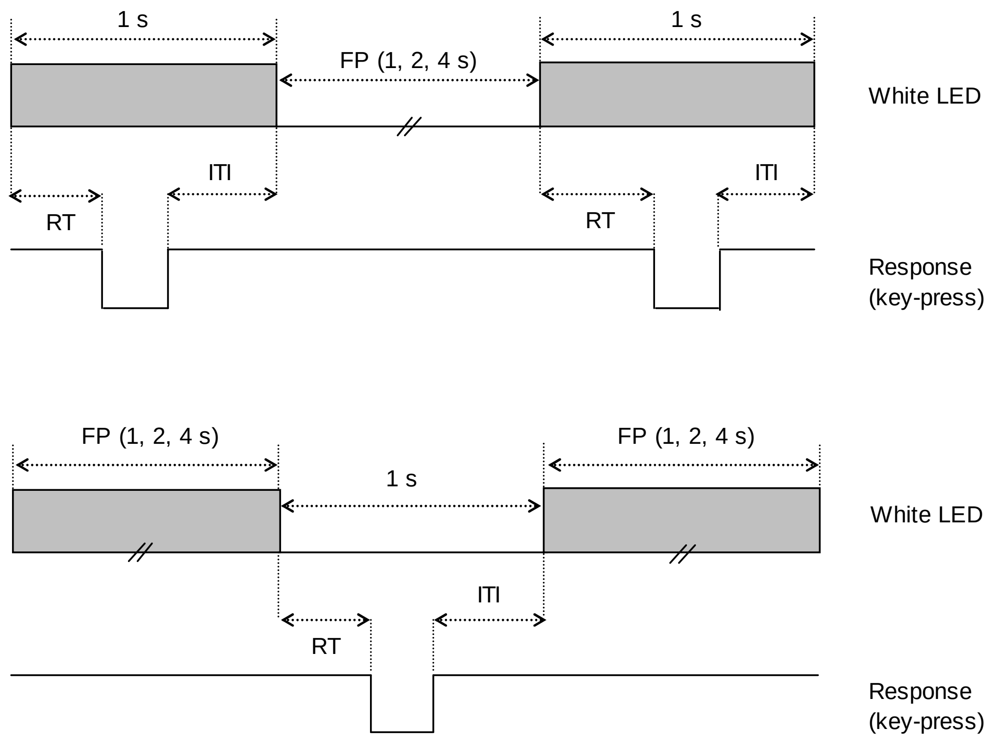
2.1. Methods

2.1.1. Subjects

Experiment was performed at the same laboratory as the first one. Twelve subjects of 28.6±3.3 years old were tested (7 women and 5 men) with normal or corrected-to-normal visual acuity.

2.1.2. Procedure

Experimental tasks and procedure were the same as in the first experiment, except that in current experiment participant's response did not switch the LED off or on, which stayed switched on (Figure 2.1 A) in RT_{ON} tasks or switched off (Figure 2.1 B) in RT_{OFF} tasks until the end of intertrial interval independently from the length of RT. In order to inform the subject that the response was given, a sound feedback (1000 Hz, 75 ms of duration) was delivered via loudspeaker. Subject had 1 s for the response as in the first experiment. Time between the RT and the end of 1 s will be called as intertrial interval (ITI). Thus in both tasks button press was related to the same action effect – a brief sound.



A.

B.

Figure 2.1. ***A*** *– reaction time to stimulus onset task;* ***B*** *– reaction time to stimulus offset task. FP – foreperiod; RT – reaction time; LED – light emitting diode, ITI – intertrial interval.*

2.1.3. Data analysis

Data analysis was the same as in the first experiment.

2.2. Results

1.34% of trials were removed from subsequent analysis as anticipations and misses.

RT_{ON} was shorter than RT_{OFF} (Table 2.1).

Table 2.1. *Mean reaction times and standard deviations of the means.*

Task	FP, ms		
	1000	2000	4000
RT_{ON}, ms	292±102	262±73	256±74
RT_{OFF}, ms	329±124	299±108	283±97
RT_{OFF} - RT_{ON}, ms	38.8±56	37.7±46.9	27.5±30.2

RT_{ON} – reaction time to stimulus onset, RT_{OFF} – reaction time to stimulus offset, OFF-ON – difference between reaction time to stimulus offset and onset, FP – foreperiod. N (number of subjects) = 12.

As in the first experiment, repeated measures ANOVA revealed significant effect of the task ($F (1, 11) = 7.74$, $p < 0.05$) and FP ($F (2, 22) = 13.38$, $p < 0.001$), but their interaction was not statistically significant ($F (2, 22) = 1.44$, $p > 0.05$). Gender was not a statistically significant factor ($F (1, 10) = 0.12$, $p = 0.74$), as well as was task priority ($F (1, 10) = 0.72$, $p = 0.41$). Gender-task ($F (1, 10) = 0.65$, $p = 0.44$) and task priority-task ($F (1, 10) = 4.26$, $p = 0.07$) interactions were not statistically significant also.

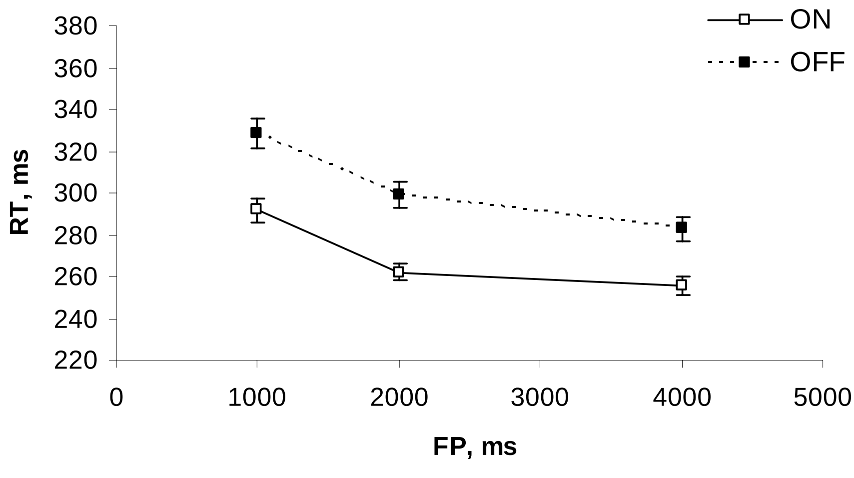


Figure 2.2. *Mean reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod of current trial. Error bars define 95% confidence interval of the mean. N (number of subjects) = 12.*

As ANOVA revealed that task and FP are statistically significant factors, in order to specify if RT_{ON} and RT_{OFF} differed statistically significantly at different FPs, two planned comparisons with the contrast coefficients of 1 and -1 (the same as in the first experiment) were performed. Analysis revealed that RT_{ON} remained statistically significantly shorter than RT_{OFF} at FP_{2000} ($F(1, 11) = 7.76$, $p < 0.05$) and at FP_{4000} ($F(1, 11) = 9.92$, $p < 0.05$).

Correlation coefficients (mean correlation coefficient is $r = 0.75$) revealed that correlation between RT_{ON} and RT_{OFF} in different FPs is strong positive ($r > 0.7$). This confirms the results from the first experiment: onset and offset are interrelated – RT_{OFF} increases as RT_{ON} increases.

Although FP and task interaction in general was not significant ($F(2, 22) = 1.44$, $p > 0.05$), repeated measures ANOVA revealed significant effect of previous FP ($F(2, 22) = 22.61$, $p < 0.001$) and classical sequential effect ($F(4, 44) = 32.18$, $p < 0.001$), but there was no significant interaction between task and sequential effect ($F(4, 44) = 0.26$, $p > 0.05$). Sequential effects did not differ between the tasks (Figure 2.3).

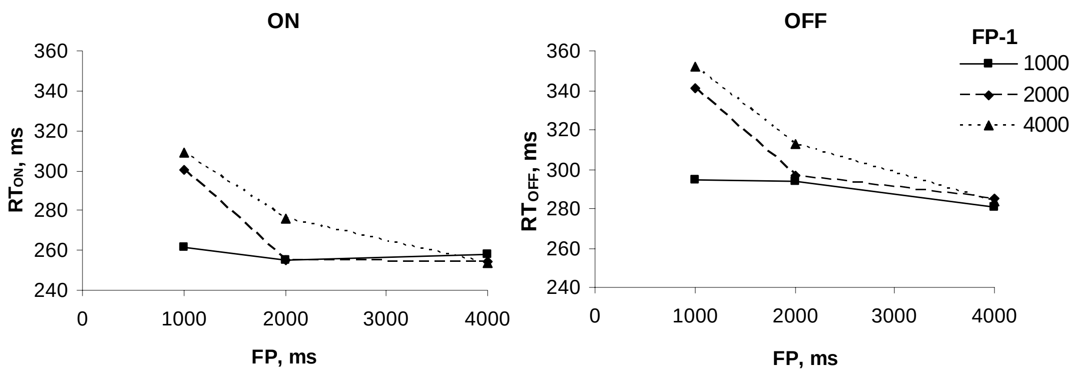


Figure 2.3. *Sequential effects in reaction time to stimulus onset (ON) and offset (OFF) tasks. RT – reaction time; FP – foreperiod of current trial; FP-1 – foreperiod of preceding trial. N (number of subjects) = 12.*

2.3. Discussion

The results of this experiment confirm the results of the first experiment: RT_{OFF} was longer than RT_{ON} (this is consistent with the results of Briggs & Kinsbourne, 1972; Di Lollo et al., 2000; Fischer & Miller, 2008; Parker, 1980; Rolke et al., 2006; Wühr & Kunde, 2006) at all FPs; gender, task priority and sequential effects did not influence the

RT_{ON}-RT_{OFF} difference. The main difference between the two experiments was the interaction between the task and FP, which was demonstrated in the first, but not in the second experiment. In the second experiment the difference between RT_{ON} and RT_{OFF} was independent from FP. When sensory consequences of the action were equalized between the two tasks (button press did not affect the condition of the stimulus) and action effect was the same for both tasks, this determined that RT_{ON}-RT_{OFF} difference did not depend on FP.

The results from the both experiments reveal the importance of the action effect (Elsner & Hommel, 2001; Hommel, 1993a, 1996; Kunde, 2001) (which is related with the response processes) to the interaction between task and FP. In order to compare the duration of premotor and motor processes in both tasks, when action effect is equalized between the tasks, the third experiment was performed in which electromyography was used.

3. THE THIRD EXPERIMENT

The task of the third experiment was to compare premotor (PMT) and motor (MT) parts between the tasks of reaction time to stimulus onset and offset.

3.1. Methods

3.1.1. Subjects

The experiment was performed at the same laboratory as the first two. Eleven subjects (six women, five men) of 29±4.6 years old with normal or corrected-to-normal visual acuity participated in the experiment.

3.1.2. Procedure

Each of the subjects performed two tasks – RT_{ON} and RT_{OFF} – the same as in the second experiment (see the Figure 2.1.), except that in the current experiment electromyographic activity of the flexor muscle *pollicis brevis* of the thumb, which was related with the response, was recorded. The order of the tasks performance was the same as in the second experiment. Six subjects performed RT_{ON} task first, five subjects – RT_{OFF}. LED and the response button, of the same type as in the first two experiments, were connected to the stimulus generating computer (Core 2 Duo CPU 3.0 GHz, 4GB

RAM) through the parallel port. Electromyographic activity was recorded by means of Ag-AgCl flat BIOSEMI electrodes, attached above the flexor muscle *pollicis brevis* of the thumb, on the thenar eminence, about 2 cm apart. The other two – CMS and DLR – BIOSEMI electrodes were used as reference electrodes, attached further, on the forearm. 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 sub-millisecond synchronization, but EMG signal was saved in another computer (Pentium 4 CPU 2.8 GHz, 2 GB RAM).

3.1.3. Data analysis

RT was registered by means of T-Scope library and later analysed by means of MS Excel and Statistica 6, 10. EMG data were recorded by means of BIOSEMI program Actiview. EMG data analysis was further performed by means of *BrainVision Analyser* program (version 1.05, Brain Products, Germany).

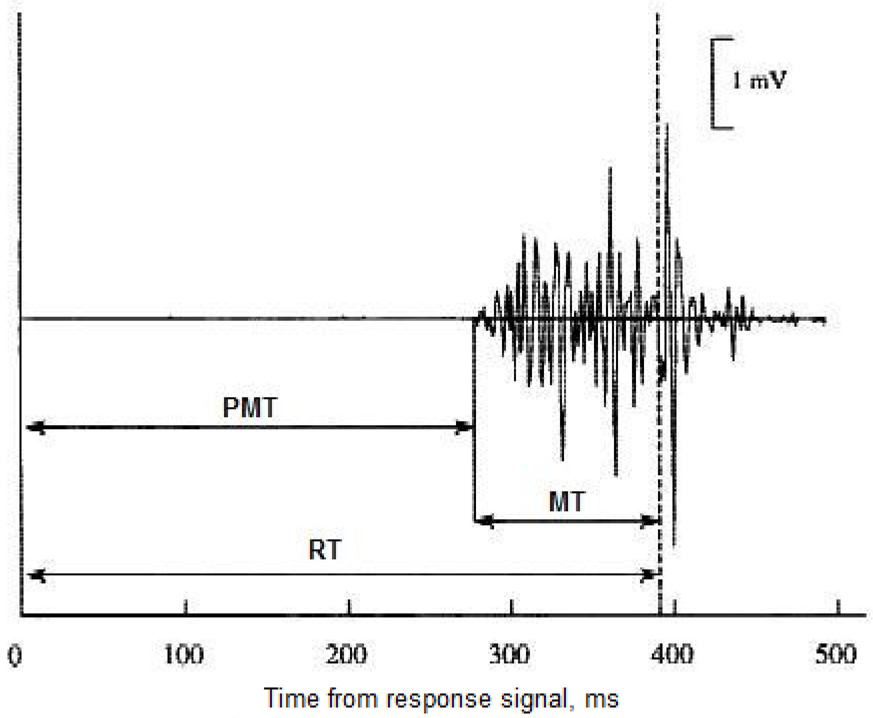


***Figure 3.1**. Differentiating reaction time into premotor (PMT) and motor time (MT) according to electromyographic activity (modified figure from Hasbroucq et al., 2001).*

Anticipations, misses (as in the previous experiments) were removed from the subsequent analysis. The start of EMG activity was determined and marked by using the methods (see Hasbroucq et al., 2001; Van Boxtel et al., 1993) of the laboratory, where the experiment was carried out. The time from the onset of the stimulus until the start of EMG activity was determined as premotor time (PMT) and the time from EMG actvity until the response registered – as motor time (MT) (Figure 3.1, Botwinick & Thompson, 1966; Hasbroucq et al., 2001).

Behavioral RT data analysis was the same as in the second experiment. PMT and MT data analyses were the same as the behavioral RT data analysis.

3.2. Results

17.35% of trials removed from subsequent analysis, because of anticipation or miss (as in the previous experiments).

Reaction time was shorter in RT_{ON} than in RT_{OFF} task (Table 3.1, Figure 3.2).

Table 3.1. *Mean reaction times and standard deviations of the means.*

Task	FP, ms		
	1000	2000	4000
RT_{ON}, ms	333±96	308±79	306±68
RT_{OFF}, ms	352±98	326±78	318±73
RT_{OFF} - RT_{ON}, ms	19.7±18.2	17.5±20.3	11.7±17.2

RT_{ON} – reaction time to stimulus onset, RT_{OFF} – reaction time to stimulus offset, OFF-ON – difference between reaction time to stimulus offset and onset, FP – foreperiod. N (number of subjects) = 11.

At the behavioral level repeated measures ANOVA revealed significant effect of the task ($F (1, 10) = 12.68$, $p < 0.05$), and FP ($F (2, 20) = 12.66$, $p < 0.05$), but task-FP interaction was not statistically significant ($F (2, 20) = 1.08$, $p = 0.36$). Gender was not significant factor ($F (1, 9) = 0.13$, $p = 0.73$), as well as task priority ($F (1, 9) = 0.25$, $p = 0.63$).

In order to specify if RT_{ON} and RT_{OFF} differed at FP_{2000} and FP_{4000}, two planned comparisons (with contrast coefficients of 1 and -1, as in previous experiments) were performed. Planned comparisons analysis revealed that RT_{ON} remains statistically significantly shorter than RT_{OFF} at FP_{2000} ($F (1, 10) = 8.16$, $p < 0.05$) and FP_{4000} ($F (1, 10) = 5.12$, $p = 0.047$).

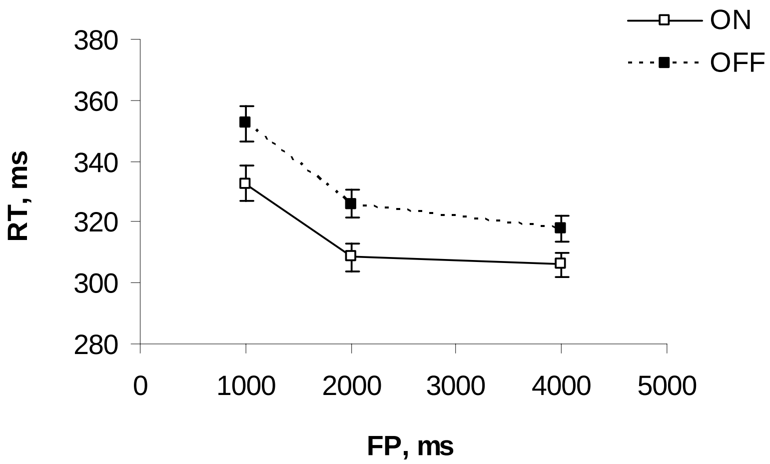


Figure 3.2. *Behavioral reaction time to stimulus onset (ON) and offset (OFF). RT – reaction time; FP – foreperiod. Error bars define 95% confidence interval of the mean. N (number of subjects) = 11.*

Average correlation coefficient between RT_{ON} and RT_{OFF} is $r = 0.9$, thus correlation is strong ($r > 0.7$) positive. This confirms the results from the previous experiments: RT_{ON} and RT_{OFF} are interrelated and RT_{OFF} increases with increasing RT_{ON}.

From the EMG data analysis additional 5.95% of trials were removed because of inappropriate EMG signal. Average PMT and MT as well as standard deviations were calculated (Table 3.2).

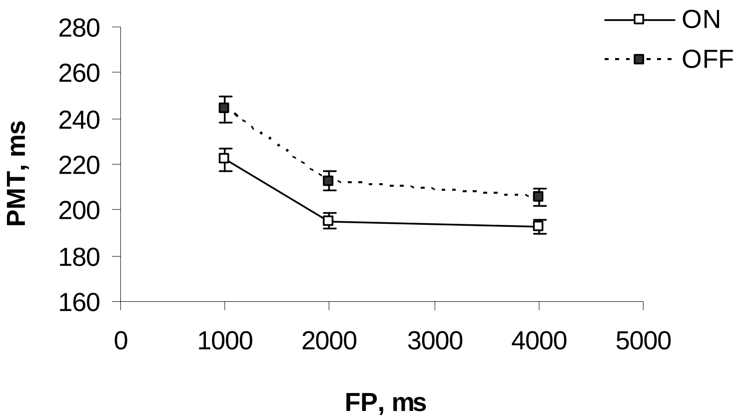
Table 3.2. *Mean premotor and motor times and standard deviations of the means.*

Task	FP, ms		
	1000	2000	4000
PMT_{ON}, ms	222±84	195±62	193±52
PMT_{OFF}, ms	244±92	213±68	206±62
PMT_{OFF} -PMT_{ON}, ms	21.1±15.9	16.8±13.2	12.5±12.3
MT_{ON}, ms	105±23	107±28	107±25
MT_{OFF}, ms	104±23	109±26	108±25
MT_{OFF} -MT_{ON}, ms	-0.54±6.07	1.29±7.39	1.10±8.99

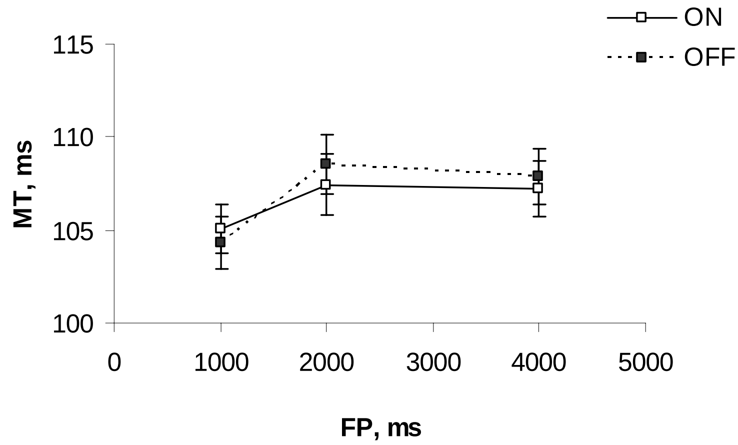
ON – reaction time to stimulus onset, OFF – reaction time to stimulus offset, OFF-ON – difference between reaction time to stimulus offset and onset, FP – foreperiod. N (number of subjects) = 11.

Repeated measures ANOVA for PMT data revealed significant effect of the task ($F (1, 10) = 23.91$, $p < 0.05$) and FP ($F (2, 20) = 20.05$, $p < 0.05$), but task-FP interaction was not statistically significant ($F (2, 20) = 2.17$, $p = 0.14$) (Figure 3.3 A). Gender was not statistically significant factor ($F (1, 9) =1.69$, $p = 0.23$) as well as task priority ($F (1, 9) = 0.01$, $p = 0.92$). Planned comparisons revealed that PMT_{ON} is statistically significantly shorter than PMT_{OFF} at FP_{2000} ($F (1, 10) = 17.79$, $p < 0.05$) and at FP_{4000} ($F (1, 10) = 11.39$, $p < 0.05$).

Repeated measures ANOVA for MT data showed that the task ($F (1, 10) = 0.09$, $p = 0.77$), FP ($F (2, 20) = 2.85$, $p = 0.08$) and their interaction ($F (2, 20) = 0.59$, $p = 0.57$) were not statistically significant factors (Figure 3.3 B). Task priority was not statistically significant factor ($F (1, 9) = 0.93$, $p = 0.36$) also. Even if gender was statistically significant factor ($F (1, 9) = 7.55$, $p < 0.05$) (men MT (96 ms) being shorter than women (116 ms), the interaction between gender and task was not statistically significant ($F (1, 9) = 0.0003$, $p = 0.99$).



A.



B.

Figure 3.3*. 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 95% confidence interval of the mean. N (number of subjects) = 11.*

3.3. Discussion

Differentiation of reaction time into parts revealed that ON-OFF difference remained statistically significant only in PMT part of RT, but the task did not reveal the task effect in the late motor components (MT part). Small, but statistically significant influence of other factors (for example, motor preparation) on the motor part of RT was demonstrated with this method (Possamaï et al., 2002; Tandonnet et al., 2003). Thus, it does not seem that no detected influence of the task on the motor part of RT in current experiment was an error. Davranche et al. (2005, 2006) showed the influence of the physical exercises on the motor part of RT. Thus, results in the current experiment demonstrate that late motor components are not important in RT_{ON}-RT_{OFF} difference. The results of this experiment confirm the results from the second experiment, concerning no interaction between the task and FP. This confirms the importance of the action effect to the interaction between task and FP, i.e. RT_{ON}-RT_{OFF} difference is not dependent on FP.

As late motor components were not affected by the ON-OFF effect, but the results of the previous two experiments reveal the influence of response-related factors on the RT_{ON}-RT_{OFF} difference, it was decided to test the influence of the response selection stage, which is earlier in the RT information processing chain, on the RT_{ON}-RT_{OFF} differences. In all the tasks in previous experiments the subjects were asked to react to stimulus onset by pressing the button in RT_{ON} tasks, and to provide the same button press response when reacting to stimulus offset in RT_{OFF} tasks. According to the theory of stimulus-response compatibility (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum et al., 1990; Proctor et al., 2002), it is possible that RT_{ON} and RT_{OFF} tasks have the responses which are more or less compatible with them and these differences can be different between the RT_{ON} and RT_{OFF} tasks. It is possible that stimulus onset (the onset of the event) is more compatible with the button press (production of the event) and stimulus offset (the offset of the event) is more compatible with the button release (the end of the produced event). The actions of button press and release are quite similar at the motor level (both actions require action initiation), but at the cognitive level they can be represented differently (as producing the event and finishing the event, respectively) (Wühr & Kunde, 2006). According to Hommel (1993a), the responses can be coded differently according to the subject‘s intention and perceived consequences of the action to the environment. Thus, it is possible that stimulus onset is more compatible with the action which produces the event (button press) and stimulus offset – with the action which finishes the produced event (button release). In that case RT_{ON}-RT_{OFF} difference would be affected and the difference would be larger in the button press than button release conditions. In order to test this hypothesis the fourth experiment was performed, in which subjects were asked to press the button when reacting to stimulus onset and offset or to release it when reacting in the same conditions.

4. THE FOURTH EXPERIMENT

The goal of this experiment was to test the influence of the response type on the differences between the reaction time to stimulus onset and offset.

4.1. Methods

4.1.1. Subjects

The experiment was performed at the Department of Neurobiology and Biophysics, Faculty of Natural Sciences, Vilnius University. Sixteen 21.6±1.5 years old subjects (8 women, 8 men) with normal or corrected to normal visual acuity participated in experiment.

4.1.2. Procedure

Each subject performed the tasks, which were the same as in the first experiment – RT to stimulus onset (white LED onset) and RT to stimulus offset (white LED offset). White LED with the diameter of 1.5 cm was attached on the grey board (19.8 x 9.7 cm) with the distance of 53 cm from the eyes, at the eye level, as in the first experiment. LED, as well as response button, were connected to the stimulus generating computer (Intel Core 2, ~1600 Mhz, 2 GB RAM) through the parallel port, no EMG activity recorded. Tasks, procedure, program as well as experimental setup were the same as in the first experiment except that in this experiment there were two response types (button press and button release), no ITI interval (no sound feedback). As there were two response types, each of the subjects performed four tasks: button press as response to stimulus onset, button press as response to stimulus offset, button release as response to stimulus onset, button release as response to stimulus offset (Figure 4.1). Tasks were counterbalanced according to balanced Latin square (Edwards, 1951). RT_{ON} and RT_{OFF} tasks, in which the subject was asked to react as soon as possible to the stimulus onset or offset by pressing the response button, were the same as in the first experiment. But in RT_{ON} and RT_{OFF} tasks, in which the subject was asked to react as soon as possible by releasing the response button, the button had to be kept pressed all the time and just shortly released when reacting to stimulus onset and offset (Figure 4.1). Each task comprised three blocks and one practice block before each of the tasks was performed. Other details were as in the first experiment.

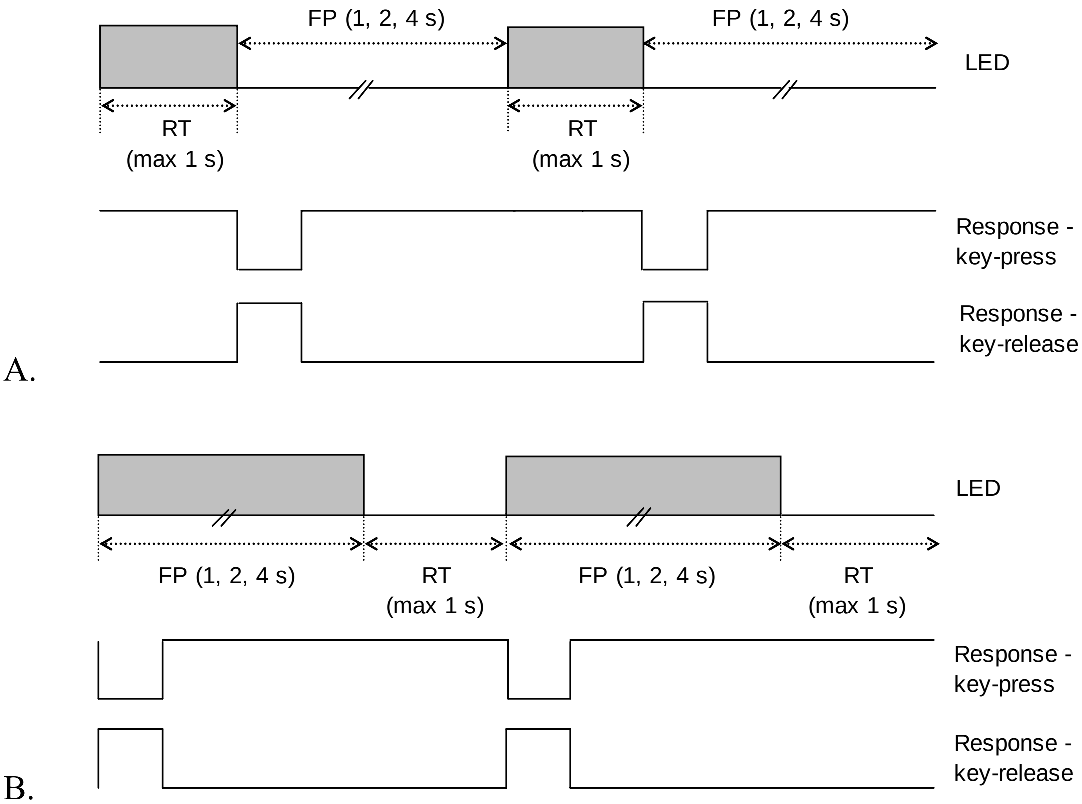


***Figure 4.1**. **A** – reaction time to stimulus onset tasks when response is key-press and key-release; **B** – reaction time to stimulus offset task when response is key-press and key-release. FP – foreperiod; RT – reaction time; LED – light emitting diode.*

4.1.3. Data analysis

Data analysis for each of the response (button press and button release) was the same as data analysis in the first experiment. ANOVA analysis was supplemented with the response type factor.

4.2. Results

1.07% of trials were removed from subsequent analysis as errors (anticipations, misses). Mean reaction times and standard deviations at different FPs in both responses were calculated (Table 4.1.).

Table 4.1. *Mean reaction times and standard deviations of the means.*

Task	FP, ms		
	1000	2000	4000
Response – button press			
RT_{ON}, ms	264±52	263±57	264±56
RT_{OFF}, ms	308±86	285±59	289±70
RT_{OFF} - RT_{ON}, ms	44.5±31.0	21.9±20.5	24.9±25.4
Response – button release			
RT_{ON}, ms	251±57	246±49	252±53
RT_{OFF}, ms	300±90	273±64	272±55
RT_{OFF} - RT_{ON}, ms	48.9±30.7	27.0±19.2	19.9±20.7

ON – reaction time to stimulus onset, OFF – reaction time to stimulus offset, OFF-ON – difference between reaction time to stimulus offset and onset, FP – foreperiod. N (number of subjects) = 16.

Repeated measures ANOVA revealed statistically significant factors of the response type ($F(1, 15) = 5.52$, $p < 0.05$), task ($F(1, 15) = 57.76$, $p < 0.001$), FP ($F(2, 30) = 13.87$, $p < 0.001$), but response type-task ($F(1, 15) = 0.06$, $p = 0.82$), response type-FP ($F(2, 30) = 1.05$, $p = 0.36$) interactions were not statistically significant. Analysis revealed that task-FP interaction was statistically significant ($F(2, 30) = 13.08$, $p < 0.001$), as in the first experiment, but response type-task-FP interaction was not ($F(2, 30) = 1.5$, $p = 0.25$). Gender was not statistically significant factor ($F(1, 14) = 1.8$, $p = 0.20$), as well as gender-task interaction ($F(1, 14) = 0.93$, $p = 0.35$).

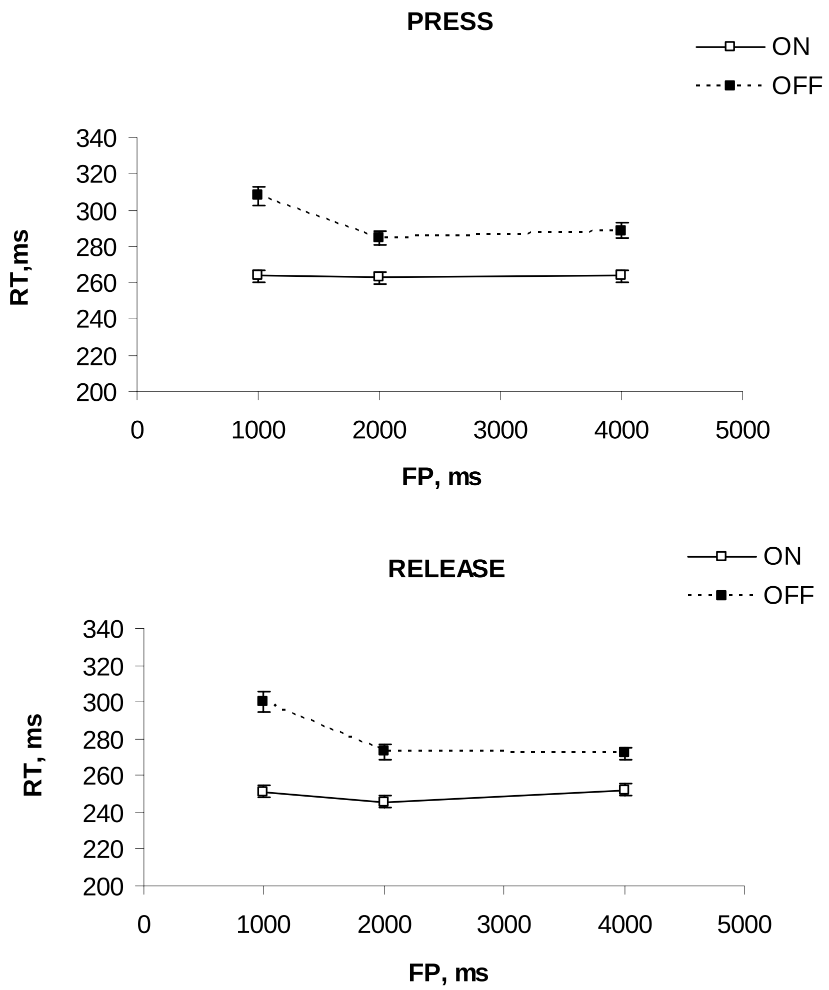


Figure 4.2. *Reaction time to stimulus onset (ON) and offset (OFF) when responses were:* ***A*** *– button press and* ***B*** *– button release. RT – reaction time; FP – foreperiod. Error bars define 95% confidence interval of the mean. N (number of subjects) = 16.*

In order to compare RT between the onset and offset tasks at FP_{2000} and FP_{4000}, two planned comparisons (with the same contrast coefficients (1; -1)) as in the previous experiments were performed. And the other two planned comparisons in each task (with the coefficients of 2;-1;-1 and 1;-1) were performed in order to compare RT in the same task between different FPs. Planned comparisons revealed that RT_{ON} remained statistically significantly shorter than RT_{OFF} at FP_{2000} when the response was button press ($F(1, 15) = 18.24$, $p < 0.001$) and button release ($F(1, 15) = 31.65$, $p < 0.001$), as well as at FP_{4000} when the response was button press ($F(1, 15) = 15.42$, $p = 0.001$) and button release ($F(1, 15) = 14.74$, $p < 0.05$) (Figure 4.2.).

Planned comparisons for comparing RT in the same task revealed that in the button press condition RT_{ON} at FP_{1000} did not differ from the mean RT_{ON} between FP_{2000} and FP_{4000} ($F (1, 15) = 0.03$, $p = 0.87$), RT_{ON} at FP_{2000} did not differ from RT_{ON} at FP_{4000} ($F (1, 15) = 0.11$, $p = 0.74$). RT_{OFF} at FP_{1000} differed significantly from mean RT_{OFF} between FP_{2000} and FP_{4000} ($F (1, 15) = 37.42$, $p < 0.001$), RT_{OFF} at FP_{2000} differed significantly from RT_{OFF} at FP_{4000} ms ($F (1, 15) = 60.09$, $p < 0.001$). In button release condition RT_{ON} at FP_{1000} differed significantly from the mean RT_{ON} between FP_{2000} and FP_{4000} ($F (1, 15) = 33.46$, $p < 0.001$), RT_{ON} at FP_{2000} differed significantly from RT_{ON} at FP_{4000} ($F (1, 15) = 7.63$, $p < 0.05$). RT_{OFF} at FP_{1000} differed significantly from mean RT_{OFF} between FP_{2000} and FP_{4000} ($F (1, 15) = 21.43$, $p < 0.001$), but RT_{OFF} at FP_{2000} did not differ from RT_{OFF} at FP_{4000} FP ($F (1, 15) = 0.12$, $p = 0.74$).

Correlation between RT_{ON} and RT_{OFF} revealed that the mean correlation coefficient in button press condition as well as in button release condition is the same, i.e., $r = 0.69$ (correlation is moderate ($0.5 < r < 0.7$) positive). This confirms the results from the previous experiments – RT_{ON} and RT_{OFF} are interrelated and RT_{OFF} increases as RT_{ON} increases. This pattern is present in both button press and button release conditions.

4.3. Discussion

The fourth experiment was performed to test if response type influences the RT_{ON}-RT_{OFF} differences. Two response types (button press and button release) were used in each of the tasks. As there was raised assumption that stimulus onset can be more compatible with action which produces the event (button press) and stimulus offset – with the action which finishes produced event (button release), statistically significant task and response type interaction as well as larger RT_{ON}-RT_{OFF} difference in button press than release conditions were expected. However, the results (Table 4.1) show that RT_{ON}-RT_{OFF} difference was even larger in button release than in button press condition at FP_{1000} and FP_{2000}. Even if response type (button release RT was shorter at all FPs in both tasks than button press RT) and task (RT_{ON} and RT_{OFF} differed statistically significantly when the response was button press and button release) were statistically significant factors, but the interaction between the task and the response type was not statistically significant. Thus, RT_{ON}-RT_{OFF} difference did not depend on the response type and there was no (in)compatibility between the stimulus (ON or OFF) and the response (button press or release). The reason for these results could be that RT_{ON}-RT_{OFF} difference rises not in the response selection stage of RT. The results are compatible with the choice RT results of Wühr & Kunde (2006).

Furthermore, the results from the current experiment confirm the results of the first experiment: task and FP interaction was statistically significant, i.e. RT_{ON}-RT_{OFF} difference depended on FP.

5. GENERAL DISCUSSION

The goal of this research – to study the influence of response-related factors on the difference between the reaction time to stimulus onset and offset. Four experiments were performed in order to test the influence of foreperiod, action effect, premotor and motor parts of RT and response type on the RT_{ON}-RT_{OFF} difference.

The results of all four experiments revealed shorter RT_{ON} than RT_{OFF}. This in general is compatible with the results of other authors (Briggs & Kinsbourne, 1972; Di Lollo et al., 2000; Fischer & Miller, 2008; Parker, 1980; Rolke et al., 2006; Wühr & Kunde, 2006). Results from the experiments of other authors, which used very short stimulus durations (Briggs & Kinsbourne, 1972; Di Lollo, 1980) are explained by visual persistence. But in the current research stimulus durations were quite long (1000, 2000, 4000 ms) in all experiments performed, thus, visual persistence should not influence the results. According to Briggs & Kinsbourne (1972) visual persistence is the most relevant when stimuli durations are less than 1 s. Di Lollo et al. (2000), after reviewing other authors, propose that stimulus durations longer than about 100 ms produce little if any visual persistence. In order to explain RT_{ON}-RT_{OFF} difference where longer durations of stimuli are used, Di Lollo et al. (2000) suggested response suppression hypothesis. According to this hypothesis stimulus onset in RT_{OFF} task automatically activates the response processes which has to be suppressed (because required response is response to stimulus offset), therefore RT_{OFF} is longer than RT_{ON}. However, response activation is short-lived process and decay quickly after stimulus onset either spontaneously (Hommel, 1993b, 1994) or under active suppression (Burle et al., 2002a; Ridderinkhof, 2002; van den Wildenberg et al., 2010), thus when the time interval from stimulus onset to stimulus offset lengthens, response suppression processes should be finished at the time of stimulus offset, thus RT_{ON}-RT_{OFF} difference should decrease. This hypothesis was checked by using different length of FP interval in the current research. The results from the first experiment confirm this hypothesis – RT_{OFF} is the longest (and the RT_{ON}-RT_{OFF} difference is the largest) at the shortest FP and decreases with increasing length of FP. However, considering the course of the task, it can be noticed that button press is related with LED onset (button press induces LED onset) in RT_{OFF} task, but with LED offset (button press induces LED offset) in RT_{ON} task. Thus, both tasks have different action effects and this could induce larger or smaller compatibility between the action and its sensory consequences (Hommel 1993a, 1996; Kunde, 2001): i.e., it is possible, that button press action effect – LED onset is less compatible with the button press in RT_{OFF} task than LED offset with the button press in RT_{ON} tasks. This would determine more automatic and faster response in RT_{ON} task, in accordance with Elsner & Hommel (2001) action effect model. Interpreting the results according to this model it is possible also that because of automatic connection between response and its effect, when the LED is switched on (at the start of FP) in RT_{OFF} task, the response, which is expected to result with LED offset, is automatically activated. But in RT_{OFF} task the LED actually is turned on in response to LED offset. As this incompatibility might take time to resolve for the subject, this could determine longer RT_{OFF}, especially at the shortest FP. In order to further test this hypothesis, the second experiment was performed where stimulus duration was independent from the response. The subject was informed about the response being recorded with a short sound feedback when button was pressed, thus both tasks had the same action effect – brief sound. Results revealed that RT_{OFF} was longer than RT_{ON}, but there was no interaction between task and FP.

As there was no interaction between the task and FP in the second experiment, this is not compatible with the hypothesis of Di Lollo et al. (2000): when the subject had enough time for the suppression of the response to stimulus onset, this did not reduce the difference of RT_{ON}-RT_{OFF}. Thus, response suppression probably does not play the main role here. However, large influence of action effect on RT_{ON}-RT_{OFF} difference suggests a post-perceptual localization (i.e., processes which occur after sensory processing) of the effect, possibly the stage of response selection.

Fisher and Miller (2008) although in quite different theoretical context showed larger response peak force in choice RT_{OFF} task than RT_{ON} (measured with the help of strain gauges, attached to the leaf string, which was pressed during response). However, force deployment at least partially occurs after response onset. Thus, the difference in force not necessarily explains chronometric differences between the ON and OFF tasks. However, this in general shows that motor components between the tasks could differ. Furthermore, the results from the first two experiments suggest the role of response-related factors in RT_{ON}-RT_{OFF} differences. Thus, it is worth to test if motor components differ between the RT_{ON} and RT_{OFF} tasks. Therefore the third experiment was performed.

The goal of the third experiment was to test if the ON-OFF difference is seen not only in premotor, but also in motor parts (according to EMG activity) of RT. Recording the EMG activity of flexor muscle *pollicis brevis* allowed to divide RT into PMT and MT. This method is useful because it enables to reveal if the tested factor affects the RT part before the start of electromyographic activity (i.e., muscle contraction) or also after it – i.e., motor (Davranche et al., 2005). This allows to test if the response performance or the processes occurring before it are affected (Botwinick & Thompson, 1966; Burle et al., 2002a; Davranche et al., 2005; Hasbroucq et al., 1995; 2001; 2003; Possamaï et al., 2002). The results confirmed that RT_{ON} was shorter than RT_{OFF}, as in the first two experiments, but after partitioning RT into PMT and MT, statistically significant difference between the responses in ON and OFF tasks was only in PMT part, but not in MT. These results reveal that offset disadvantage arises in premotor part of RT and late motor components do not participate in generating RT_{ON}-RT_{OFF} differences. Considering the results from the psychophysiological experiments of other authors (Hari et al., 1987; Pratt et al., 2008; Servière et al., 1977), which show that the latency of the sensory OFF potential is shorter than ON potential, it seems that offset disadvantage is generated because of the processes, occurring between the sensory part of RT and late motor components. In general, these results show that the origin of offset disadvantage is post-perceptual, but pre-motoric.

The other response-related factor is stimulus-response compatibility. It is shown that between the stimuli and the responses it is possible larger or smaller compatibility (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum et al., 1990; Proctor et al., 2002). In conflict tasks the stimulus feature, which is more compatible with the response, activates this response automatically even if this feature is non-relevant to the task (Burle et al., 2002a; Kornblum et al., 1990). Thus, the conflict between task-relevant and task-irrelevant responses arises and the task-irrelevant response has to be suppressed (Burle et al., 2002a; Kornblum et al., 1990). Thus, considering this theory, it is possible that ON and OFF stimuli could have different, stimulus-compatible responses – i.e. stimulus onset could be more compatible with the response which produces the event (button press), and stimulus offset – with the response which finishes the produced event (button release). The fourth experiment was performed, which tested if response type (button press and button release) influences the differences between RT_{ON} and RT_{OFF}. Thus, statistically significant interaction between the task and the response type (hence, larger RT_{ON}-RT_{OFF} difference in button press than release tasks) was expected, which could show if RT_{ON}-RT_{OFF} difference is related with response selection stage of RT. Even if the response type was statistically significant factor, showing shorter button release RT at all FPs, than button press RT, the interaction between task and response type was not statistically significant. This means that RT_{ON}-RT_{OFF} difference does not differ between the response types. Thus, stimulus onset is not compatible more with the button press and stimulus offset – with the button release. Shorter button release RT than button press RT could be because of several reasons, including mechanical, button-related ones. However, if any mechanical reasons could influence the absolute RTs, they would influence both tasks at all FPs. As RT difference between press and release conditions is not the same at all FPs (in ON task at FP_{1000} it is 13 ms, at FP_{2000} it is 17 ms, at FP_{4000} it is 12 ms; in OFF task at FP_{1000} it is 8 ms, at FP_{2000} it is 12 ms, at FP_{4000} it is 17 ms), thus this is not a systematic error.

Results from this experiment corresponds the results of Wühr & Kunde (2006) from the conflict tasks. They did not show compatibility between the stimulus (onset, offset) and the response type (press, release) in choice RT tasks. In current research no compatibility was shown in simple RT tasks. Riggio et al. (2012), Wühr & Kunde (2006) also demonstrated Simon effect not only in RT_{ON}, but in RT_{OFF} tasks as well. Wühr & Kunde (2006) also showed the Simon effect not only in button press, but in button release tasks also and proposed that cognitive system automatically encodes not only the location of stimulus onset, but the location of stimulus offset as well. The results from the fourth experiment in current research suggest that cognitive system automatically encodes the response not only in RT_{ON}, but in RT_{OFF} tasks also, independently from the response type. This would suggest that response selection and performance parts (evidence from the third experiment) of RT do not differ between the RT_{ON} and RT_{OFF}

tasks and RT_{ON}-RT_{OFF} difference cannot be explained by (in)compatibility between the stimulus and the response. However there is also another explanation why the compatibility between stimulus and response was not revealed in RT_{ON} and RT_{OFF} tasks. According to Wühr & Kunde (2006) stimulus offset can be represented differently among the subjects – i.e. as finishing continuous button press or as initiating finger lift movement.

The results from the third and the fourth experiments confirmed part of the results from the first and second experiments: RT_{ON} remained statistically significantly shorter than RT_{OFF} in the third (behavioral RT and PMT) and the fourth experiments. However, the interaction between the task and FP was not statistically significant in the third experiment, but in the fourth experiment this interaction was statistically significant and independent from the response type – the response type-task-FP interaction is statistically insignificant. As it can be seen from the results of button press and button release tasks (Table 4.1), the largest RT_{ON}-RT_{OFF} difference, calculated from individual RT_{ON}-RT_{OFF} differences, is at the shortest (1000 ms) FP (in button press condition: 44.5 ms, in button release condition: 48.9 ms). And it is smaller at other FPs (in button press condition: at FP_{2000} it is 21.9 ms, at FP_{4000} it is 24.9 ms; in button release condition: at FP_{2000} it is 27.0 ms, at FP_{4000} it is 19.9 ms). Thus, in both response types, task-FP interaction results confirm the results from the first experiment, which could be interpreted as stronger suppression of response to stimulus onset in the RT_{OFF} task at the shortest FP (RT_{ON}-RT_{OFF} difference at FP_{1000} is the largest), confirming the hypothesis of Di Lollo et al. (2000). The results from the third experiment confirm the results of the second experiment: task-FP interaction was insignificant (RT_{ON}-RT_{OFF} difference did not depend on FP), thus incompatible with the hypothesis of Di Lollo et al. (2000). Hence, task-FP interaction was demonstrated only when action effect for both tasks was different.

While discussing the results of task-FP interaction, it is important to consider the sequential effects – i.e. RT of current short FP is longer if preceded by longer FP, but the influence of previous FP becomes irrelevant at the longest current FP (Los, 2010; Niemi & Naatanen, 1981 for review). As the results from the first experiment revealed that the interaction between the task and FP is statistically significant and FP is related with sequential effects (Niemi & Naatanen, 1981), the influence of sequential effects on the task was tested. Even if the interaction between the task and FP was significant when action effects between tasks were different (in the first experiment), the analysis of the sequential effects did not reveal statistically significant interaction between the sequential effects and the task when action effects differed between the tasks (in the first experiment) and when they did not differ (in the second experiment). These results confirm the view that FP and sequential effects are explained by different processes, i.e. different functionally and anatomically (Vallesi et al., 2007; Vallesi & Shallice, 2007), even if they interact (Vallesi et al., 2007).

Besides the main results, the gender factor was also tested. Even if gender differences in cognitive abilities, as spatial reasoning, mathematical calculation and reasoning and verbal tasks are demonstrated (Geary et al., 2000; Kimura, 2004), but the data concerning reaction time differences between the genders are quite contradictory (Mikhelashvili-Browner et al., 2003). Furthermore, the outcome of the search for the results concerning comparison RT_{ON}-RT_{OFF} differences between genders was unsuccessful. However, ANOVA analysis of the results from the experiments in the current research did not show statistically significant task-gender interaction, thus gender did not influence the difference between reaction time to stimulus onset and offset.

In general, the results of this research demonstrate the influence of response-related factors on the difference between the reaction time to stimulus onset and offset: foreperiod (during this period the processes of response preparation occur), action effect (which shows the importance of action consequences), premotor reaction time (which, while considering the data from event related potentials of other authors, suggest the role of early motor components in generating the differences between the reaction time to stimulus onset and offset). However, the results also demonstrated that when action effect is equalized between the tasks, the difference between the reaction time to stimulus onset and offset is independent from foreperiod. Possible interpretation of these results is that the suppression of the automatically activated response to stimulus onset is not a key factor, determining the offset disadvantage when the action effect is equalized between the tasks. Furthermore, the results of this research revealed that the response type (button press and button release) does not influence the difference between the reaction time to stimulus onset and offset and considering the results from the third experiment that these differences are not revealed in the late motor components, it is possible to assume that response selection and performance stages do not differ between the reaction time to stimulus onset and offset tasks. However the results of the first and the second experiments in the current research and the results from neurophysiological and psychophysiological experiments of other authors (Bair et al., 2002; Hari et al., 1987; Pratt et al., 2008; Servière et al., 1977) suggest that the processes, responsible for the generation of the differences between the reaction time to stimulus onset and offset are post-perceptual (i.e., occurring after the processing the information about the stimulus), but response-related. In general, the results of this research reveal that offset disadvantage is generated by few factors, not by one.

CONCLUSIONS

- Difference between the reaction time to stimulus onset and offset depends on the duration of foreperiod, but only when the action effect between the reaction time to stimulus onset and offset tasks is different.
- Action effect influences the difference between reaction time to stimulus onset and offset:

  1) when action effect is different between the tasks, difference between the reaction time to stimulus onset and offset is the largest at the shortest foreperiod and decreases as foreperiod increases;

  2) when action effect is equalized between the tasks, the difference between the reaction time to stimulus onset and offset does not change as foreperiod increases.
- Premotor time is shorter in the reaction time to stimulus onset than to stimulus offset tasks, but motor time does not differ between the tasks.
- Difference between the simple reaction time to stimulus onset and offset is independent from the type of mechanical response (button press and button release).

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Reziumė

Gyviems organizmams prisitaikymui prie aplinkos svarbus reagavimas ne tik į stimulo atsiradimą, bet ir į išnykimą. Reakcijos laiko į stimulo įjungimą ir išjungimą skirtumų tyrimai gali suteikti platesnės informacijos apie informacijos kodavimo, apdorojimo, stimulo-atsako ryšio, atsako formavimo mechanizmus. Įprastai reakcijos laikas į stimulo įjungimą nustatomas trumpesnis nei reakcijos laikas į stimulo išjungimą. Kai stimulai yra labai trumpos trukmės (iki 1 s), šis reakcijos laiko skirtumas aiškinamas regimuoju užlaikymu. Kai stimulų trukmė ilgesnė, reakcijos laiko į stimulo įjungimą ir išjungimą skirtumai aiškinami jau ne sensoriniais, bet su atsaku siejamais procesais – t.y. automatiškai kilusio atsako, į stimulo įjungimą slopinimu reakcijos laiko į stimulo išjungimą užduotyse. Tačiau reakcijos laiko į stimulo įjungimą ir išjungimą skirtumus gali veikti ir kiti, su atsaku siejami veiksniai – priešstimulinis intervalas, veiksmo efektas, atsako tipas, priešmotoriniai ir motoriniai procesai. Šio darbo tikslas – nustatyti šių, su atsaku susijusių veiksnių poveikį reakcijos laiko į stimulo įjungimą ir išjungimą skirtumui. Tuo tikslu buvo atlikti keturi eksperimentai. Rezultatai parodė, kad reakcijos laiko į stimulo įjungimą ir išjungimą skirtumas priklauso nuo priešstimulinio intervalo trukmės – mažėja priešstimuliniam intervalui didėjant, bet tik tuomet, kai reakcijos laiko į stimulo įjungimą ir išjungimą užduotims būdingas skirtingas veiksmo efektas. Kai veiksmo efektas abiems užduotims suvienodintas, reakcijos laiko į stimulo įjungimą ir išjungimą skirtumas nekinta priešstimuliniam intervalui ilgėjant. Priešmotorinis laikas yra trumpesnis reakcijos laiko į stimulo įjungimą nei į stimulo išjungimą užduotyse, tačiau motorinis laikas tarp užduočių nesiskiria. Paprasto reakcijos laiko į stimulo įjungimą ir išjungimą skirtumas yra nepriklausomas nuo mechaninio atsako tipo (mygtuko paspaudimo ir atleidimo).

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