Brazilian Journal of Medical and Biological Research (1998) 31: 1313-1318
ISSN 0100-879X Short Communication

Gap effect and reaction time distribution: simple *vs* choice manual responses

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Research supported by CNPq, CAPES, FINEP, FAPERJ, PROPP-UFF and PRONEX/MCT.
Publication supported by FAPESP.
W. Machado-Pinheiro is the recipient of a CAPES fellowship.

Received January 20, 1998
Accepted July 27, 1998

Abstract

It is well known that saccadic reaction times (SRT) are reduced when the target is preceded by the offset of the fixation point (FP) - the gap effect. Some authors have proposed that the FP offset also allows the saccadic system to generate a separate population of SRT, the express saccades. Nevertheless, there is no agreement as to whether the gap effect and express responses are also present for manual reaction times (MRT). We tested the gap effect and the MRT distribution in two different conditions, i.e., simple and choice MRT. In the choice MRT condition, subjects need to identify the side of the stimulus and to select the appropriate response, while in the simple MRT these stages are not necessary. We report that the gap effect was present in both conditions (22 ms for choice MRT condition; 15 ms for simple MRT condition), but, when analyzing the MRT distributions, we did not find any clear evidence for express manual responses. The main difference in MRT distribution between simple and choice conditions was a shift towards shorter values for simple MRT.

Key words
- Attention
- Reaction time
- Gap effect
- Vision
- Express responses

It is well known that when a motor response to a visual stimulus is preceded by a warning signal its latency is reduced (1). Moreover, when the warning signal is the offset of a light stimulus, some special phenomena appear. Saslow (2) showed that if a fixation point (FP) is turned off some time before the onset of an imperative stimulus (the gap paradigm) the saccadic reaction time (SRT) decreases in relation to the condition with no FP offset (overlap paradigm) or with simultaneous FP offset and stimulus onset (gap 0). This reduction of SRT in the gap paradigm was called the “gap effect” by Fischer and co-workers (for details, see Ref. 3).

Many investigators have confirmed the presence of the gap effect for SRT (3-12). Some have proposed that the gap paradigm reduces saccade latency and also facilitates the appearance of a very short latency population in the SRT distribution, the so-called express saccades (ES) (for a review, see Ref. 3). However, the universality of ES is still controversial. Several investigators, though observing a reduction of SRT in the gap paradigm, could not find a population of short latency responses. They suggested that

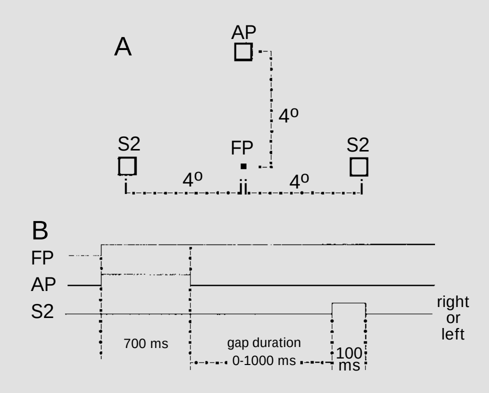

Figure 1 - *A*, Schematic representation of stimulus display; *B*, temporal sequence of occurrence of the fixation point (FP), the first stimulus or attention point (AP), and the imperative stimulus (S2).

it would be more fruitful to focus attention on the gap effect *per se,* whether or not ES are present in the SRT distribution (9,11-14). Thus, there are grounds to suggest that the gap effect and ES are distinct phenomena.

A very interesting question is whether the gap effect exists for manual reaction times (MRT). Reuter-Lorenz et al. (11) did not find the effect; Kingstone and Klein (9) found some latency facilitation, but attributed it to factors other than the gap effect. Fischer and Rogal (15), Ross and Ross (16), Iwasaki (8) and Bekkering et al. (4) found a gap effect for choice manual responses which, however, was proportionally smaller than that for SRT.

Express manual responses have not yet been demonstrated. Many investigators (8,11, 15,17,18) tried to find such a population of manual responses using the gap paradigm. In their studies, a choice MRT was used to avoid an anticipatory behavior during the experiments but no express manual responses were observed.

The aim of the present study was to determine how the offset of a peripheral visual stimulus to which the subject is paying attention modifies the MRT to a second visual stimulus. We employed a non-blocked array of gap durations to investigate the gap effect and the MRT distributions in two conditions, i.e., simple and choice MRT.

Eight volunteers (four males and four females) participated in this study. All of them were right-handed according to the Edinburgh Inventory (19), had normal or corrected vision, and their ages ranged from 20 to 24 years. The subjects were tested in a sound-attenuated room under dim ambient light. They sat in front of a CRT screen driven by a PC-486 microcomputer, which timed the stimuli and recorded the MRT. The head was positioned on a head-and-chin rest so that the distance between the eyes and the screen was approximately 57 cm. Before data collection, subjects were submitted to some training, where the importance of maintaining fixation was stressed. During this training session, eye movements were monitored by an experimenter sitting behind the subject using a suitably oriented mirror.

Each trial began with the simultaneous presentation of a central point (fixation point - FP) and a square (attention point - AP, 0.5^o x 0.5^o) located 4^o above it. After 700 ms, AP went off and after a variable gap duration the imperative stimulus (an identical square - S2) flashed for 100 ms 4^o to the left or to the right of the FP. There were three possible gap durations between the offset of AP and the onset of S2, i.e. 0, 250 or 1000 ms, which occurred randomly and with the same probability throughout the experiment (Figure 1). In addition, the gap duration of 1000 ms varied randomly from 800 to 1200 ms. The subjects were instructed to fixate the FP and to pay attention to AP, because its offset was the cue that S2 would occur at any moment. There were two conditions: a) simple MRT, in which subjects had to press a key with the right index finger as soon as they detected the imperative stimulus (S2), irrespective of whether it occurred to the left or to the right of the FP. b) Choice MRT, in which subjects had to press the key spatially corresponding to the side of the stimulus (left or right) with the corresponding index finger (left or right, respectively), as soon as they detected S2. After each manual response, the latency (in milliseconds) appeared on the screen for 1000 ms. Stimulus luminance was 11.5 cd/

m^2, and background luminance was 0.2 cd/m^2. All subjects performed four sessions of 300 trials (four blocks of 75 trials with some minutes of rest between them) on separate days. Fifty MRT for each gap duration and side were recorded daily. The first session was only for training and its data were not considered. On the second and third days, the subjects performed the choice MRT condition, and on the fourth day, the simple MRT condition. MRT shorter than 100 ms or longer than 700 ms were considered to be errors (anticipations and slow responses, respectively) and were discarded. In the choice MRT condition, pressing the key not spatially corresponding to S2 was also considered an error. When one of these errors occurred, instead of the MRT, the message “anticipation” or “slow response” or “error” appeared on the screen for 1000 ms. All error-trials were repeated at the end of each session. They corresponded to 2.98% in all trials.

The medians of the MRT obtained on the second, third and fourth days were submitted to an analysis of variance (ANOVA) in which day (second, third or fourth), visual hemifield (left or right) and gap duration (0, 250 or 1000 ms) were used as within-subjects factors. The data were also submitted to post hoc analysis using the Newman-Keuls method. The level of significance adopted was $P<0.05$.

ANOVA showed that day and gap duration were significant sources of variance ($F(2,14) = 27.378$, $P<0.001$ and $F(2,14) = 22.864$, $P<0.001$, respectively). Post hoc analysis revealed that the MRT observed on the second day (228 ms) did not differ significantly from that observed on the third day (222 ms), but these MRTs, which were obtained in the choice condition, were different from that observed on the fourth day, when simple MRT was used (204 ms). For the gap duration factor, the MRT for gap 0 (231 ms) was significantly different from those for gaps 250 and 1000 (211 and 212 ms, respectively), while these two did not differ significantly.

Since the MRTs for the second and third days were alike, we pooled the data in Figure 2A. This figure shows the variation of MRTs as a function of condition and gap duration. Note that the MRTs for gap 250 and for gap 1000 did not differ (217 and 219 ms for choice MRT; 200 and 198 ms for simple MRT, respectively), but both differed from the MRT for gap 0 under both conditions (240 and 215 ms for the choice and simple conditions, respectively). The differences between choice and simple MRT at each gap duration were almost the same, approximately 22 ms. In short, it can be seen that a) for all gap durations choice MRTs were longer than simple MRTs, and b) MRTs for gap 0 were longer than those for gaps 250 and 1000 under both conditions.

Interaction was also observed between day and hemifield ($F(2,14) = 5.012$, $P = 0.022$). On the second and third days, when the choice condition was used, the latency of the responses to stimuli on the left visual field (225 and 219 ms for the second and third days, respectively) was shorter than the responses to stimuli in the right visual field (232 and 226 ms, respectively). However, on the fourth day, when the simple condition was used, there was no significant difference between hemifields (205 and 203 ms for left and right targets, respectively).

We carried out a second ANOVA to determine whether the gap effect (difference between MRT of gap 0 and gap 250) differed between the choice and simple MRT conditions. In this ANOVA, gap effect was used as the dependent variable and condition (choice or simple reaction time) and visual hemifield (left or right) were used as within-subject factors. ANOVA showed that the gap effect for the choice and the simple MRT condition was significantly different ($F(1,7) = 5.877$, $P = 0.044$). The gap effect was stronger for the choice than for the simple MRT condition (22 *vs* 15 ms), but

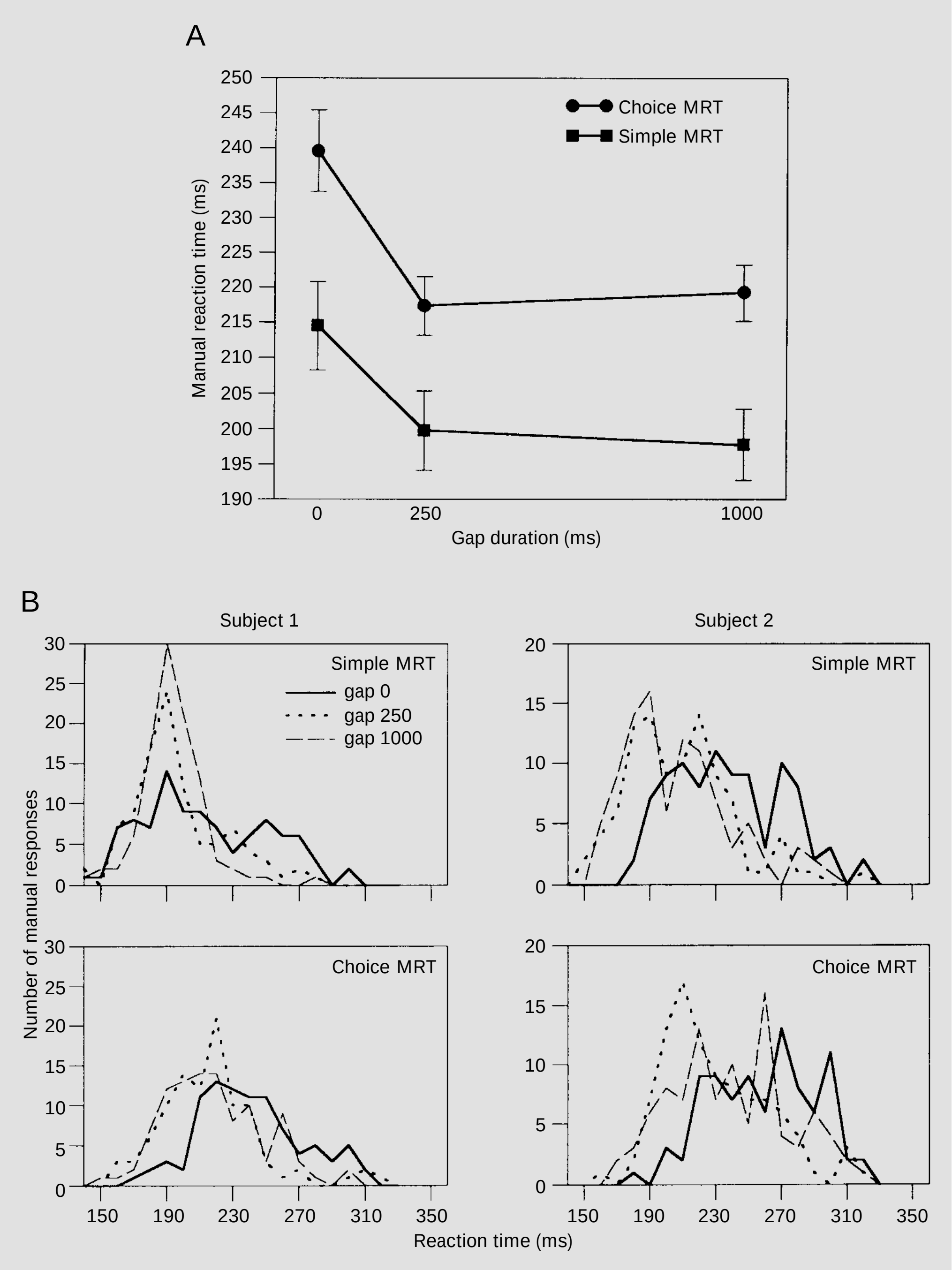

Figure 2 - Main results of the experiment: *A*, Mean latency of manual reaction times (MRT) as a function of gap duration and condition (simple or choice) for the 8 subjects studied. The error bars indicate ± 1 SEM. *B*, Distribution of MRTs for two subjects in the simple (upper graph) and choice (lower graph) MRT conditions. The number of manual responses (ordinate) is plotted as a function of reaction times (abscissa). A binwidth of 10 ms was used; the data from the right and left hemifields for each condition were pooled (100 manual responses for each curve). Solid lines, gap duration of 0 ms; dotted lines, gap duration of 250 ms; dashed lines, gap duration of 1000 ms.

was present in both conditions.

MRT distributions were calculated for each of the eight subjects for all gap durations in both conditions. A binwidth of 10 ms was used. The first bin included MRTs from 140 to 149 ms and the last from 350 to 359. Figure 2B shows the MRT distributions for two subjects in the simple (upper panel) and choice MRT condition (lower panel) for gap durations of 0, 250 and 1000 ms. The plots of the simple condition were obtained using the data of the fourth day, and those of the choice condition using the data of the third day. Data from the left and right hemifields were pooled (100 MRTs for each curve). The tendency towards smaller values in the simple MRT condition in relation to the choice MRT condition observed in Figure 2A was also present in the MRT distributions of Figure 2B for all gap durations. Moreover, there was also a tendency towards smaller values for gaps 250 and 1000 compared to gap 0 for both conditions. There was no clear evidence for a separate subpopulation of MRT, equivalent to the express saccades. Only for two of the eight subjects studied can bimodality be suggested: for subject #1 in the simple condition and gap 0 (solid line in the upper-left graph), and for subject #2 in the simple condition and gaps 250 and 1000 (dotted and dashed lines in the upper-right graph). Subject #1 showed a possible first population of MRTs around bin 190 and a second around bin 250. The second and smaller peak could be seen only at a gap duration of 0 ms, while the first, although existing for the three tested gap durations, was considerably higher at gap durations of 250 and 1000 ms. Subject #2 showed the two possible populations of MRT around bins 190 and 210-220, respectively, at gap durations of 250 and 1000 ms. The other six subjects (data not shown) showed no sign of bimodality under any condition or gap duration tested. Therefore, bimodal distribution of response latencies, although suggested for some subjects, was not consistent in our sample. An intriguing fact is that, although the gap effect was stronger for the choice than for the simple MRT condition, the few bimodal MRT distributions we found were always in the simple condition. Therefore, we found a gap effect without a clear population of express manual responses. These results strongly support the idea that the gap effect and the express responses are distinct phenomena.

Fischer and Weber (for details, see Ref. 3) have considered the gap effect as the difference between reaction times in the overlap and the gap 200 condition. In the present study, we followed Saslow's (2) original approach and used the MRT at gap 0 (simultaneous AP offset and stimulus onset) as baseline for the gap effect. The gap effect was present in both the simple and choice MRT conditions and ranged from a mean value of 15 ms for the simple MRT to 22 ms for the choice MRT condition (see Figure 2A), suggesting a stronger gap effect for the choice MRT condition.

Bekkering et al. (4) found the gap effect for choice MRT but not for simple MRT and proposed that the gap effect is present only for spatially oriented responses. Our results show that the requirement to identify the stimulus location and to select the appropriate response increases MRT, i.e., choice MRTs are longer than simple MRTs. However, the response selection is not necessary to elicit the gap effect since this effect was found in both the choice and simple paradigms.

Our findings complement the data of others who used the choice MRT condition and a fixed array of gap durations and who were also unable to demonstrate express manual responses (8,11,15,17,18). Therefore, over a wide range of conditions express manual responses could not be clearly demonstrated. If such a phenomenon does exist for manual responses the optimal conditions to generate manual express responses are yet to be found.

In short, we observed the gap effect for both simple and choice MRT without clear evidence of express MRT. In our view, the offset of AP facilitates the automatic orienting of attention to the target position at short gap durations. AP offset would elicit a disengagement of attention and, if the target occurs while the attention is disengaged (200-300 ms), it is captured more quickly than if the attention is still engaged. This explanation, however, cannot be used for the gap duration of 1000 ms since the studies with SRT showed that the optimal interval for the gap effect is between 200 and 300 ms (5,10).

Acknowledgments

We would like to thank Dr. Carlos Eduardo Rocha-Miranda (Academia Brasileira de Ciências) and Dr. Ronald Ranvaud (ICB-USP) for their valuable comments on an early version of the manuscript. We are also grateful to Mr. Antônio Romanazzi Vieira, from Programa de Geoquímica of the Universidade Federal Fluminense, who developed a detector of light stimuli for accurate determination of the time sequence in our experiments.

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