Effect of space between fingers on tactile duration discrimination

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Abstract

The purpose of this study was to examine how space between tactile stimuli marking time affects the processing of duration. Twelve participants were recruited in an experiment where the method of constant stimuli was used. Eight participants perceived empty time intervals as longer when the intervals were marked by two electric pulses stimulating different (middle and little) fingers than the same (middle) finger while four participants perceived intervals as shorter when two pulses were delivered to different fingers. However, increasing the angle between the middle and little fingers did not magnify the spatial effect in both groups of participants. Finally, discrimination level remained the same regardless of whether participants overestimated or underestimated intervals marked by two pulses stimulating different fingers.

Grondin, Kuroda and Mitsudo (2011) examined how duration processing of inter-stimulus intervals is changed when the intervals are marked by two electric pulses stimulating different hands instead of the same hand. They reported that delivering two pulses to different hands led to longer perceived duration than delivering them to the same hand. They argued that this effect is a variation of the *kappa effect*, where an empty time interval is perceived as longer when it is bounded by two signals further away from each other in space. The kappa effect has been tested in the visual and auditory modalities, and even in the tactile modality (see Suto, 1952, 1955; Yoblick & Salvendy, 1970). Indeed, in Grondin et al.'s study, an interval was perceived as longer when it was marked by two pulses delivered to different tactile locations (hands).

However, instead of being an effect of space, the results of Grondin et al. (2011) could be attributed to the latency to integrate two markers stimulating different cortical hemispheres. A stimulus to the left hand is projected to the right hemisphere and a stimulus to the right hand is projected to the left hemisphere. If there is some latency to integrate stimuli projected to different hemispheres relative to the same hemisphere, such latency might have resulted in longer perceived duration in Grondin et al.'s study.

This argument becomes plausible when one considers what was suggested by Gescheider (1966). Gescheider examined how temporal resolution is changed when an inter-onset interval is marked by two vibrotactile signals stimulating different fingers, instead of the same finger. A threshold was estimated in this study: when an interval between two markers was briefer than this threshold, participants could not perceive these markers as discrete events but rather perceived them as fused into a single event. Gescheider reported that the threshold remained the same (10 ms) regardless of whether two pulses were delivered to the same (index) or different (ring and index) fingertips of the same hand, while delivering two pulses to the index fingertips of different hands led to a higher threshold (12.5 ms). This might suggest that duration processing is not affected by the cortical locations of stimuli within the same hemisphere while it changes depending on whether two markers stimulate the same or different hemispheres.

The present experiment was conducted to determine whether inter-stimulus intervals would be perceived as longer when they were marked by two pulses stimulating different fingers (of the same hand) than the same finger. In each trial, two intervals to be compared were successively delivered to the left hand. Two pulses bounding the first interval were both delivered to the middle fingertip. The onset pulse of the second interval was delivered to the middle fingertip while the offset pulse was delivered to the middle or little fingertip. The angle between the middle and little fingers was approximately 20° or 40°. Note that in this procedure two pulses stimulated the same or different cortical regions but within the same hemisphere.

Method

Participants

Twelve participants, six males and six females aged 19-48 years, self-reporting being right-handers, were recruited. They were students or employees at Université Laval, except one who was an unemployed resident of Québec. They consented to their participation by signing a form approved by the institutional ethical committee, and received $20 CAN for their participation.

Apparatus and stimuli

Stimulus presentations were controlled by E-prime software installed in an IBM computer. Empty time intervals were marked by electrical pulses of 20 ms. To electrify each fingertip, two electrodes (a plus pole and a minus pole) were attached to both sides of the distal interphalangeal (Figure 1). These electrodes were covered with conductive gel and were fixed with medical tape. An experimenter calibrated the voltage before the beginning of each session; the voltage was fixed to a point at which participants reported perceiving stimuli clearly but without any discomfort.

Four pulses were successively presented in each trial, the first two marking the *standard* interval and the last two marking the *comparison* interval. These intervals were manipulated in terms of temporal duration from the offset of the preceding pulse to the onset of the following pulse (i.e., these intervals were inter-stimulus intervals). The standard interval was fixed at 500 ms while the comparison interval was varied from 300 to 700 ms in steps of 80 ms, resulting in six comparison intervals. The standard and the comparison were separated by an inter-stimulus interval of 2000 ms.

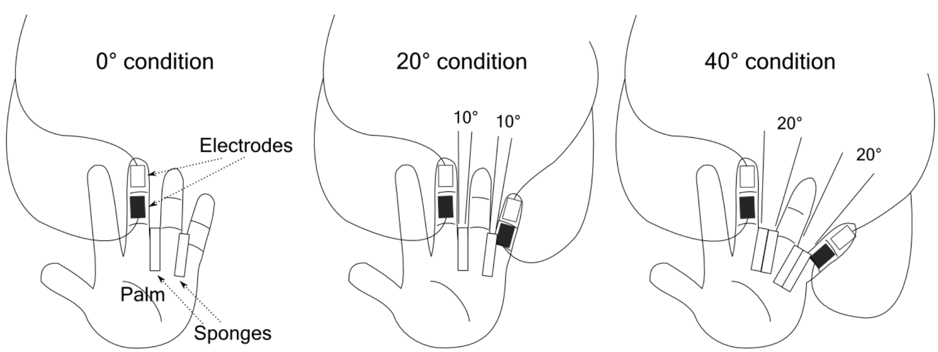

Figure 1. Electrodes' attachment.

All four pulses were delivered to the left hand. Two pulses bounding the standard were both delivered to the middle finger. The onset pulse of the comparison was delivered to the middle finger while the offset pulse of the comparison was delivered in one of the three conditions. In the 0° condition, the offset pulse was delivered to the middle finger, i.e., both onset and offset pulses were delivered to the same (middle) finger. In the 20° condition, it was delivered to the little finger, with the angle between the middle and little fingers being approximately 20°. In the 40° condition, it was delivered to the little finger, with the angle between the middle and little fingers being approximately 40°.

Angles between fingers were fixed with sponges (which were conventionally to be used as medical toe separators; see Figure 1). In the 0° and 20° conditions, one sponge was inserted between the middle and ring fingers and between the ring and little fingers. In the 40° condition, two sponges were inserted between the middle and ring fingers and between the ring and little fingers.

Procedure

Participants were instructed to judge whether the comparison interval was shorter or longer than the standard interval. Participants responded verbally and the response was registered by an experimenter who also stayed in the experimental booth. The next trial started 2 s after the registration of the response.

There were three sessions, each one being dedicated to one experimental condition. The order of these sessions was counterbalanced. Each session consisted of four blocks each containing 60 trials; the six comparison intervals were presented ten times each in random order. A break of about 30 s was taken between the blocks. Each session took about 30 minutes.

Results

The probability of perceiving a comparison as longer was calculated for each comparison interval, resulting in 6-point psychometric functions. Each point of functions was based on 40 responses (4 blocks × 10 repetitions). The cumulative normal distribution was fitted to the resulting curves. The goodness of fit was high: The R^2 value was above .90 in all 36 cases (12 participants × 3 experimental conditions).

There are two parameters of interest. The first one is the bisection point (BP), which is a point at which the function crossed 0.5. Note that this parameter here is used to express the perceived duration of the comparison interval. If the comparison interval is perceived as longer than the standard, participants respond "longer" more frequently, resulting in a downward shift of the BP. In other words, a lower BP indicates a longer perceived duration of the comparison interval. The second one is the standard deviation (SD) of the fitted cumulative normal distribution. Dividing one SD by 500 (the standard interval) gave the Weber fraction (WF), where a lower value indicates a steeper slope of the function and thus indicates better discrimination (Grondin, 2008). Individuals' BP and WF are shown in Figure 2.

There were individual differences in the direction of spatial effect on their perceived duration (BP). Indeed, a repeated-measure analysis of variance (ANOVA) showed no significant difference for the pooled data, $F(2, 22) = 1.215$, $p = .316$, $\eta_p^2 = .100$. A cluster analysis based on squared Euclidian distance and Ward method divided participants into two groups (Figure 3). Note that before constructing the distance matrix for this analysis we standardized BPs *in each participant*, i.e., we calculated in each participant a mean BP across three experimental conditions, subtracted the mean from the BP of each condition, and divided the resulting value by a standard deviation across the three conditions. In eight participants, the comparison interval was perceived as longer, i.e., the BP was lower, when two pulses were delivered to different fingers than the same finger (the overestimation group). In four participants, the comparison interval was perceived as shorter when two pulses were delivered to different fingers (the underestimation group).

In each group, the 20° and 40° conditions led to near identical duration. The ANOVA showed that some difference was significant for the overestimation group, $F(2, 14) = 15.877$, $p < .001$, $\eta_p^2 = .694$, while the trend analysis revealed that the quadratic trend, $F_{quad}(1, 7) = 7.883$, $p = .026$, $\eta_p^2 = .530$, as well as the linear trend, $F_{lin}(1, 7) = 24.862$, $p = .002$, $\eta_p^2 = .780$, was significant. Indeed, multiple comparisons subjected to Ryan's adjustments showed that the 20° condition ($p < .001$) and the 40° condition ($p < .001$) led to longer perceived duration than the 0° condition while the difference between the 20° and 40° conditions was not significant ($p = .935$). For the underestimation group, there was no significant difference, $F(2, 6) = 3.204$, $p = .113$, $\eta_p^2 = .516$.

Discrimination (WF) was not affected by the location of pulses in both groups. The ANOVA showed no significant difference for the overestimation group, $F(2, 14) = .784$, $p = .476$, $\eta_p^2 = .101$, for the underestimation group, $F(2, 6) = 1.817$, $p = .242$, $\eta_p^2 = .377$, nor for the pooled data, $F(2, 22) = 2.359$, $p = .118$, $\eta_p^2 = .177$.

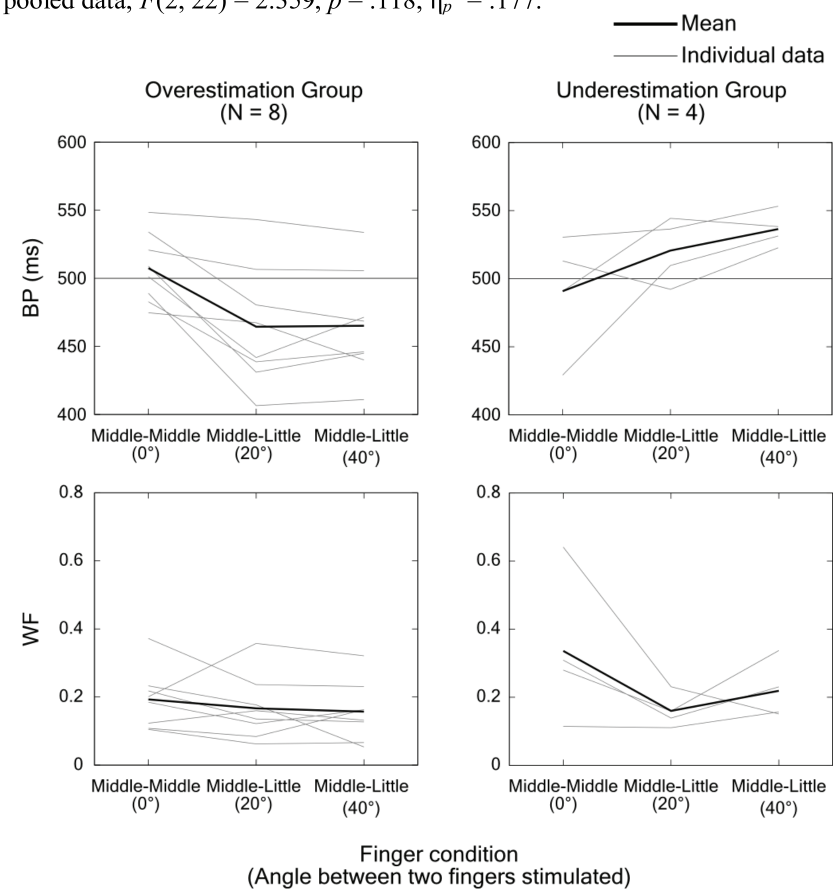

Figure 2. Bisection Point (BP: upper panel) and Weber Fraction (WF: lower panel) in each experimental condition for participants overestimating (left panel) and underestimating (right panel) the comparison intervals

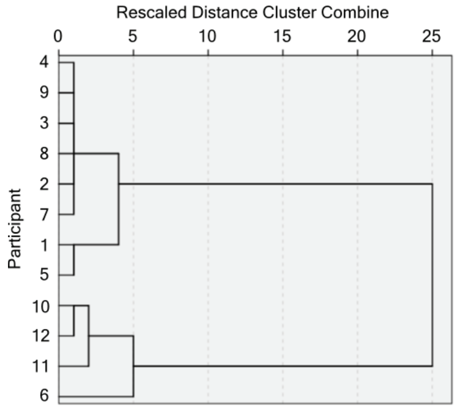

Figure 3. Dendrogram obtained by a cluster analysis on standardized BPs

Discussion

The results of the present study indicated that whether empty time intervals are overestimated or underestimated when they are marked by two pulses stimulating different fingers depends on individuals. Indeed, eight of twelve participants perceived empty time intervals as longer while four participants perceived intervals as shorter when two pulses were delivered to different fingers instead of to the same finger. Moreover, increasing the angle between the middle and little fingers did not magnify the spatial effect observed in both groups of participants; the 20° and 40° conditions led to near identical perceived duration in each group. This finding is consistent with that reported by Grondin et al. (2011). In their study, intervals were perceived as longer when two pulses were delivered to different hands than when presented to the same hand, while placing the two hands 3 feet apart resulted in almost the same duration as placing the hands nearby.

Grondin et al. (2011) delivered two pulses marking intervals to the same or different hands. In this procedure, two pulses stimulated the same or different cortical hemispheres. However, the present study revealed that there were individual differences in the perceived duration when two pulses stimulated different cortical regions within the same hemisphere. Given that intervals were overestimated even when the two hands were placed nearby in Grondin et al., delivering two pulses to different hemispheres seems a crucial factor causing the overestimation of duration.

The finding of the present study is partially inconsistent with that observed in our pilot experiment where participants perceived intervals as longer when the onset and offset markers were delivered to the index and ring fingers, respectively, compared to when both markers were delivered to the index finger. It is known that the index finger as well as the thumb has a better sensitivity for detecting stimuli than the other fingers (Johansson & Vallbo, 1979). Given that two pulses were delivered to the fingers of similar sensitivities in the present study, the overestimation observed in our pilot experiment is probably attributed to the fact that the index finger detects stimuli faster than the ring finger.

Temporal sensitivity (WF) remained almost the same regardless of whether participants overestimated or underestimated intervals marked by two pulses stimulating different fingers. Note that eight participants perceived intervals as significantly longer while their discrimination was not impaired when two pulses were delivered to different fingers. This is consistent with that observed in our pilot experiment, where discrimination remained the same even when the onset and offset markers were delivered to the index and ring fingers, respectively, compared to when both markers were delivered to the index finger. This could not be explained by utilizing the concept of an internal clock. It is widely accepted in the time perception literature that there is an internal clock for processing temporal information (see Grondin, 2001, 2010). This clock is usually assumed to be a pacemaker-counter device where the first module is reported to emit pulses that are accumulated by the second one. The amount of accumulation determines perceived duration; more pulses result in longer perceived duration. Moreover, more pulses result in more variability of accumulation, i.e., longer perceived duration leads to lower sensitivity. Indeed, in Grondin et al. (2011), delivering two pulses to different hands led to longer perceived duration and impaired sensitivity. However, in the present study, delivering two pulses to different fingers did not result in impaired sensitivity even when intervals were perceived as longer.

The absence of impaired sensitivity (by space between markers) in the present study is strikingly different from that reported by Grondin et al. (2011). In their study, discrimination was impaired when two pulses marking intervals were delivered to different hands relative to the same hand. However, Grondin et al.'s and the present studies each can be linked with the study of Gescheider (1966). In Gescheider's study, a) temporal resolution remained the same regardless of whether two pulses were delivered to the same or different fingers of the same hand, b) while resolution was impaired when two pulses were delivered to different hands. The former result (a) is consistent with that observed in the present study while the latter (b) is consistent with that reported by Grondin et al. In brief, temporal sensitivity is impaired when intervals are marked by two pulses stimulating different hands but remains the same when two pulses are delivered to different fingers within the same hand.

Acknowledgements

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