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Does spatiotemporal integration occur with single empty time intervals instead of two neighboring intervals in the visual modality?

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Abstract

The *kappa effect* is an illusion involving spatiotemporal integration in the cognitive process and is demonstrated with three successive signals delimiting two neighboring empty time intervals. The present experiment was conducted with single time intervals delimited by two signals, instead of three, to examine whether perceived duration would be modulated by space. Each of the two flashes was delivered from the left or right side in one session (horizontal direction), while each was delivered from the upper or bottom side in the other session (vertical direction). Empty time intervals were perceived as longer when two flashes were delivered from different locations than when delivered from an identical location, but only when the flashes were presented in the horizontal direction. Given that the kappa effect can occur when three signals are presented vertically, spatiotemporal integration seemed difficult to occur with single time intervals compared to two neighboring intervals.

Keywords: kappa effect; temporal discrimination; peripheral vision; imputed velocity

Introduction

Space and time are integrated in the cognitive process in order to perceive the motion of external objects. Spatiotemporal integration has been investigated since the early 20th century in the field of psychophysics (Abe 1935; Helson 1930), while this issue has recently attracted attention from neuroscience researchers (e.g., Bonato, Zorzi, & Umiltà, 2012; Vallesi, McIntosh, & Stuss, 2011).

The *kappa effect* is one of the famous illusions involving spatiotemporal integration in perception (Cohen, Hansel, & Sylvester, 1953; Jones & Huang, 1982). This effect takes place, for example, with three flashes, A, B and C, which are presented successively at equal temporal intervals. Two neighboring time intervals, A-B and B-C, are perceived as equal to each other if these flashes are aligned at equal spatial intervals. However, A-B duration is perceived as shorter than B-C duration, despite the physical equality of these durations, if B is spatially closer to A than to C; as well, A-B duration is perceived as longer than B-C duration if B is spatially closer to C than to A. The effect is thus

interpreted as indicating a perceptual tendency to overestimate duration when spatial distance is increased.

The kappa effect is explained by the imputed-velocity model, positing the constancy of motional speed or velocity (Alards-Tomalain, Leboe-McGowan, & Mondor, 2013; Henry & McAuley, 2009; Jones, & Huang, 1982; ten Hoopen, Miyauchi, & Nakajima, 2008). According to this model, the kappa-effect (three-stimuli) pattern is perceived as consisting of a single object appearing three times, instead of three discrete objects appearing successively. This single object is perceived as passing through space with constant speed. Speed constancy is physically kept when three stimuli are presented at equal temporal intervals and at equal spatial distances, but not kept if the middle stimulus is made close to the initial or to the last one in space, when time intervals are kept equal. This speed inconstancy, however, is re-adjusted by the perceptual system. The first duration is perceived as shorter than the second one when the middle stimulus is spatially close to the initial one, while the first duration is perceived as longer than the second one when the middle stimulus is close to the last one, so that the single object is perceived as moving between three spatial locations with constant speed.

The imputed-velocity model does not help to predict any spatial effects on the perception of single time intervals delimited by two signals. Indeed, the presentation of only two signals does not imply whether speed is constant or not. Several studies nevertheless have demonstrated phenomena that seemed to be variations of the kappa effect with single intervals. Price-Williams (1954) conducted an experiment where participants adjusted a single time interval between two flashes and made it equivalent to another interval (the adjustment method), and indicated that intervals are perceived as longer when they are delimited by two flashes located further away from each other. Grondin (1998) conducted an experiment where participants categorized single time intervals delimited by two flashes as short or long (the single-stimulus method), and found (in Experiment 2) that participants tended to respond “long” when the first and second flashes were located on the left

and right side, or the right and left side, respectively, compared to when both stimuli were delivered from an identical location on the left or the right side.

However, Guay and Grondin (2001) indicated that longer spatial distance resulted in shorter perceived duration, instead of longer, with single intervals. In their experiment, each of the two flashes was delivered from one of the three locations aligned on a vertical axis; the above (A), the middle (M), and the below (B). Participants tended to judge empty time intervals delimited by A and B as “short” compared to intervals delimited by A and M or by M and B. Since, in Grondin (1998), perceived duration increased when two stimuli were delivered from different locations aligned on a horizontal axis, the vertical and the horizontal presentations of two flashes might have different effects on perceived duration. However, in Guay and Grondin’s study, M was located on the central visual field (fixation point) while A and B were located on the peripheral field. This visual-field difference might have affected the results. Indeed, Aedo-Jury and Pins (2010) reported that empty time intervals were perceived as shorter when two stimuli were delivered from a location further away from fovea.

Given the small number of relevant studies with single intervals, it would make sense to re-examine whether spatiotemporal integration would occur with single intervals delimited by two successive flashes. In the present experiment, two flashes were located on identical or different locations but both in the peripheral field. These flashes were aligned on a horizontal or a vertical axis. The method was almost compatible with that adopted by Grondin (1998).

Method

Participants

Seventeen participants, including an author T.K., were recruited. They were students or employees at Kyushu University, 6 males and 11 females, aged 19-32 years. They self-reported having normal non-corrected or corrected visual acuity.

Apparatus and stimuli

In order to guarantee the good timing accuracy of presentation of two flashes, we made equipment consisting of two light emitting diodes (LEDs) as used in Arai, Suetomi and Nakajima (2000). The timing accuracy of the equipment was indeed checked by conducting physical measurements with a photo diode. Two 5-mm round red LEDs (OptoSupply OSR6LU5B64A-5V) were lit or unlit by electric currents that were outputted from a 2-channel audio amplifier (audio-technica AT-HA20) connected to a computer (Epson AT990E). The electric signals of two successive flashes were digitally generated and saved in a stereo WAV file that was sampled at 44100 Hz and quantized to 16 bits. Two channels of the WAV file corresponded to the two LEDs. Signals for lighting the LEDs were 3000-Hz 20-ms sinusoidal waveforms; these sinusoids resulted in alternating currents but the LEDs could rectify the currents. Amplitude rose and decayed during 5 ms with raised-cosine ramps at the beginning and the end of each sinusoidal signal, these ramps being included in the signal length. Thus, empty time intervals were delimited by two 20-ms flashes (including 5-ms rise and decay times). Microsoft Visual Basic 2012 was used to generate waveforms and to make a computer program conducting the experiment.

Empty time intervals were manipulated in terms of duration from the termination of the preceding flash to the onset of the following flash (i.e., they were inter-stimulus intervals). They lasted either 220 or 280 ms.

The two LEDs were attached near the edges of a square white board, which was located in front of a computer display (Figure 1). The board had a hall at its center, and a part of the computer display could be seen through this hall. A red cross of around 5 mm that participants fixated was presented on the center of the display. This cross and the LEDs were aligned on a horizontal or a vertical axis. The direction of the LEDs (horizontal or vertical) was changed by rotating the white board. The LEDs were located on the left side (L) and the right side (R) to the fixation point when they were aligned horizontally, while they were on the upper side (U) and the bottom side (B) when aligned vertically. Two flashes were emitted from identical or different LEDs, resulting in four conditions for each direction: LL, LR, RL and RR for the horizontal direction; UU, UB, BU and BB for the vertical direction. Each LED was 18° apart from the fixation point in visual angle. Participants were seated about 1 m in front of the board.

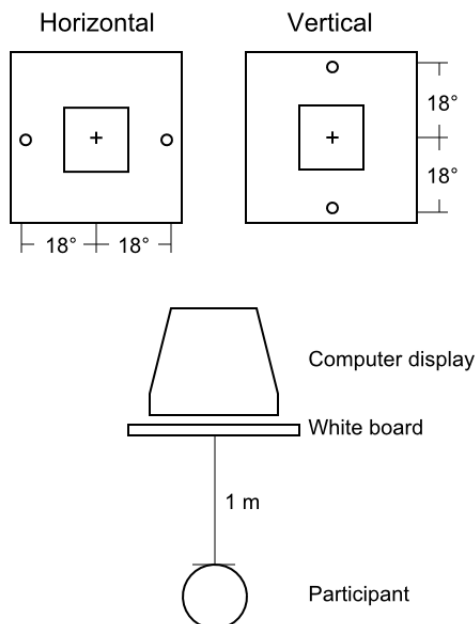


Figure 1: Experimental settings.

In order to avoid adaptation and afterimage effects on retina, flashes were presented in a normally illuminated room as in Arao et al. (2000) and Price-Williams (1954), instead of a darkroom. The luminance of the white board was between 16 and 30 cd/m². The luminance of the flashes was above 250 cd/m² when measured 1 m in front of the board. However, due to the very small size of the LEDs, it was technically difficult to specify precise luminance values of the flashes. In order to cancel out potential luminance difference between the two LEDs, the location of the LEDs was interchanged between nine participants and eight participants.

Design and procedure

The present experiment was based on a 2 (directions) × 4 (locations) × 2 (durations) design. The two direction conditions were presented in separate sessions whose order was counterbalanced and the statistical analysis was conducted separately on these conditions. Each of the two sessions was divided into two sub-sessions, each one consisting of five blocks. In each block, the eight patterns (4 locations × 2 durations) were presented four times each in a random order.

The categorization method (or the signal-detection-theory approach) as used in Grondin (1998) was adopted. Participants were instructed to respond “short” when an inter-stimulus interval delimited by two flashes was briefer than 250 ms (i.e., 220 ms) and to respond “long” when the interval was longer than 250 ms (280 ms). After the response, a feedback message indicating whether the response was correct or incorrect was presented at the center of the display during 1.2 s. The next trial started 1 s after the termination of the feedback.

Participants responded by pressing a button of a computer mouse. In one sub-session, participants pressed the left and the right buttons for responding “short” and “long,” respectively. In the other sub-session, they pressed on the right and the left buttons for responding “short” and “long,” respectively. The order of these sub-sessions was counterbalanced.

Participants were instructed to respond as correctly as possible, but for the first few trials of the first block, they were allowed to choose “short” or “long” randomly because they did not know how long the around-250-ms interval would be perceived as. Thus, the first block of each sub-session was regarded as training and removed from the data analysis. Participants were instructed not to adjust their perceived duration according to spatial distance between presented stimuli. They were also instructed not to count the cadence or make sounds synchronized with flashes (e.g., hand tapping and internal voicing) for discrimination. Hand tapping and internal voicing might reduce the spatial effects because sounds were made at a constant location.

A break of a few seconds was taken between the blocks. Each session took about 30 min and both sessions were conducted in one day.

Dependent variables

As mentioned earlier, the first block of each sub-session was regarded as training and removed from the data analysis. The two sub-sessions were collapsed, resulting in 32 responses for each session, for each duration and for each location condition (2 sub-sessions × 4 blocks × 4 responses).

Two signal-detection-theory measures, d' and β , were estimated from participants’ responses as in Grondin (1998). d' indicates how well participants discriminate between the 220-ms and the 280-ms intervals; a higher value indicates better discrimination. β indicates how likely participants were to perceive intervals as “long” instead of “short”; a lower value indicates that participants were likely to respond “long.” Note that β is usually used in the literature to express the tendency for participants to prefer responding one of the two alternatives in detection tasks, while in the present study this measure is interpreted as a sign of perceived duration (see also Kuroda & Grondin, 2013); if intervals are perceived as longer, participants should more frequently respond “long” instead of “short.”

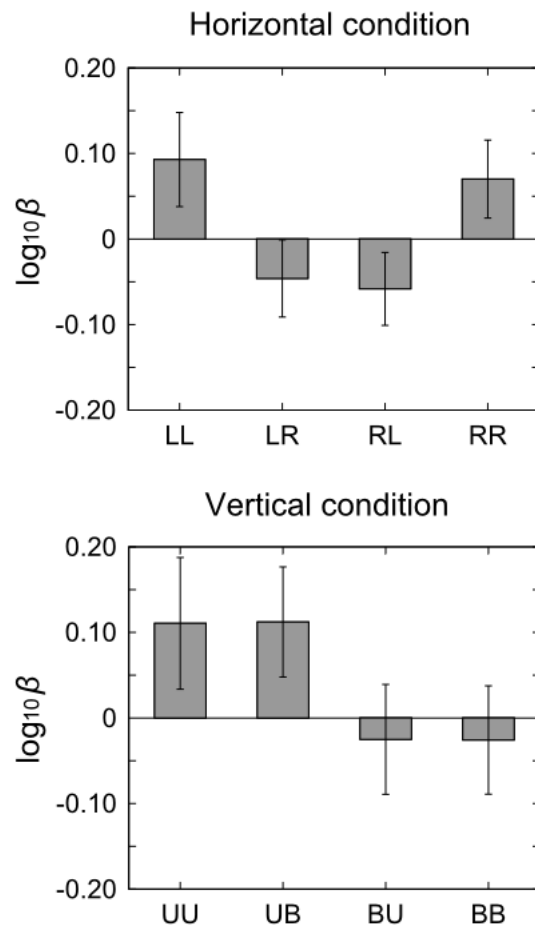


Figure 2: Mean $\log_{10}\beta$ of each location condition for the horizontal (upper panel) and for the vertical condition (lower panel). Bars are standard error of mean between participants.

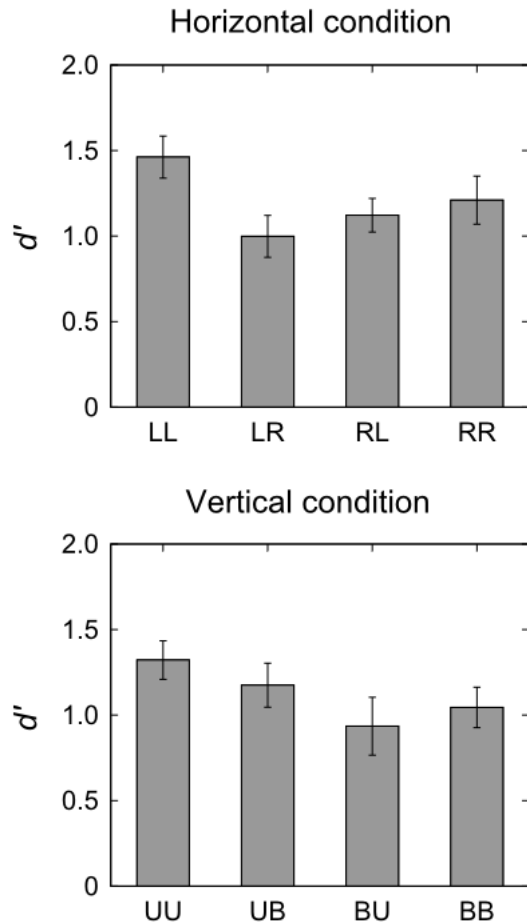


Figure 3: Mean d' of each location condition for the horizontal (upper panel) and for the vertical condition (lower panel). Bars are standard error of mean between participants.

d' was given by Z_{false} minus Z_{hit} (Macmillan, & Creelman, 2005). Z_{hit} is a z score of one minus the hit probability and Z_{false} is a z score of one minus the false-alarm probability. The hit probability here means how frequently participants correctly responded “long” when the interval was actually long (i.e., 280 ms). The false-alarm probability means how frequently participants wrongly responded “long” when the interval was actually short (i.e., 220-ms). d' was more than 0 except in 3 cases out of 136 (17 participants \times 4 locations \times 2 directions).

β was given by dividing Y_{hit} by Y_{false} , which were the y -axis values of standard normal distribution corresponding to Z_{hit} and Z_{false} , respectively (Macmillan, & Creelman, 2005). However, we indeed used $\log_{10}\beta$ instead of β for keeping the linearity of scale and using zero as equal responses of “short” and “long.”

Statistical analysis

Statistical comparison was conducted separately on the two direction (horizontal and vertical) sessions with an analysis of variance (ANOVA; with SPSS PASW 18.00). This

ANOVA was based on a two-way (2×2) factorial design with repeated measures and based on linear mixed algorithms where compound symmetry was adopted as the covariance matrix structure. The first factor and the second factor were the preceding flash’s location and the following flash’s location, respectively (left vs. right for the horizontal session; upper vs. bottom for the vertical session). Main effects could reveal whether the location of each flash, per se, changed results, whereas the interaction was of interest for the current discussion. The interaction will be significant if perceived duration change when the preceding and the following flashes were delivered from different locations compared to an identical location.

Results

The mean $\log_{10}\beta$ of each experimental condition is shown in Figure 2. For the horizontal session, the results of the linear mixed ANOVA indicated that LR and RL conditions led to lower $\log_{10}\beta$ (longer perceived duration) than LL and RR conditions. Indeed, neither the preceding-location effect, $F(1, 48) = 0.122, p = .729$, nor the following-location effect was significant, $F(1, 48) = 0.011, p = .916$, while the interaction was significant, $F(1, 48) = 7.100, p = .010$. Note that in this model the degree of freedom for denominators was given by (2 preceding \times 2 following locations $- 1$) \times (17 participants $- 1$). For the vertical session, whereas BU and BB seemed to result in lower $\log_{10}\beta$ than UU and UB, the preceding-location effect was only marginally significant, $F(1, 48) = 3.469, p = .069$, and the following-location effect was not significant, $F(1, 48) < 0.001, p = .995$. The interaction was not significant, $F(1, 48) < 0.001, p = .987$.

The mean d' of each experimental condition is shown in Figure 3. For the horizontal session, the significant interaction, $F(1, 48) = 8.918, p = .004$, indicated that delivering two flashes from an identical location (LL and RR) resulted in higher d' than delivering them from different locations (LR and RL). The preceding-location effect was not significant, $F(1, 48) = 0.481, p = .491$, while the following-location effect was significant, $F(1, 48) = 4.124, p = .048$. For the vertical session, the preceding-location effect was significant, $F(1, 48) = 5.931, p = .019$, indicating that d' was higher when the preceding flash was delivered from the upper side than when delivered from the bottom side. Neither the following-location effect, $F(1, 48) = 0.030, p = .862$, nor the interaction, $F(1, 48) = 1.461, p = .233$, was significant.

Discussion

Empty time intervals were perceived as longer when these intervals were marked by two successive flashes delivered from different locations than from an identical location, but only when the flashes were presented in the horizontal direction. Indeed, participants more frequently responded “long” (lower $\log_{10}\beta$) in the LR and RL sequences than in the LL and RR sequences, thus replicating the results of Grondin (1998). However, this identical- vs. different-

locations difference was not observed when two flashes were presented in the vertical direction. Guay and Grondin (2001) also reported, as mentioned in the Introduction, that empty time intervals were not perceived as longer but rather were perceived as shorter when they were marked by two flashes further away from each other in the vertical direction. However, Cohen, Hansel and Sylvester (1955) demonstrated the occurrence of the kappa effect when three flashes (instead of two) were presented in the vertical direction (although there were some differences between downward and upward presentations). Given this, the presentation of two successive signals seemed to have little effect on inducing spatiotemporal integration, compared to that of three signals resulting in the kappa effect, when these signals were presented vertically. The future researches should use three successive flashes with the same experimental settings as in the present experiment.

It seemed disputable to posit that a common mechanism underlies the spatial effects observed in the horizontal condition of the present experiment and the kappa effect that occurs with three signals. As mentioned in the Introduction, the kappa effect is attributed to the perceptual tendency to keep the constancy of motion speed, but the presentation of only two signals in the present experiment does not imply whether speed is constant or not. Instead, the results of the horizontal condition might be attributed to the fact that two flashes stimulated different cortical hemispheres or an identical hemisphere. In the LR and RL sequences, two flashes were delivered from different visual fields, resulting in the stimulation of different cortical hemispheres. In the LL and RR sequences, both flashes were delivered from either the left or the right field, resulting in the stimulation of one hemisphere. The processing of empty time intervals across different hemispheres might have resulted in longer perceived duration than the processing of intervals within an identical hemisphere. This argument becomes plausible when one considers what is indicated by Grondin, Kuroda and Mitsudo (2011) and by Kuroda and Grondin (2013). Both studies used empty time intervals of around 500 ms delimited by two electro-tactile signals. Grondin et al. reported that empty time intervals were perceived as longer when two signals were presented to different (left and right) hands than when presented to the same hand. Kuroda and Grondin, however, reported that there were some individual differences regarding whether intervals were perceived as shorter or longer when two signals were delivered to different (middle and little) fingers of the same hand, compared with when delivered to an identical finger. In Grondin et al., two signals stimulated different or identical hemispheres, but in Kuroda and Grondin, two signals stimulated different or identical cortical regions of the same hemisphere. Moreover, Grondin et al. reported that discrimination was impaired (the Weber fraction was increased) when two signals stimulated different hemispheres (hand) compared with when stimulating the same hemisphere. This was consistent with the results of the present experiment where discrimination was impaired (*d'*

was decreased) when two signals were delivered from different (left and right) visual fields than when delivered from the same field. Note that any identical- vs. different-locations differences were not observed in the vertical condition where each flash stimulated both hemispheres regardless of whether these flashes were delivered from identical or different locations. Given this, duration processing of single empty time intervals might be modulated by whether two signals stimulate identical or different cortical hemispheres, instead of how long these flashes are apart in the external space.

Finally, it is interesting that discrimination was improved when the first flash was delivered from the upper side than when delivered from the bottom side. This result did not seem consistent with the idea that the resolution of spatial attention is more precise for lower visual fields (see He, Cavanagh, & Intriligator, 1997). If discrimination had gained benefits from spatial attention paid to the first flash, it should have been improved when the first flash was delivered from the bottom instead of the upper side. Alternatively, the result might be compatible with that reported by Previc and Naeyegele (2001) where participants faster detected targets delivered from upper fields. Duration processing might be facilitated when its beginning is marked by a signal that can be easily detected.

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