Effect of Numeric Order on Subjective Duration of Following Stimulus

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Abstract. A perceived duration is affected by the magnitude of a stimulus. In most studies, the magnitudes are attributed to the target stimulus itself. We focused on a representation of magnitude organized in the brain, using ascending and descending numbers. We investigated whether these representations affected the duration judgment. A subject watched the ascending, descending, or randomly ordered numbers and judged the duration of a square presented just after the last digit. In all conditions, subjects overestimated the duration of the target stimulus. The overestimation was larger in the ascending than in the descending condition. The temporal judgments were not significantly different when only a single digit was presented before the target. Thus, the order of presentation has a significant effect in the temporal processing of following visual stimulus. We conclude that the priming by the order of numbers affected to the temporal processing of subsequent stimulus.

Keywords: time perception, duration estimation, temporal illusion

1 Introduction

Temporal processing is ubiquitous in our life. The neural basis of temporal processing and its relation to the subjective sense of time are still unclear. Many psychological studies have shown that our subjective sense of time is easily manipulated in laboratory experiments [1].

An Oddball stimulus appeared in a sequence of an identical stimulus is perceived longer than its actual interval [2]. This oddball effect happened even when the subjects knew the position when the oddball stimuli appeared in the train of stimulus [3]. The authors argued that oddball stimuli captured the perceiver's attention, resulting in an expansion of subjective time. In fact, the attended object was perceived longer than its actual presented duration [4].

When the presented stimulus could be predicted, the subject underestimated the presentation interval [5]. Subject's expectation of the stimuli might "shrink" the presented duration of the stimulus. This result indicated that higher cognitive process affected the time perception. In contrast, the underestimation of repeated presentation of the identical stimulus occurs on briefly presented stimuli, each of which were presented too short to reach the awareness of subject [6]. This indicated that a lower mechanism was also involved in constructing the psychological time.

The property of stimulus itself affects our perceived duration. Non temporal factors such as spatial size and magnitude of stimulus also affect its perceived subjective duration. The presented duration of larger stimulus was estimated to be longer than that of the smaller one [7]. This effect also occurred with more conceptual stimuli such as numbers [8]. A theory of magnitude [9] hypothesizes various dimensions such as space, time, quantity are represented by common neural mechanism.

In those studies, however, the magnitude which affected the temporal estimation have been attributed to the stimulus itself. It is unclear whether a low perceptual or a high cognitive mechanism is engaged to the temporal effect of magnitude. In this study, we investigated whether higher mechanism relating the magnitude could induce a temporal effect.

Human being has an ability to extract abstract information from external stimulus and categorize them in various dimension and magnitude, subsequently using this information to predict a following stimulus. Therefore, we hypothesized that these magnitudes and predictions which were synthesized internally in the brain would also affect the temporal estimation.

Even if we can predict the next stimulus when the digit appears successively in order, our introspection is different between an ascending and a declining numbers. Ascending numbers may be categorized to a representation like as "up" and "expansion", while declining numbers may be categorized to a representation like as "down" and "contraction". Subjects also may predict that the next stimulus will be bigger/smaller in ascending/declining numbers. Our hypothesis was that these insights would affect our time perception. We expected that ascending numbers would induce temporal overestimation of the stimulus presented just after numbers.

2 Experiment 1

2.1 Methods

Subjects. Nine subjects (8 naïve (3 female) and author T.H, mean±s.d age = 28±2.4) participated in the experiment. They have normal or corrected-to-normal vision. Written informed consent was obtained from all participants.

Apparatus and Stimulus. Stimulus presentation and collecting of subject's response were controlled by a PC (Panasonic CF-W4). Visual stimuli were presented on a 17-inch monitor (Eizo FlexScan S1911/S1922) with a refresh rate of 60 Hz. Subjects sat in front of the monitor with the distance of 60 cm with a chin rest. One of nine white digits (from '1' to '9' (0.04°in width and 0.07° in height)) and a white square (0.06°) were presented at the center of the monitor with a black background.

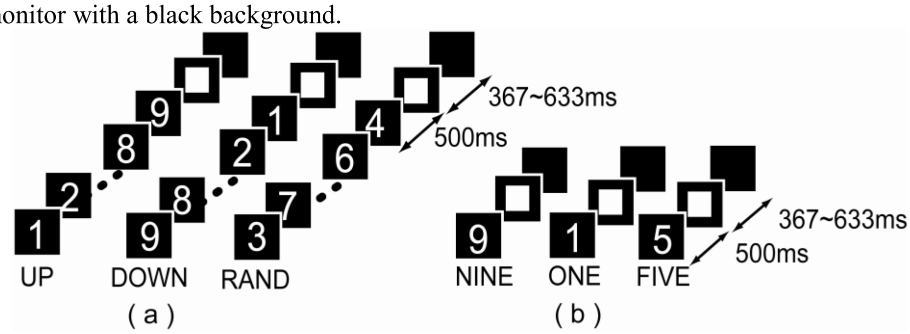

Fig. 1. Experimental procedures. (a) sequential numbers, (b) single number.

Procedure. The experiment consisted of a sequential numbers condition and a single number condition (Figure.1). In the sequential numbers condition, each of numeric stimuli was presented successively with a standard duration (500ms). Subjects were instructed beforehand that the presented duration of each digit were equal. There were three types (UP, DOWN and RAND) of orders in digits presentation. In the UP condition, each number appeared in an ascending order, while number goes down in order in the DOWN condition. In the RAND condition, the presented orders of digits were randomized. Therefore, in this condition subjects couldn't predict the next number. RAND condition was included for enhancing the subject's attention to the order of digits, by making the ascending and descending order salient. RAND condition was also designed to avoid the subjects suspecting the aim of experiment.

After the last digit was presented, the white square was presented with one of nine durations (367, 400, 433, 467, 500, 533, 567, 600 and 633 ms). No delay was inserted within successive digits and between the last digit and the target. After the stimulus presentation, participants judged whether the duration of the last square was longer or shorter than that of each of numeric stimulus and responded by pressing the button of mouse with their right hand.

Three types of number presentation were mixed randomly in one block. Each of test duration was presented once for each of conditions in a block. Therefore, each block contained 27 trials (9 durations × 3 conditions). Subjects conducted a total of 10 blocks.

Furthermore, to investigate whether there was any effect of the last digit to the duration estimation, we conducted the single number condition. Experimental setting was the same as the sequential numbers condition except that only one of three digits ("9", "1", or "5", NINE, ONE or FIVE condition, respectively) was presented as a reference stimulus for 500 ms before the target appeared with valuable delays. The '9' and '1' were the last digits in ascending order and in descending order, respectively. 10 blocks were conducted in each condition. The sequential and single number conditions were changed by five blocks and the orders of them were counterbalanced among the subjects.

Data Analysis. Subject's responses were plotted as a function of the test durations. Using maximum likelihood estimation, the data for each subject for each condition were fitted to the Weibull function:

$$F(x;\alpha,\beta) = 1 - \exp\left\{-\left(\frac{x}{\alpha}\right)^{\beta}\right\}.$$

where F represents a proportion of 'long' responses. x is the test duration. α and β are fitting parameters. Fitting parameters for each subject were used to estimate their PSE (Point of Subjective Equality: 0.5 point of fitted responding curve) and JND (Just Noticeable Difference: a difference of estimated duration between 0.75 and 0.5 point). A PSE indicated a target interval where the subjects perceived the target as the same duration with the interval of each digit. JND indicated sensitivity of temporal discrimination.

2.2 Results

Figure.2 shows the mean proportion of 'long' responses plotted as a function of the test durations in each condition. Figure.3 shows the mean PSE for each condition. In the sequential numbers condition, PSEs of all conditions were significantly different from 500ms (UP: 433±36 ms (mean±s.d), $t(8)=-5.22$, $p<0.001$, DOWN: 455±22 ms, $t(8)=-5.49$, $p<0.001$, RAND: 455±48 ms ,$t(8)=-2.56$, $p=0.033$). In the single number condition, only ONE condition was significantly different from 500ms (NINE: 449±69 ms, $t(8)=-2.08$, $p=0.070$, ONE: 452±57 ms, $t(8)=-2.35$, $p=0.046$, FIVE: 461±52 ms, $t(8)=-2.07$, $p=0.071$). The difference of PSE between UP and DOWN condition was significant (paired t-test, $t(8)=-2.37$ $p=0.044$) but between ONE and NINE was not(paired t-test, $t(8)= 0.34$, $p=0.73$). Therefore, the subjects overestimated the duration of target stimulus more in UP condition than in DOWN condition and this difference was not caused by the digit just before the target. The JNDs were not different significantly in both pairs (paired t-test, UP vs DOWN: $t(8)=0.12$, $p=0.90$, ONE vs NINE: $t(8)=-0.68$, $p=0.51$) (Fig.4).

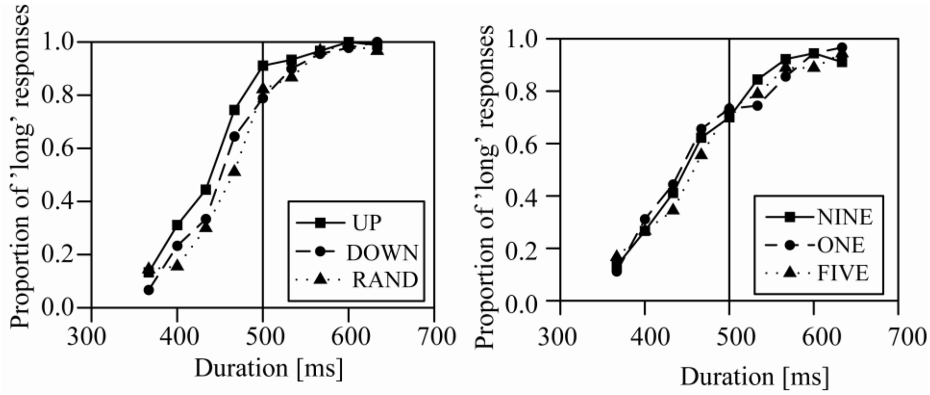

Fig.2. Response curves of the sequential numbers (left) and single number (right) conditions.

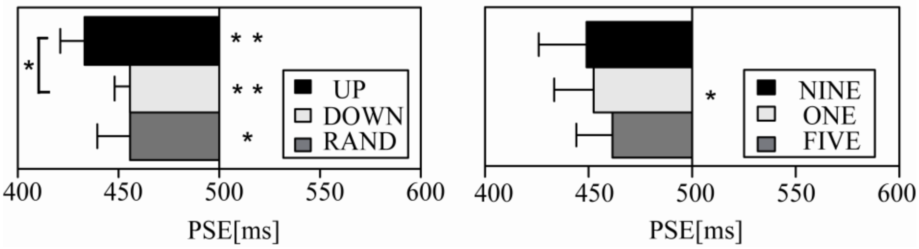

Fig.3. Mean of Point of Equality (PSE) of the sequential numbers (left) and single number (right) conditions.

3 Experiment 2

In experiment1, the mental representation induced by the number presentation influenced the temporal processing of following stimulus. A repetition of the same digit might also make a stable and invariant representation. This representation was obviously different from representations made by ascending and descending numbers. We hypothesized that time perception would be varied among these number presentations.

3.1 Methods

Subjects. Eight subjects (7 naïve (3 female) and author T.H, mean±s.d age = 28±2.4) participated in the experiment. They had normal or corrected-to-normal vision. Written informed consent was obtained from all participants.

Apparatus and Stimulus. The experiment was controlled on a desktop PC (EPSON Endeavor). Visual stimuli were presented at the center of a 21-inch CRT monitor (Sony, Trinitron, CPD-G520) with a refresh rate of 100 Hz. Subjects sat in front of the monitor at the distance of 60 cm with a chin rest. One of nine white digits ('1' to '9' (0.05° in width and 0.08 in height)) and a white rectangle (0.04° in width and 0.08 in height) were presented in a black background.

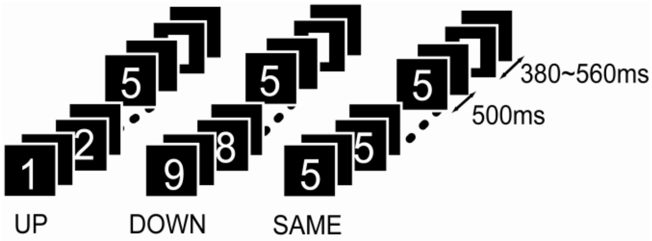

Fig.4. Experimental procedure

Procedure. Figure.4 shows the experimental procedures. Five digits were presented in order before the presentation of the target stimulus. There were three conditions in number presentations. The digits from '1' to '5'and from '9' to '5' were presented sequentially in the UP and DOWN conditions, respectively. In the SAME condition, all of presented digits were '5'. There was the blank interval between each digit. The blank interval was randomly chosen from 300, 350, 400, 450, 500 ms. We used the random interval to avoid the subjects using rhythmic information for temporal estimation. Each digit was presented 500 ms. The range of presentation interval of target stimulus was from 380 to 560 ms by 20 ms bin. The subjects judged whether the target interval was longer or shorter than the presented interval of each digit. Three conditions were mixed and randomly presented in a block. The subject responded by pressing the key of mouse. The target interval for each condition was presented one time in one block. One block contained 27 trials. The subjects conducted 10 blocks all.

3.2 Results

The data were analyzed in the same way as in experiment 1. The results are shown in figure.5. The PSEs in all conditions were significantly smaller than 500ms (one sample t-test, UP: 456±23 ms $t(7)=-5.00$, $p=0.0015$, DOWN: 459±29 ms, $t(7)=-3.71$, $p=0.0074$, SAME: 435±25 ms, $t(7)=-6.53$, $p=0.00032$). We conducted one way repeated measures ANOVA for PSEs and JNDs. The ANOVA detected the significant effect of presented numerical order for temporal estimation of the target interval ($F(2,14)=5.998$, $p=0.013$). On the contrary, JNDs were not different significantly among the conditions ($F(2,14)=1.348$, $p=0.29$). We next conducted paired t-test for each pair (UP vs DOWN: $t(7)=-0.49$, $p=0.63$, UP vs SAME: $t(7)=2.77$, $p=0.027$, DOWN vs SAME: $t(7)=2.72$, $p=0.029$). The PSE in the SAME condition was significantly smaller than that in the UP and DOWN conditions. Results indicated that the perceived duration of target interval was overestimated more in the SAME condition than in the UP and DOWN conditions. We estimated that the transition was lower in the SAME condition than in the UP and DOWN conditions. Therefore, the saliency of target was higher in SAME condition than in UP and DOWN condition. So, the target caught the subject's attention more in SAME condition than in UP and DOWN condition. Since attention affects the perceived interval, the subjects overestimated the target interval more in the SAME condition than in the UP and DOWN conditions.

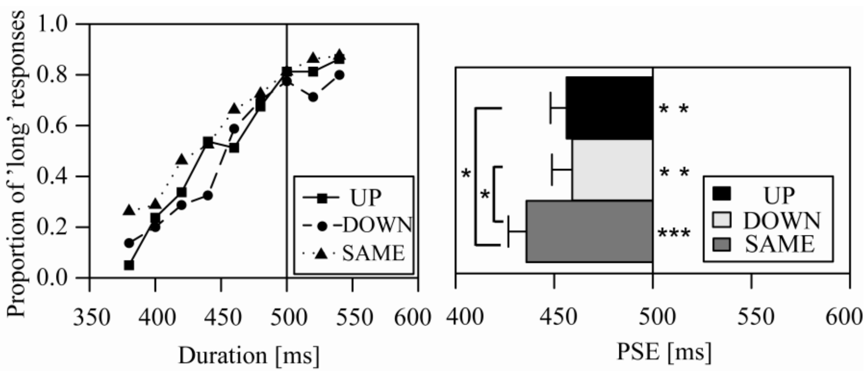

Fig.5. Response curve and Point of Equality (PSE)

4 Discussion

In this study, we examined whether temporal estimation was affected by the context just before the target. In experiment 1, when the digits were presented in ascending order (UP), subject perceived the following square as longer in duration than in the descending order (DOWN). The non-significant difference of JNDs between the UP and DOWN conditions indicated that the subjects' sensitivities of time estimation were not changed between these conditions. These results, in all, indicate that the preceding context affects the subsequent temporal processing in the brain.

Both the oddball [2] and the prediction [5] effects might contribute to the subjects' altered temporal estimation in the present study. In the sequential numbers condition, the oddball effect always occurred because the visual property of target was largely different from that of the digits. This effect expanded the perceived subjective duration of the target stimuli. At the same time, in the UP and DOWN conditions, but not in the RAND condition, the subjects could predict the next digit, resulting in the perceived duration of digit being contracted than actual. Therefore, it is possible that the overestimation in the UP and DOWN conditions were induced by the oddball and the prediction effects, while that in the RAND condition was induced by only the oddball effect. This suggestion is confirmed by the statistical analysis where the shifts of PSE from the standard duration in the UP and DOWN conditions were more robust than that in the RAND condition.

In addition to these effects, we propose based on the results that the presented order of numbers before the target stimulus affected subjects' temporal estimation. The subjects tended to overestimate the target duration in the UP condition to a significantly larger extent than in the DOWN condition. This contextual effect was not so strong as the oddball effect, possibly due to the representation generated in the brain being weakly linked to the target. We give below a few possible explanations why the order of numbers affected the subject's temporal estimation.

The first possibility is that the subjects' expectation to the next stimulus, which was made by the pattern of stimulus presentation, affected the temporal estimation. In this case, the subjects expected that the next stimulus would be bigger (or smaller) than the previous one. So, they had larger (smaller) prediction when they watched the target stimuli in the UP (or the DOWN) condition. In the same manner as larger stimuli was perceived longer, this expectation also affected the processing of target stimuli and led to a more significant overestimation in the UP condition than in the DOWN condition.

Another possible account is to deal with the train of digit more comprehensively. The ascending (declining) number induced the internal representation of expansion (contraction) within the subject's brain, resulting in a differential processing of the target stimulus subsequently entered. The processing of the target stimuli might be effected by this brain state, changing the perceived subjective duration. When the target stimuli interacted with the brain state which represent either expansion or contraction, the target was consequently perceived as longer or shorter.

This internal brain state generated by the digits train may be also related to attentional state. Ascending numbers can draw up arousal level more than the declining numbers, resulting in the subjects attending to the stimuli more in the UP condition than in the DOWN condition. Since the attention expanded perceived duration [2] [4], the subject could overestimate the target stimuli more in the UP condition as a result.

In summary, we showed that the order of numbers presented before the target stimuli affected the perceived subjective duration. When the integer presentation before the target was upward, the subjects overestimated the target duration larger than when the order was downward. The digits train before the target might induce different brain states, resulting in affected temporal processing of the target stimulus presented right after the numbers. We conclude that the context of stimulus presentation is important in the construction of our time perception.

References

1. Eagleman, D.: Human time perception and its illusions. Curr Opin Neurobiol 18, 131-136 (2008)
2. Tse, P., Intriligator, J., Rivest, J., Cavanagh, P.: Attention and the subjective expansion of time. Percept Psychophys 66, 1171-1189 (2004)
3. van Wassenhove, V., Buonomano, D., Shimojo, S., Shams, L.: Distortions of subjective time perception within and across senses. PLoS One 3, e1437 (2008)
4. Mattes, S., Ulrich, R.: Directed attention prolongs the perceived duration of a brief stimulus. Percept Psychophys 60, 1305-1317 (1998)
5. Pariyadath, V., Eagleman, D.: The effect of predictability on subjective duration. PLoS ONE 2, e1264 (2007)
6. Pariyadath, V., Eagleman, D.: Brief subjective durations contract with repetition. J Vis 8, 11.11-16 (2008)
7. Xuan, B., Zhang, D., He, S., Chen, X.C.: Larger stimuli are judged to last longer. Journal of Vision 7, (2007)
8. Oliveri, M., Vicario, C., Salerno, S., Koch, G., Turriziani, P., Mangano, R., Chillemi, G., Caltagirone, C.: Perceiving numbers alters time perception. Neurosci Lett 438, 308-311 (2008)
9. Walsh, V.: A theory of magnitude: common cortical metrics of time, space and quantity. Trends Cogn Sci 7, 483-488 (2003)