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〈Brief report〉

Robust repulsion in perceived motion direction induced by visual working memory despite the demand characteristics

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Motion repulsion is a visual illusion in which perception of moving dots is shifted away from its actual direction with the presence of another field of dots moving in a different direction. Kang et al. (2011) have demonstrated that the motion repulsion also occurs for the perceived field of dots when subjects hold another field of moving dots in working memory. Here, it was tested whether the perceptual shift induced by working memory is resistant to the demand characteristics, subjects' tendency of conforming to the expected hypothesis of the experimenter. Subjects were tested over two separate days. On the first day of participation, they were presented with a sequence of two random-dot motion displays and performed a perceptual judgment task for the second motion display while holding the first display in their working memory. On the second day of participation, the same experiment was run; but the subjects were informed that their performance was inaccurate (inaccuracy instruction group) or judgments were shifted away from the direction of the other motion stimulus (repulsion instruction group). Despite these instructions, perceptual repulsion was robustly reproduced. This result indicates that our visual working memory representation robustly alters perception, providing converging evidence for a close relation between working memory and perception.

Key words : Memory, Perception, Motion Repulsion, Demand Characteristics

〈연구 보고〉

운동반발을 이용한 작업기억표상과 지각표상의 상호작용 연구: 요구특성의 영향

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운동반발은 두 개의 무선점 운동(random-dot motion display)자극이 중첩되어 제시될 때 발생하는 착시현상으로, 지각된 운동방향은 실제 물리적인 운동방향에 비해 더 왜곡되어 보인다. Kang과 동료들(2011)은 이 착시현상을 이용해, 작업기억에 표상된 운동자극이 지각표상의 운동방향을 왜곡하는 결과를 보여주었다. 본 연구에서는 작업기억에 의한 지각표상의 왜곡이 피험자가 실험자의 의도에 맞게 실험결과를 내려는 경향, 즉 요구특성의 결과인지를 검토하였다. 피험자는 두 번에 걸쳐 실험에 참가하였는데, 두 번째 참가시, 처음 참가시 얻은 결과가 정확하지 못하거나, 실제 운동자극보다는 지각된 운동방향이 다른 운동자극의 방향의 반대방향으로 왜곡되었음을 언급하고, 보다 정확한 반응을 요구하였다. 그럼에도 불구하고, 운동반발은 효과는 사라지지 않았다. 이는 작업기억과 지각표상이 상호작용함을 보여주는 선행연구에 수렴적인 증거를 제시하며, 그 상호작용에 있어 하향식 정보처리 기제의 한계를 보여준다.

주제어 : 작업기억, 지각표상, 운동반발, 요구특성

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It has been thought that working memory only receives perceptual representation and then processes it (Pylyshyn, 1999; Shiffrin & Atkinson, 1969). However, growing literature suggests that working memory actually influences perception so as to bias our perceptual experiences. For example, neurophysiological and neuroimaging results show that early visual cortex V1 represents memoranda in working memory (Harrison & Tong, 2009; Serences et al. 2009; Supèr et al., 2001). Sensitivity to perceived motion direction is facilitated when subjects hold dots moving in the same direction in their visual working memory (Mendoza et al., 2011). Recently, several studies have even shown that contents in visual working memory alter our perception by using ambiguous figures including binocular rivalry (Scocchia et al., 2014), color appearance in context (Olkkonen & Allred, 2014) and visual illusion called motion repulsion (Kang et al., 2011).

In motion repulsion, perceived motion direction is shifted away from its actual direction when two fields of moving dots are superimposed, especially when the relative motion direction between those two is separated approximately by 45° apart (Marshak & Sekuler, 1979). In Kang et al. (2011), the authors presented separately those two fields of moving dots in sequence and found that the perceived motion direction of a single field of moving dots was shifted away from its actual direction when subject were holding another field of moving dots in their visual working memory. They also ruled out several alternative hypotheses such that this perceptual shift induced by working memory cannot be explained by adaptation, priming, dual task demands, mnemonic strategy and memory demand in perceptual judgment (Kang et al., 2011).

Here, whether the demand characteristics, subjects' intension conforming their behaviors to the experimenter's purpose (Orne, 1979), do play a significant role in producing perceptual shift induced by working memory was tested. Note that the authors (Kang et al., 2011) argued against the possible role of the demand characteristics because the subjects could arrive the two opposite interpretations of the experimenter's purpose: one is motion repulsion and the other is motion attraction in which the two motion directions become similar. Nevertheless, it remains to be empirically tested whether the perceptual shift induced by the working memory is indeed insensitive to the demand characteristics. Empirical validation is especially important in that a recent study argues that multiple "top-down" effects could have been responsible for changes in appearance (Firestone & Scholl, 2014).

To test the influence of demand characteristics by explicitly informing subjects their inaccurate perceptual judgments, a procedure used to assess illusory memories was adopted (McDermott & Roediger, 1998). Specifically, Roediger and McDermott (1995) showed that people tend to falsely recognize a related, but nonpresented item if they study a list of associated words. This false memory phenomenon was robustly reproduced even when the subjects were informed about the phenomenon (McDermott & Roediger, 1998). In the present study, subjects performed perceptual judgment task while holding another field of moving dots in their working memory (Figure 1A). Importantly, the same subjects were invited again within a week since their first participation. In one group of subjects, they were informed that their performance at the first participation was *not accurate* and were asked to perform the task more carefully. In the other group of subjects, they were informed that their perceived motion directions of the second moving dots were *shifted away from the actual motion directions* and were asked to perform as accurately as possible. These two groups were assumed to produce different magnitude in the demand characteristics.

Method

Participants Follow the original experiment (Kang et al., 2011), seven subjects were recruited for each group and, thus, fourteen subjects in total with normal or corrected-to-normal visual acuity participated with informed consent approved by the Vanderbilt University Institutional Review Board (8

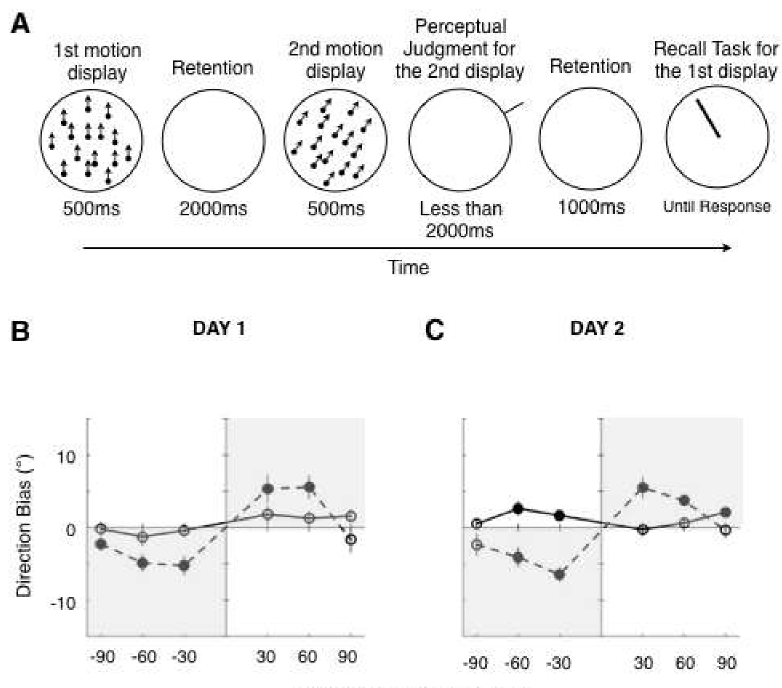

Figure 1. Stimulus sequence and the result of experiment. A) Schematic illustration of the stimulus sequence of the experiment. B-C) The results of the experiment. The direction biases of the perception (dotted line) and memory (solid) displays are plotted as a function of the relative motion direction. Filled circles indicate that the direction biases that are significantly different from 0 ($p < 0.05$). Error bars indicate the ±1 S.E. Data points lying in the shaded quadrants mean the repulsive biases of the perceptual judgment task and attractive biases of the memory recall task. B) The results of subjects' first day participation. C) The results of subjects' second day participation. Both inaccuracy and repulsion instruction groups' data were collapsed.

female; mean age 21.4).

Appartus Stimuli were presented on a Sony E540monitor (1024H x 768V resolution; 100 Hz frame-rate; 34.63 cd/m^{2}mean luminance; 90 cm in front of the observers) in a dimly illuminated room by using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) running for Matlab (Mathworks, MA).

Stimuli and Procedure The procedure of the experiment was identical to the main experiment of Kang et al. (2011) except the instruction given to the subjects when they were invited for their second participation. The procedure is briefly described as follow. Figure 1A schematically illustrates the stimulus sequence presented against a dark background (0.2cd/m^2). When subjects pressed the spacebar, each trial began. The 600ms fixation point was followed by the first random-dot motion stimulus (500msec), consisting of approximately 157 dots. Each dot was 0.05° in its diameter and those dots were presented within a circular aperture of 4° in diameter. Each one was replotted at random location every 100 msec. The direction bandwidth of the moving dots was normally distributed with a designated direction for its mean and 20° standard deviation. The second motion display was then presented for 500msec after a two second fixation interval. While the subjects were holding the motion direction of the first motion display, they performed a perceptual judgment task immediately after the offset of the second motion display by judging whether the motion direction was counterclockwise (CCW) or clockwise (CW) by moving the cursor within a region either CCW/CW of the reference bar. The reference bar was a thin white line (0.03° wide,14 cd/m^2), extending approximately 0.3° outside an imaginary aperture of the motion stimuli. This response had to be made within 2 seconds after the offset of the second motion display. One second after the perceptual judgment task, subjects performed a memory recall task for the first motion stimulus by adjusting a clock-hand to the remembered motion direction. If the remembered motion direction differed from the actual motion direction by more than 30°, feedback was given by presenting another green clock-hand, pointing the actual direction of motion for 500 msec.

The relative motion direction between the first and the second motion displays was chosen among ±30°, ±60° or ±90° on each trial. If it was positive, the second motion display was shifted CCW in relative to the first display and if it was negative the second display was shifted CW in relative to the first display. The reference bar was shifted from the actual motion direction of the second display from −18° to 18° with 6°step size. Subjects' response of the perceptual judgment task resulted in a psychometric curve and the threshold level shift was obtained by estimating point of subjective equality (Wichmann & Hill, 2001).

Distinguished from the previous study (Kang et al., 2011), all subjects were invited again within a week of their first participation and performed the same task. Importantly, for one group of subjects (inaccuracy instruction group, N=7), they were informed that their performance of the previous participation was inaccurate and asked to perform better. For the other group of subjects (repulsion instruction group, N=7), they were informed that there were systematic biases showing repulsive interaction between the first and second motion displays especially when the relative motion directions were small. Yet I also gave assurance that the inaccurate perceptual judgments are common because the task is demanding.

Result

Figure 1B and 1C show the bias of subjects' perceived motion direction (dotted lines) and remembered motion direction (solid lines) as a function of the relative motion direction for the first and the second day, respectively. The filled circles indicate that the bias at a given relative motion direction are significantly different from 0 ($p<0.05$). In the figures, data points in the shaded quadrants indicate the repulsive shift in the perceptual judgments and the attractive shift in the memory recall task.

The results of the inaccurate instruction and the repulsion instruction groups were collapsed because there were no difference in perceived motion direction and remembered motion direction between those two groups as shown below. For statistical analysis, the results of the positive and the negative relative motion directions were collapsed (see Kang et al., 2011) and then a three-way mixed design of ANOVA with factors of instruction (inaccuracy and repulsion) X day (day 1 and day 2) X relative motion direction (30°, 60° and 90°) was performed for the perceived and remembered motion directions, separately. There was no main effect of instruction for both perception ($F(1,12)=0.772$, $p=0.40$) and memory ($F(1,12)=0.627$, $p=0.44$). In addition, the instruction did not interact with any other factors for both perception and memory representations ($F<3.23$, $p > 0.079$). Note that subjects from both groups performed the identical task when they first visited the laboratory.

Even though the instruction did not influence the repulsion, there were some differences in the magnitude of motion repulsion over the two participations. Repulsion in perceived motion direction was robustly induced by working memory on the first day (Figure 1B) such that the main effect of the relative motion direction was significant ($F(1,12)=27.50$, $p<0.001$). In contrast, repulsion in remembered motion direction (solid lines) was almost absent for all relative motion directions when participants first visited the laboratory, resulting in insignificant main effect of the relative motion direction ($F(1,12)=0.55$, $p=0.46$).

More important, despite the fact that subjects were informed about their performance, the systematic bias in perceived motion direction was robustly reproduced when the subjects were invited again (Figure 1C). Specifically, the perceived motion direction (dotted line) was robustly shifted away from the remembered motion direction, resulting in similar repulsion magnitude over the two days ($F(1,12) = 0$, $p >0.5$). Memory representations (solid line) were also slightly shifted away from the perceived motion directions on the second day compared to their first participation, resulting in a significant main effect of the participation day ($F(1,12) = 6.35$, $p < 0.05$) and an interaction between the relative motion direction and the participation day ($F(1,40) = 6.58$, $p < 0.05$).

Does it mean that our memory representation is more susceptible to the perceptual representations over days? Additional analysis about the variability in subjects' recall task revealed that the absence of the memory bias on their first participation might be due to the dual task demands based on the standard deviation of the response errors, which has been used as an index for memory precision (Bays & Hussain, 2008; Zhang & Luck, 2008). The standard deviation of the response errors accompanied with subjects' memory recall performance was significantly reduced across the two days ($F(1,12) = 12{,}86$, $p < 0.01$). It means that the memory representation becomes less noiser over days, possibly due to a better maintenance accompanied with reduced dual task demands. However, similar reduction in variability in subjects' perceptual judgment performance measured by the slope of the estimated psychometric curves was not significant across the two days ($F(1,12) = 0.20$, $p > 0.5$), mirroring the non-significant changes in subjects'perceptual performance over the two days.

Discussion

Previously, Kang et al. (2011) have shown that the perceptual repulsion induced by working memory cannot be explained by adaptation, priming, dual task demand, mnemonic representation and repulsion between the two memory representations. In addition, the present study failed to eliminate the repulsion occurring between the working memory and perceptual representations even though the subjects were invited again to perform the same task after informing the performance of their first participation. In contrast, the results show that repulsion between the working memory and the perceptual representations became more robust as subjects got used to the task.

The implications of the finding go beyond the demonstration of robust perceptual repulsion induced by visual working memory. The failure of biasing perception by demand characteristics indicates that the limit of top-down control in working memory's influencing perceptual processing. In many theories of cognition, top-down control is an inseparable element comprising working memory (Baddeley, 2007). Consistent with this, previous studies have shown that subjects' top-down control is an important factor in determining individual difference in working memory capacity (Edin et al., 2009; Vogel & Machizawa, 2005), quality of working memory representation (Huang & Sekuler, 2010), visual imagery (Keogh & Pearson, 2011) and guiding attention (Soto et al., 2010; Woodman et al., 2007). Nevertheless, the present result demonstrates that our top-down control is limited in influencing the interaction between visual working memory and perception.

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