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SHORT AND SWEET

Time-to-contact estimation modulated by implied friction

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Abstract. The present study demonstrated that friction cues for target motion affect time-to-contact (TTC) estimation. A circular target moved in a linear path with a constant velocity and was gradually occluded by a static rectangle. The target moved with forward and backward spins or without spin. Observers were asked to respond at the time when the moving target appeared to pass the occluder. The results showed that TTC was significantly longer in the backward spin condition than in the forward and without-spin conditions. Moreover, similar results were obtained when a sound was used to imply friction. Our findings indicate that the observer's experiential knowledge of motion coupled with friction intuitively modulated their TTC estimation.

Keywords: timing behavior, motion perception, motor action, multimodal perception

Predicting the future state of external events is a fundamental mental function allowing us to adapt to a dynamic environment. The visual system efficiently monitors and anticipates the dynamic visual environment on the basis of one's own experiential knowledge about physical laws (eg McCloskey, 1983; Shepard, 2001). A baseball player appropriately predicts the falling point of a batted ball by using visual information about its velocity, acceleration, launching angle, distance from the hitter, and so on, to safely catch it. Expert players can do this better than novices, thanks to their considerable experiential knowledge of the physics of the ball's motion.

The effect of experiential knowledge on motion prediction has also been observed in the laboratory, in time-to-contact (TTC) studies (see Tresillian, 2005, for review). Early studies have suggested that TTC estimation is based on the direct perception of an optical variable, called τ (Lee, 1976), which is the ratio of the object's image size to the rate of change of the size, as well as on other optical factors (López-Moliner & Bonnet, 2002; Sun & Frost, 1998). Other previous studies have discussed cognitive motion extrapolation related to attention and eye movements (Tresilian, 1995). Moreover, Lacquaniti and his colleagues have clarified the role of an internal model of Earth gravity in motion prediction via experiments on Earth and in space (McIntyre, Zago, Berthoz, & Lacquaniti, 2001). Subsequent research has expanded the notion of internal model to a broader context of complex interactions between an object and its environment such as force fields (Brown, Wilson, Goodale, & Gribble, 2007) and complex pathways (de Rugy, Marinovic, & Wallis, 2012).

The present study examined whether experiential knowledge of friction affects TTC estimation. Friction is a physical factor that regulates object motion, but its effect has not been examined in the TTC literature. A spatial distortion, representational momentum, is modulated by object spin that implies friction (Yamada, Kawabe, & Miura, 2010). Mechanisms of representational momentum and TTC estimation are partially shared with each other (Gray & Thornton, 2001). Therefore, we predicted that TTC estimation would also be affected by object spin. Furthermore, to reveal whether the use of experiential knowledge is independent of input modality, we also examined the effect of frictional sound on TTC estimation.

In the experiments stimuli were displayed on a 19-inch CRT monitor at a viewing distance of 60 cm. A computer was used to control stimulus presentation and data collection. A fixation cross was at the center of the screen. A white circular target with a radius of 0.84 deg smoothly moved leftward or rightward for a distance of 13.4 deg, and then moved behind an occluding surface with a width of 6.7 deg. In experiment A sixteen observers were asked to press a key when they thought that the target had contacted the exit side of the occluder while keeping their eyes fixated on the cross. The diameter line of the target was drawn in black and rotated clockwise or counterclockwise, or remained static. In combination with the motion direction, three types of spin conditions were employed: forward, backward, and without spin (see figure 1a). The target speed was 6.7 deg s^{-1}. No feedback on the response correctness was provided to the observers. A total of 60 trials involving three spin types, two motion directions (leftward and rightward), and 10 repetitions were conducted in a randomized order.

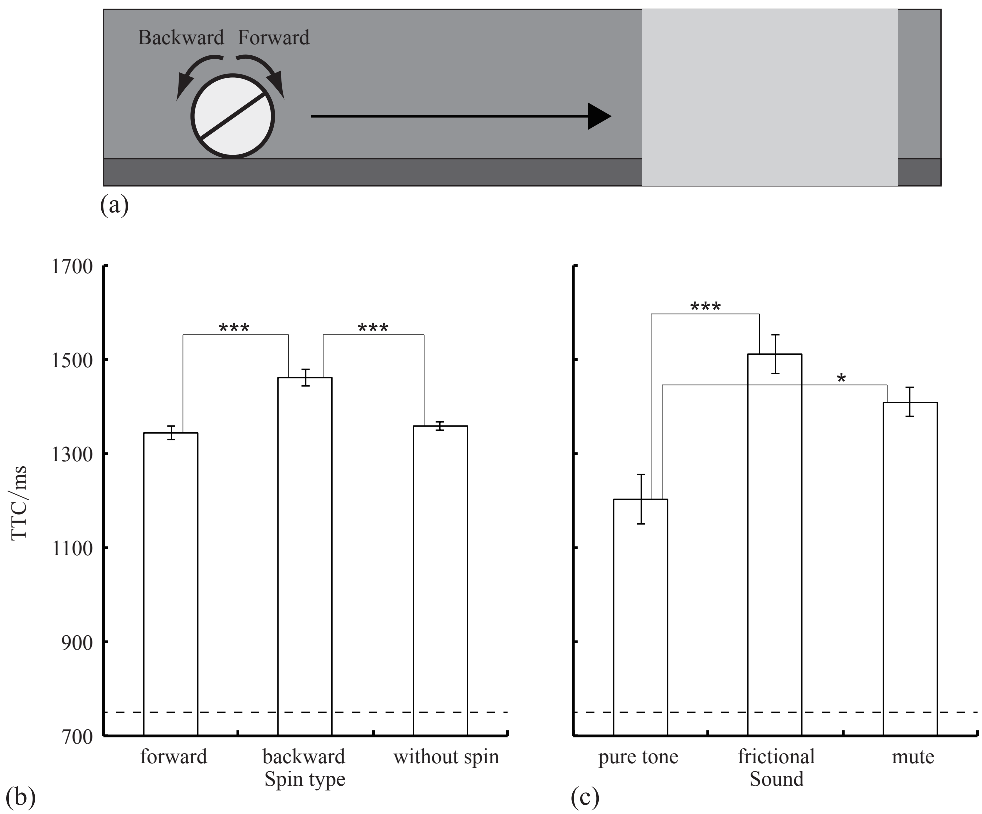

Figure 1. (a) Schematic representation of the spin conditions. (b) Results of experiment A: error bars denote SEM. (c) Results of experiment B: error bars denote within-subject SEM. *$p < 0.05$; ***$p < 0.001$. Notes. The dashed lines represent actual time to contact (TTC) (750 ms), suggesting the overall overestimation of produced TTC.

The time from the disappearance of the target to the observers' reaction was defined as the TTC for each spin type (figure 1b). A one-way analysis of variance (ANOVA) of TTC with spin type as a factor showed a significant main effect ($F_{2,30} = 12.77$, $p < 0.0001$). Multiple comparisons using Ryan's method indicated that TTC was significantly longer in the backward spin condition than in the forward spin and without-spin conditions (ps < 0.0003).

In experiment B we used the visual stimuli from the without-spin condition; but instead of the spin conditions, three sounds were presented during a stimulus movement: pure tone (a 500 Hz sine wave), frictional sound (a rubbing sound of concrete blocks), and mute. Another ten observers participated. An ANOVA showed a significant main effect of sound ($F_{2,18} = 8.96$, $p < 0.003$). Unlike experiment A, multiple comparisons indicated only that TTC was significantly shorter in the pure tone condition than in the friction sound and mute conditions (ps < 0.02). This tendency would possibly be because the pitch and level invariances of the pure tone induced perception of smooth or frictionless motion of the target. Even so, the results again indicate that auditorily implied friction affects TTC.

Here, we have shown that TTC estimation is affected by friction cues such as object spin and sound. Implied friction lengthened TTC estimation regardless of the cued sensory modality, suggesting that friction cues are ubiquitous. The findings suggest that this modulation of TTC estimation came from the observer's intuition of object motion coupled with friction, based on their experiential knowledge. The visual system predicts the future states of a dynamic event by incorporating not only experiential knowledge of Earth gravity (McIntyre et al., 2001) but also that of friction (Yamada et al., 2010). How these experience-based cues are integrated between them (eg Rushton & Wann, 1999) and with low-level optical cues like τ is still an open question.

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