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LAST BUT NOT LEAST

Rolling perception without rolling motion

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Abstract. The texture of a rolling circle depicts the translational and rotational components of its motion. In the case of a homogeneous circle, however, visual cues to the rotational component of motion are absent. To examine how the visual system resolves undetermined motion cues, optically neutral circles were displaced so that changes in their orientation were invisible. Contextual cues systematically triggered the perception of illusory rotation, suggesting that the visual system uses contextual cues along with intrinsic surface cues to compute percepts of rolling objects. This might also explain why people rarely experience the perception of ambiguous motion.

Whenever a pool or snooker player hits a cue ball, the ball rolls across the table. However, because cue balls are homogeneous, observers cannot measure the rotational component of their motion. Indeed, the optical cues to rotation that can be seen when a homogeneous ball rotates are equivalent to those of a stationary homogeneous circle (Wallach et al 1954). Thus, optical information cannot be used to determine the rotation of a hit cue ball. Relatedly, Saturn's rotation rate remains undetermined because its uniform shape and surface render measurement of its rotation impossible (Giampieri et al 2006). Are observers unable to perceive the rotation of homogeneous spheres? Or, does the visual system fill in the absent rotational information? If so, what cues does the visual system use to compute optically absent rotational information?

In the demonstrations reported below, which can be downloaded from http://psychology.rutgers.edu/~songjoo/rolling or from the Perception website: http://dx.doi.org/10.1068/p5887, we examined whether observers use cues extrinsic to a sphere during the perceptual analysis of its motion. In all conditions, naive observers viewed moving homogeneous circles and rated their motion percepts on an 11 point scale. Scale ends indicated the perception of pure translation (−5) or pure rolling (+5). Each animation was shown four times (twice as depicted in the corresponding figure and twice mirror-reversed) in random order. Observers were told that there were no correct answers and asked to report only what they actually saw. Main effects were assessed with repeated-measures ANOVAs. Animations were presented on a flat monitor screen (1920 × 1200 pixels) in a dimly lit room until subjects responded.

When a moving sphere is supported by ground surface, the resulting friction causes the sphere to roll. We tested whether ground support influences the perception of object rolling (figure 1). 11 observers viewed a circle (radius = 0.81 deg) that followed a smooth pendular trajectory in the presence (figure 1b) or absence (figure 1a) of a stationary 'ground' line. Another 11 observers viewed inverted displays (figures 1c and 1d). The circle (average speed = 4.4 deg s^{-1}) smoothly accelerated and decelerated as it repeatedly traveled up and down the pendular trajectory. In the upright conditions (figures 1a and 1b), participants reported significantly more rolling in the presence of a support ground (mean = 3.73) than in its absence (mean = −1.36) ($F_{1,10} = 35.24$, $p < 0.001$). No effect of ground support was found with the inverted stimuli ($F_{1,10} = 0.331$, $p = 0.578$). Thus, the perception of a homogeneous motion of the circle depends upon its spatial relationships with a supporting ground and gravity.

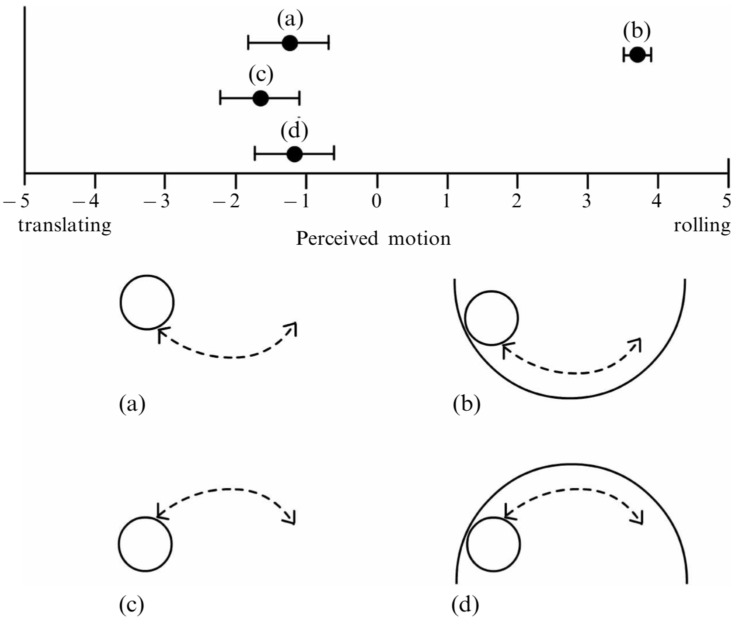

Figure 1. Circles appear to roll when supported by a ground (b) and to translate in the absence of ground support (a), (c), and (d).

We next examined whether causality influences the visual perception of object rotation. Michotte (1962) classically demonstrated that observers spontaneously attribute the onset of the displacement of one ball to contact with a colliding object. But, do observers perceive any rotation in that displacement? To answer this question, 19 naive observers viewed two animations of a homogeneous sphere undergoing displacement. In one animation, the displacement of a sphere dropped along the ground was triggered by a collision with another sphere (figure 2b). The dropped sphere (radius = 0.6 deg) fell at a speed of 1.2 deg s^{-1} and then, after colliding with the other sphere, smoothly displaced laterally with an initial speed of 0.8 deg s^{-1} and slowed until

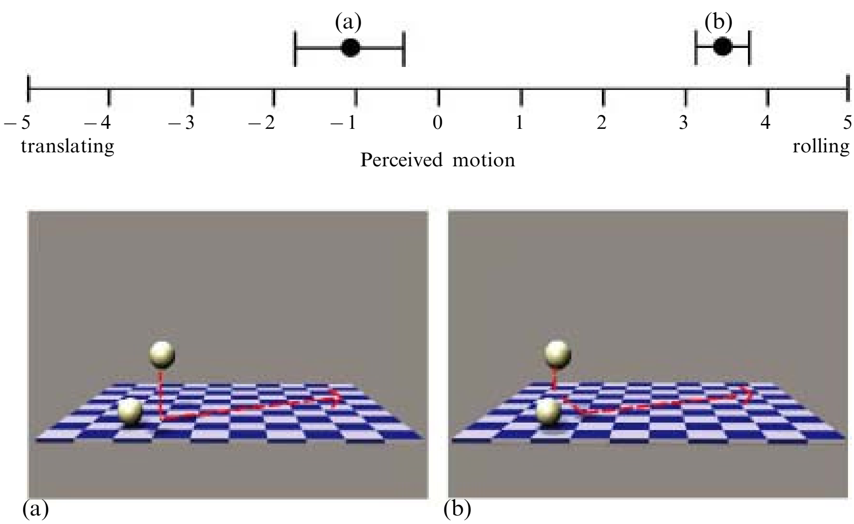

Figure 2. [In colour online, see http://dx.doi.org/10.1068/p5887] Event causality influences the rolling perception. A dropped ball either does (b) or does not (a) collide with another ball. The collision (b) increases the subsequent magnitude of perceived rolling (±1 SEM).

it came to a stop 3.6° further. In an otherwise identical animation, the dropped sphere missed the other sphere (figure 2a). Observers' ratings indicated that collision altered the amount of perceived rotation ($F_{1,18} = 46.98$, $p < 0.001$). When the subsequent displacement of the dropped sphere could be attributed to a collision, the displaced sphere appeared to roll (mean = 3.50). Without a collision, the displaced sphere appeared to translate (−1.09). This result suggests that event causality influences the perception of rotation.

Is human action sufficient to trigger apparent rotation of an object? In one animation, a person simply stood on a homogeneous ball as it was displaced (figure 3a). In other animation, the person appeared to cause the ball's displacement by walking on it (figure 3b). In both displays, the sphere (radius = 0.98 deg) was displaced across 3.5 deg with an average speed of 0.57 deg s^{-1}. The main effect of causal human action on rolling perception was significant ($F_{1,18} = 84.73$, $p < 0.001$). Observers who viewed the homogeneous ball in isolation, that is without the person, rated its motion as translating (mean = −1.7). These results suggest that the visual system overcomes the insufficiency of optical cues to rotation by considering the causes of motion onset.

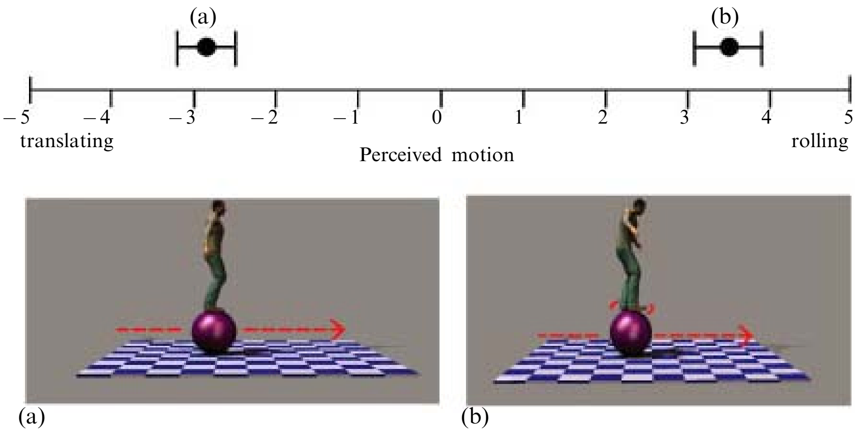

Figure 3. [In colour online.] Human action influences rolling perception. A man either stands (a) or walks (b) on top of a ball thereby causing its displacement. When the displacement of the ball can be attributed to human action (b), the ball appears to roll significantly more (±1 SEM).

Finally, the speed with which a doughnut rolls down a table depends upon the slope of the table relative to gravity. Does the perception of object rotation similarly depend upon surface slope? Another 19 naive observers viewed two animations of a torus being displaced along a smoothly curved support surface (figure 4). The average speed of torus (radius = 0.81 deg) displacement was 0.8 deg s^{-1} and was either consistent (figure 4b) or inconsistent (figure 4a) with the slope of the surface. The inconsistent speed condition was created by slicing the consistent-speed trajectory into small segments and randomly shuffling them without replacement. A significant main effect of torus speed on the rolling perception was found ($F_{1,18} = 36.84$, $p < 0.001$). When the slope and speed were consistent, the torus appeared to roll (mean = 2.91). When they were inconsistent, the torus appeared to translate (mean = −2.24). This result further suggests that the visual system uses the physical plausibility of an object's displacement to compute perceived rotation.

These demonstrations suggest that the visual system uses contextual cues to interpret optically unspecified rolling motion. This challenges models of rotation perception that only consider bottom–up, spatiotemporal analyses of surface features. The current work is consistent with the hypothesis that the visual system has internalized regularities in the physical world (Gibson 1979; Shepard 1984). Since rotational motion is

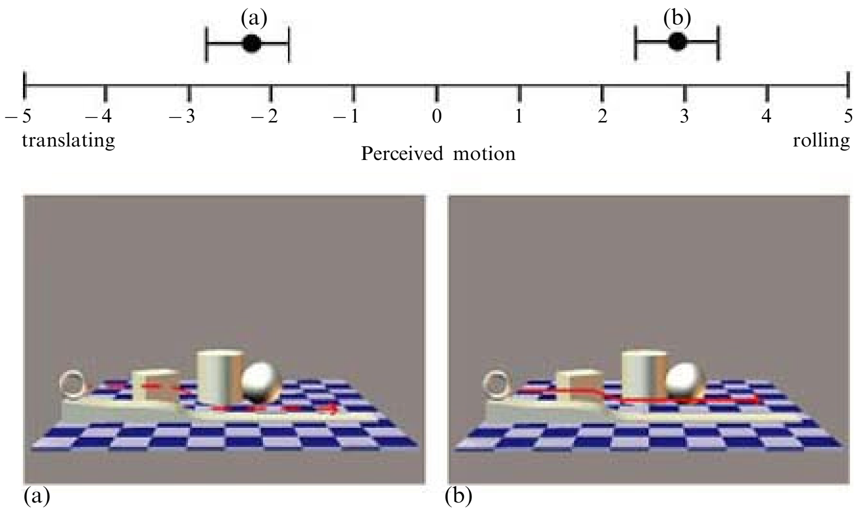

Figure 4. [In colour online.] Displacement trajectory relative to surface slope influences rolling perception. A torus is displaced along a surface with a speed that is either consistent (b) or inconsistent (a) with the slope. When the speed of displacement of the torus is consistent with the slope (b), the magnitude of perceived torus rotation increases (±1 SEM).

processed in the medial superior temporal area (MST) (Graziano et al 1994), the current behavioral results raise the possibility that area MST receives input from neural areas involved in the analysis of contextual information such as gravity (Indovina et al 2005).

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