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The use of visual cues in gravity judgements on parabolic motion

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ABSTRACT

Evidence suggests that humans rely on an earth gravity prior for sensory-motor tasks like catching or reaching. Even under earth-discrepant conditions, this prior biases perception and action towards assuming a gravitational downwards acceleration of 9.81 m/s^2. This can be particularly detrimental in interactions with virtual environments employing earth-discrepant gravity conditions for their visual presentation. The present study thus investigates how well humans discriminate visually presented gravities and which cues they use to extract gravity from the visual scene. To this end, we employed a Two-Interval Forced-Choice Design. In Experiment 1, participants had to judge which of two presented parabolas had the higher underlying gravity. We used two initial vertical velocities, two horizontal velocities and a constant target size. Experiment 2 added a manipulation of the reliability of the target size. Experiment 1 shows that participants have generally high discrimination thresholds for visually presented gravities, with weber fractions of 13 to beyond 30%. We identified the rate of change of the elevation angle ($\dot{y}$) and the visual angle (θ) as major cues. Experiment 2 suggests furthermore that size variability has a small influence on discrimination thresholds, while at the same time larger size variability increases reliance on $\dot{y}$ and decreases reliance on θ. All in all, even though we use all available information, humans display low precision when extracting the governing gravity from a visual scene, which might further impact our capabilities of adapting to earth-discrepant gravity conditions with visual information alone.

1. Introduction

Improvements in applicability and cost-efficiency of Virtual and Augmented Reality technologies have led to a surge in their popularity. More and more applications are pushing boundaries by immersing users into worlds that defy the regularities of our natural environment. Among these pervasive laws is the pull of gravity, which is ubiquitous and almost invariant across the world (9.78 m/s^2 at the Equator and 9.832 m/s^2 at the poles). Our life-long exposure to this specific value gives rise to the concern that altered gravity values might pose a significant challenge to users. And in fact, perceptuo-motor performance under earth-discrepant gravity conditions has been receiving some attention over the past decades: Prominently, an internal representation of earth gravity has been suggested to be involved in a series of sensory-motor tasks such as catching and reaching. While arbitrary accelerations are generally not picked up by the perceptual system (Brenner et al., 2016; Werkhoven, Snippe, & Alexander, 1992), humans can make use of this gravity prior to improve catching performance for objects accelerated by earth gravity. This discrepancy between arbitrary accelerations and acceleration through earth gravity is particularly salient when online information is not available (partially occluded trajectories) or unreliable (noisy presentation). The utility of such model has been substantiated in numerous ways: (McIntyre, Zago, & Berthoz, 2001; McIntyre, Zago, Berthoz, & Lacquaniti, 2003) showed that even after extensive exposure to zero gravity in space, catching movements were initiated too early with regard to Time-to-Contact for balls dropping at a constant speed, indicating that humans rely on their representation of earth gravity even when visual and bodily cues indicate a discrepant gravity. A series of studies conducted in a semi-virtual task on earth (Zago & Lacquaniti, 2005; Zago et al., 2004) demonstrated that even after extensive training over up to two sessions, participants did not fully adapt to visually presented zero gravity and were still expecting targets to accelerate downwards. Even remembered locations of horizontally moving projectiles seem to drift downwards, in direction of earth-gravity, over time (De Sá Teixeira, Hecht, & Oliveira, 2013). Also, brain imaging and lesion studies have showed areas differentially activated for (Indovina et al., 2005) or dedicated to (Maffei et al., 2016) computations involving earth-gravity. While concerns have been raised about the parsimony of this way of framing the results (Baurès, Benguigui, Amorim, & Siegler, 2007; but see also (Zago, McIntyre,

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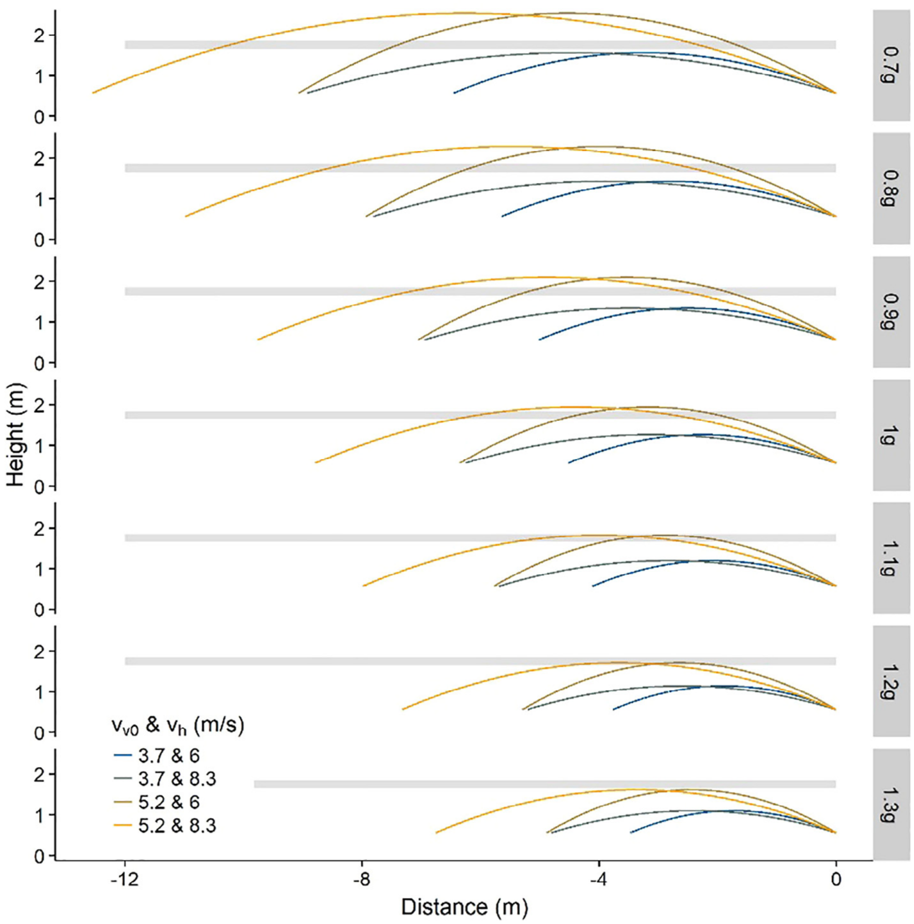

Fig. 1. Lateral view of the spatial trajectories of the parabolas that served as stimuli. The panels represent different gravity values ranging from 0.7 g to 1.3 g in steps of 0.1 g. Spatial differences are due to different initial vertical velocities (3.7 or 5.2 m/s) and different horizontal velocities (6 or 8.33 m/s). The shaded rectangles designate the range of eye-levels of participants (1.65 m–1.88 m). The observer's position is a x = 0 m.

Senot, & Lacquaniti, 2008) for a rebuttal), the overall picture remains intact: There is evidence that an internal representation of earth-gravity is accessed and applied even when this is to the detriment of the performer. While this internal model of earth gravity has been studied thoroughly, it remains largely unknown how humans (would) extract the underlying gravity value from the dynamics of a visual scene. To bridge this gap in our understanding, the present study takes a look at how well the visual system computes gravity from observing its effects on the objects in a virtual environment. Furthermore, we scrutinize the roles of different visual and temporal cues humans may rely upon for their decision.

On a more theoretical level, our study aims at interpreting gravity perception judgements within a Bayesian framework. According to this framework, sensory information ("likelihood") is integrated with previous knowledge about the world ("prior"), yielding a more precise and usually more accurate final percept ("posterior"). The weights of likelihood and prior are a function of their respective reliability. Within this framework, the internal model of gravity can be described as a so called strong prior (Jörges & López-Moliner, 2017): as the evolution of the human species as well as the development of every single human took place under a largely invariant gravity value of 9.81 m/s^2, the reliability of this prior is extremely high. It thus overrules all sensory information represented as the likelihood. However, the experimental results cited above only imply a strong relative weight of the prior with regards to the likelihood; this is also consistent with a weak likelihood combined with an average prior or a weak likelihood combined with a strong prior. While some evidence has been provided that visual acceleration information is relatively unreliable (Benguigui, Ripoll, & Broderick, 2003; Brenner et al., 2016; Werkhoven et al., 1992), the nature of the likelihood remains to be investigated specifically for gravitational accelerations.

2. Experiment 1

2.1. Participants

A total of eleven (n = 11) participants performed the task, among them two of the authors (BJ and JLM). All had normal or corrected-to-normal vision. One (n = 1) subject was excluded because they didn't follow instructions and another (n = 1) was excluded because their performance was at chance level for all stimulus strengths and a post hoc stereo-vision test revealed that they were stereo-blind. The remaining participants were in an age range of 19 and 51 years and five (n = 5) were female. We did not test their explicit knowledge of physics, as previous studies suggest that explicit knowledge about gravity has no effect on performance in related tasks (Flavell, 2014; Kozhevnikov & Hegarty, 2001). All participants gave their informed consent. The research in this study is part of an ongoing research program that has been approved by the local ethics committee of the University of Barcelona. The experiment was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.2. Apparatus

Two Sony laser projectors (VPL-FHZ57) were used to provide overlaid images in a back-projection screen (244 cm height and 184 cm width) with a resolution of 1920 × 1080 pixels. The frequency of refresh of the image was 85 Hz for each eye. Circular polarizing filters were used to provide stereoscopic images. Participants stood at 2 m distance centrally in front of the screen and were using polarized glasses to perceive the object stereoscopically. The shown disparity was adapted to each participant's inter-ocular distance.