# Do Humans Maintain a Representation of the Air Drag in their environment?

## Introduction

The importance of ecologically valid stimuli for the study of interceptive actions is self-evident. Nonetheless, many studies neglect air drag when simulating stimuli in virtual reality. While this can facilitate some aspects of setup and analysis, it may lead to systematic errors in results. There is evidence that humans represent and use different physical properties of their environment, such as the size of known objects (Hosking & Crassini, 2010; López-Moliner, Field, & Wann, 2007), their mass (Neupärtl, Tatai, & Rothkopf, 2020) or gravity (Bosco et al., 2015; Gómez & López-Moliner, 2013; Indovina et al., 2005; B. Jörges & López-Moliner, 2019; Björn Jörges & López-Moliner, 2017, 2020; La Scaleia, Zago, Moscatelli, Lacquaniti, & Viviani, 2014; Lacquaniti et al., 2013; J McIntyre, Zago, & Berthoz, 2001; Joseph McIntyre, Zago, Berthoz, & Lacquaniti, 2003; Mijatovic, La Scaleia, Mercuri, Lacquaniti, & Zago, 2014; Senot, Zago, Lacquaniti, & McIntyre, 2005; Senot et al., 2012; Zago, La Scaleia, Miller, & Lacquaniti, 2011), in their interactions with the environment. The present study aims to investigate whether air drag is among these physical properties represented by the brain. We thus expect systematic errors when no air drag is simulated, and an accurate performance when air drag is simulated (Hypothesis 1). Furthermore, if humans represent air drag, it stands to reason that they also represent air ­drag-relative properties of known objects such as their density and their respective drag coefficient. We thus expect to observe systematic errors when the air drag acting upon a simulated object does not correspond to its appearance (e. g. a ball with the appearance of a tennis ball, but air drag-relevant properties of a basketball; Hypothesis 2).

## Methods

## Participants

We tested n = 20 participants. They were between \_\_\_\_ and \_\_\_\_ years old and had all normal or corrected-to-normal vision. All of them were Psychology students at University of Barcelona and could participate in research activities to acquire course credits. None of the participants were stereoblind .

Apparatus

We presented overlaid images on a back-projection screen (244 cm tall and 184 cm wide) with two Sony laser projectors (VPL-FHZ57). They provided a resolution of 1920 × 1080 pixels and a refresh rate of 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 used polarized glasses to achieve stereoscopic vision. The shown disparity was adapted to each participant’s interocular distance. Responses were given with .

Setup

­We presented participants with parabolic motion in the fronto-parallel plane in a rich 3D environment that provided cues about the distance to the target, at a simulated distance of 6m from the participant. The ball disappeared after reaching peak (between 55 % and 60 % of the full flight duration) and participants indicated by button press when the ball dropped back to the height it was launched from (indicated by a simulated table). Then, the ball reappeared in a random position drawn from a uniform distribution simulated point-of-impact on the table and participants used a joystick to move the ball, indicating the position where they thought the ball hit the table. The target had the appearance of a tennis ball (texture, size) and the physical properties (mass, density, drag coefficient) of a tennis ball (Tennis ball, Congruent), the appearance of a basketball and the physical properties of a basketball (Basketball, Congruent), the appearance of a tennis ball and the physical properties of a basketball (Tennis ball, Incongruent) or the appearance of a basket ball and the physical properties of a tennis ball (Basketball, Incongruent). The ball could start with an initial horizontal velocity of 3.0 or 3.5 m/s. The initial vertical velocity was given such that the overall flight time (visible + invisible) was 1.0, 1.2 or 1.4 s. In half of trials, the trajectory unfolded in the absence of air drag, that is the target’s x and y positions were given by the regular equations for parabolic motion:

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|  | [1] |
|  | [2] |

refers to the horizontal velocity, which is constant without air drag, refers to the initial vertical velocity, *g* is earth gravity (9.81 m/s²) and *t* is the time. The other half of trials were simulated under the influence of air drag, where we used Equations 3 and 4 respectively to simulate the target’s x and y position in time.

As the drag force acting upon a moving target is changing continuously according to its current velocity, the trajectories of objects affected by air drag are typically drawn in a synthetic fashion; i. e. on each frame, the x and y positions for the next frame are computed based on the current velocity of the object (see e. g). We found that the analytic equations provided under <https://demonstrations.wolfram.com/ProjectileWithAirDrag/> matched the synthetically computed trajectories closely when we assumed a drag coefficient *c* of \_\_\_\_\_ . The following equations yield the x and y positions of the object at each moment of the trajectory:

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|  | [3] |
|  | [4] |

*m* is the mass of the object, *g* is earth gravity (9.81 m/s²) and *c* is the drag coefficient.

## Predictions for Confirmatory Analyses

In this paper, we test the following confirmatory hypotheses:

1a) Humans use their internalized knowledge of air drag in their habitual environment to predict object motion. Therefore, performance should be accurate for those trials where air drag is simulated. Participants are expected to respond too late when no air drag is simulated in the visible part as the trajectory because air drag would slow the target down on its way from peak back to the initial level. To test this hypothesis, we use Bayesian Linear Mixed Modelling, implemented in the packages brms (Bürkner, 2018) and rstan (Stan Development Team, 2016) for R (R Core Team, 2017). We fit a Mixed Model with air drag as fixed effect (a binary categorical variable with the values “Present” and “Absent”) and random intercepts per participant to explain timing error ratio (. In brms syntax, the Mixed Model is specified as:

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|  | [5] |

After the fitting is complete, we can use the hypothesis() function from R to test to what extent the data supports certain hypothesis. In our case, the first hypothesis is that the regression coefficient for “Air Drag: Absent” is larger than zero. Support for this hypothesis means that humans use the same internalized knowledge to extrapolate motion independently of whether air drag was presented during the visible part of the trajectory or not. The second hypothesis is that the intercept for the “Air Drag: Present” condition is 1, indicating accurate responses when air drag is simulated. The third hypothesis we test is that the intercept for the “Air Drag: Absent” condition is 1, indicating accurate responses when no air drag is simulated. If the data support that the intercept for “Air Drag: Present” is 1, this presents evidence that humans do represent air drag. Support for the hypothesis that the intercept for “Air Drag: Absent” is 1 means, in turn, that humans do not represent air drag and extrapolate motion merely based on the observed velocities and gravity.

For the spatial task, we expect high accuracy for “Air Drag: Present” and an undershoot for “Air Drag: Absent”. We follow the same procedure as for the timing response and fit the following Mixed Model:

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Here, we test the hypotheses that the regression coefficient for “Air Drag: Absent” is smaller than 0, that the intercept for “Air Drag: Present” is 1 and that the intercept for “Air Drag: Absent” is 1. If the data support that the intercept for “Air Drag: Present” is 1, this presents evidence that humans do represent air drag. Support for the hypothesis that the intercept for “Air Drag: Absent” is 1 means, in turn, that humans do not represent air drag and extrapolate motion merely based on the observed velocities and gravity.

## Analysis Plan

We removed those trials as outliers where the temporal or the spatial error were 2.5 standard deviations below or above the mean per condition and participant. To test hypothesis 1a

## Results

Both timing and spatial responses will be centered around the expected values of motion occurring under the assumption of air drag, independently of whether motion under air drag is presented or not. That is, the accuracy will be higher for trials where air drag is simulated, and lower for trials where no air drag is simulated. More concretely:

Hypothesis 1a) – the temporal errors for trials where air drag is simulated should be centered around zero, while responses should occur slightly too late with respect to the simulated time-of-impact for no-air-drag;

Hypothesis 1b) – the spatial errors for air drag trials should be centered around zero, while there should be an undershoot (response too far to the left in our setup) for no air drag trials

In the case that only one of the two hypotheses is supported by the evidence, we give more weight to hypothesis 1b) as differences are more pronounced, giving it a higher power (see power analysis). We furthermore adjust the alpha for both hypotheses through a bonferroni correction, as we use two hypothesis to test for the same result.

If we find an effect of air drag, we further compare trials where the texture of the target is congruent with its air drag relevant properties (e.g. a target of tennis ball texture, size and mass) with trials where they are incongruent (e.g. a target of tennis ball texture, but basket ball size and mass).

We expect increased accuracy for congruent trials. Our power analysis reveals that the effect is too small to be reasonably detectable in the temporal domain. For this reason, we rely only on the spatial domain for this hypothesis:

Hypothesis 2) – For congruent trials with airdrag, the absolute mean spatial error will be lower than for incongruent trials.

Any further analysis will be marked as exploratory.