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Electronic supplement materials

(A): Online prestudy

This experiment closely resembles Experiment 2, but did not include the screen size and viewing distance procedure. This study was conducted to get a qualitative comparison to the results in Experiment 1 – that is, can similar data patterns be observed in an online experiment than in the laboratory experiment (without directly comparing the size of the evidenced effects). This experiment was also conducted to gain experience about typical features of student set-up, in order to design Experiment 2 of the manuscript. Overall, the data patterns observed in this online prestudy was very comparable to the data patterns observed for the laboratory experiment (Experiment 1), for both continuous motion stimulation as well as implied motion stimulation.

Methods

Participants

Based on sample size calculations as in Experiment 2, a sample size of N=36 was chosen. Four participants were excluded from data analysis due to a high dropout of trials, indicating a lack of engagement in the task (for more information, see the data-preparation section). The final sample (25 female, 1 diverse, 6 male; 1 left-handed; mean age: 21.09 years – range between 18 and 38 years) consisted of 32 new students from the University of Trier.

Design, Apparatus and Stimuli, Procedure, and Data preparation

The design, apparatus and Stimuli, procedure, and data preparation were identical to Experiment 2 with the following exceptions. The final experimental set-ups were different for the participants - in the following, number of participants is given in brackets. Participants used the touchpad of a laptop as mouse (17) or an external computer mouse (15) following self-report. As operation system, the Apple Mac OS (3) as well as Microsoft windows (29), and as

browser, Google Chrome (25) and Mozilla Firefox (7) were detected. All screens used a 60 Hz refresh rate, yet, resolutions different strongly between participants: 1920x1200 (1); 1920x1080 (3); 1600x900 (1); 1536x864 (9); 1500x1000 (2); 1440x900 (4); 1368x912 (1); 1366x768 (6); 1280x720 (4); 1128x752 (1). Actual size of the screen (e.g., in cm or inch) was not assessed. The screen size procedure as well as the viewing distance estimation procedure was not conducted. Consequently, the results in pixel cannot be converted into results in visual angle (arcmin), and therefore are reported with pixels.

The data preparation criteria were identical to Experiment 1; additionally, if participant did not respond within 3000 ms, no response was detected and therefore this trial was necessarily excluded from data analysis. 2.43% of trials were due to these criteria excluded[1]. As in Experiment 1, I analysed if the exclusion of trials occurred for some participants more often, indicating a general lack of engagement in the task. Four participants were therefore excluded[2].

Results

Representational Momentum

Implied motion: Estimates of Representational Momentum were compared to zero, and a significant forward shift was found, $t(31) = 8.16$, $p < .001$, $d = 1.44$, indicating the expected Representational Momentum phenomenon (for mean shift scores, see Table E1). Once again, a 3 (stimulus timing: slow vs. middle vs. fast) x 3 (stimulus distance: short vs. medium vs. long) repeated measures ANOVA was conducted, shift scores were used as dependent variable, and for violations of sphericity, Greenhouse-Geisser corrections were used. As in Experiment 1, the results indicated a main effect of stimulus timing, $F(1.12, 34.74) = 57.80$, $p < .001$, $\eta_p^2 = .651$,

[1] The exclusion of these trials did not significantly change the results of the main 3 x 3 repeated measure ANOVA for implied motion trials and the main one-factorial repeated measure ANOVA of continuous motion trials reported in the results section.

[2] The exclusion of these four participants did not significantly change the results of the main 3 x 3 repeated measure ANOVA for implied motion trials and the main one-factorial repeated measure ANOVA of continuous motion trials reported in the results section.

and polynomial contrast coding revealed a linear increase of the forward shift with faster stimulus timing (fast: 19.52 pixels; middle: 9.46 pixels; slow: 5.64 pixels), $F(1, 31) = 65.39$, $p < .001$, $\eta_p^2 = .678$. The main effect of stimulus distance, $F(2, 62) = 3.09$, $p = .052$, and the interaction between the two factors, $F(2.68, 83.09) = 1.62$, $p = .196$, were not significant on its own.

Table E1.

Implied motion trials: Mean shifts scores (standard deviations in brackets) as a function of stimulus distance (short vs. medium vs. long) and stimulus timing (slow vs. middle vs. fast) for Representational Momentum as well as Representational Gravity scores in the online prestudy.

	short			medium			long		
	slow	middle	fast	slow	middle	fast	slow	middle	fast
*Representational Momentum (horizontal shift scores)**									
Experiment (prestudy)	6.18 (6.54)	9.03 (6.65)	19.14 (10.31)	4.97 (7.40)	9.04 (7.25)	17.56 (12.48)	5.76 (8.33)	10.30 (10.43)	21.86 (16.48)
*Representational Gravity (vertical shift scores)***									
Experiment (prestudy)	1.75 (2.78)	2.14 (2.98)	1.80 (3.23)	1.51 (3.20)	1.34 (2.75)	0.96 (5.55)	1.41 (2.87)	1.50 (3.72)	1.33 (4.40)

**positive values indicate a forward shift, negative values indicate a backward shift. **Positive values indicate a downward displacement, negative values indicate an upward displacement*

Continuous motion: Estimates of Representational Momentum were compared to zero, and as with the implied motion stimuli, a significant forward shift was observed, $t(31) = 3.52$, $p = .001$, $d = 0.62$, indicating the typical Representational Momentum phenomenon. A one-factorial repeated measure ANOVA with the factor stimulus speed (1 vs. 3 vs. 6 vs. 10 vs. 15 vs. 20 vs. 25 vs. 30 vs. 35 pixels per frame) was conducted (for mean shift scores, see Table E2). As in Experiment 1, the main effect of stimulus speed was significant, $F(2.46, 76.29) = 6.96$, $p = .001$, $\eta_p^2 = .183$, and polynomial contrast coding, which contrast weights accounted for the actual pixels shifts of each condition, revealed a significant linear trend, $F(1, 31) = 12.00$, $p = .002$, $\eta_p^2 = .279$. The forward shift increases with increasing stimulus speed.

Representational Gravity

Estimates of Representational Gravity were compared to zero, and for both stimulus motions, a descriptive downward displacement was observed indicating Representational Gravity, yet, this downward displacement only reached significance for implied motion stimuli (-1.53 pixels), $t(31) = 2.93$, $p = .006$, $d = 0.52$, but barely not for the continuous motion, but were in the expected direction (-1.34 pixels), $t(31) = 1.77$, $p = .086$, $d = 0.31$. A 3 (stimulus timing: slow vs. middle vs. fast) x 3 (stimulus distance: short vs. medium vs. long) ANOVA was conducted for the implied motion stimuli, and a one-factorial ANOVA with the factor stimulus speed (1 vs. 3 vs. 6 vs. 10 vs. 15 vs. 20 vs. 25 vs. 30 vs. 35 pixels per frame) was conducted for the continuous motion stimuli to investigate the influence of stimulus speed on the Representational Gravity phenomenon. Once again, none of the main effects and interaction for both, implied motion stimuli, Fs < 2.03, $p < .140$, as well as continuous motion stimuli, $F(5.47, 169.76) = 1.99$, $p = .077$, were significant, indicating no influence of stimulus speed on the downward displacement.

Table E2.

Continuous motion trials: Mean shifts scores (standard deviations in brackets) as a function of stimulus speed (1 vs. 3 vs. 6 vs. 10 vs. 15 vs. 20 vs. 25 vs. 30 vs. 35 pixels per frame) for Representational Momentum as well as Representational Gravity scores in Experiment 1 and Experiment 2.

	1	3	6	10	15	20	25	30	35
*Representational Momentum (horizontal shift scores)**									
Experiment (prestudy)	4.47 (6.97)	4.91 (11.72)	5.21 (15.79)	7.25 (19.01)	9.94 (20.21)	12.39 (23.07)	15.65 (24.28)	16.65 (24.84)	17.09 (24.01)
*Representational Gravity (vertical shift scores)***									
Experiment (prestudy)	2.13 (5.28)	2.16 (4.76)	1.72 (4.65)	2.05 (5.37)	1.54 (5.45)	1.15 (5.16)	–0.02 (5.40)	0.63 (4.73)	0.71 (5.76)

**positive values indicate a forward shift, negative values indicate a backward shift. **Positive values indicate a downward displacement, negative values indicate an upward displacement*

(B): Screen size, viewing distance, & visual angle analysis of Experiment 2

In this section, the screen size procedure and the viewing distance procedure are more closely analyzed. The screen size procedure is designed to infer actual screen size based on a procedure in which participants had to indicate the size of a a priori known object (here, a credit card). Therefore, participants adjusted the size of an on-screen credit card to match the actual size of a credit card, this allows to assess how many pixel correspond to one cm. Horizontally, on average, 46.85 pixels corresponded to one cm (min: 32 pixels, max: 64.7 pixels); vertically, 45.18 pixels corresponded to one cm (min: 32 pixels, max: 60 pixels). With screen resolution (in pixels) being tracked by the computer program, this allows to calculate the average screen width (33.95 cm; min: 20.4 cm; max: 60 cm) and screen height (16.98; min: 10.7 cm; max: 27.5 cm).

The viewing distance estimation was done by using the blind spot of participants. The basic idea is simple (for the elaborate argument and the calculations, see Li et al., 2020). The distance between the blind spot and retinal focus is about 13.5°, and this is fairly constant across participants. Therefore, participants saw a stimulus moving away from fixation, and had to indicate when the stimulus could not be seen anymore. The indicated location was measured in pixels, but when combined with the information from the screen size procedure, the viewing distance can be approximated, and visual angle of the stimuli can be computed. While screen size is fixed for each participant, viewing distance can change within one experiment. Therefore, the viewing distance procedure was conducted three time. In a first step, it was analyzed if viewing distance changed during the experiments / across the three measurement points. A one-factorial ANOVA with measurement point as within factor and calculated viewing distance as dependent variable indicated no main effect of measurement point, $F(2, 60) = 0.189$, $p = .829$, $\eta_p^2 = .006$; this was supported by the Bayesian ANOVA in which the Null model was 8.89 times more likely than the model with the main effect. On average, viewing distance was 63.03

cm, and was significant higher than the 45 cm used in Experiment 1, $t(30) = 4.95$, $p < .001$, $d = 089$; $BF_{10} = 861$.

Based on the information about viewing distance and screen size, stimulus information in pixel can be transferred to visual angle scores. Horizontally, one degree of visual angle corresponded on average to 50.19 pixels (min: 36.07 pixels; max: 121.02 pixels). Vertically, one degree of visual angle corresponded on average to 52.34 pixels (min: 31.87 pixels; max: 98.39 pixels). By dividing these values by 60, the scores can be transformed into arcmin.

In the lead up to Experiment 2, an alternative approach which details programming all stimulus features in term of visual angle information from Experiment 1 is discussed. Therefore, the set-ups of Experiment 2 were analyzed to see if a programming of the Experiment based on the visual angle information of Experiment 2 could have been possible. In the long distance condition of Experiment 1, the stimulus travelled 760 pixels across the screen and ended approximately at the center of the screen. This correspondent to a distance of about 25.1° given the exact experimental set-up. So, the question is if a distance of 25.1° could have been presented on the participants screen (since the stimulus ended at the center of the screen, this distance could only be presented either the left or right half of the participants screen). Interestingly, for none of the participants, this would have been possible. This indicates that the approach taken for Experiment 2 by using stimulus features which could definitely been presented on the screen and then post-hoc assess actual stimulus speed and estimated location in visual angle was the more successful approach.

(B): Analyzing the influence of response set-up (mouse vs. touchpad) and time of participation

The present study allows for the exploratory analysis of any influence of the actual response set (if participants responded with a touchpad or with a mouse following self-report) and also when participants conducted the experiment. That is, while laboratory experiments are

typically conducted during typical office / university hours (between 8 am and 6 pm), participants were allowed to conduct the experiment whenever they wanted. To analyze any potential influence of response set or time of participation, participants were categorized into a mousepad (18 participants) or touchpad (13 participants) group for the analysis of response set; or, alternatively, into a group of typical university hours (between 8 am and 6 pm; 20 participants) or not (11 participants).

Representational Momentum: The same analyses as reported in the main text for Experiment 2 were conducted, but extended by either including the between participant factor of time or response set-up. Crucially, no further main effect or interaction with either factor was evidence for both, implied motion, Fs < 2.13, p > .152, as well as continuous motion stimuli, all Fs < 0.60, p > .776.

Representational Gravity: As for Representational Momentum, the same analyses were conducted. Here, a main effect for response set-up was observed for continuous motion stimuli, $F(1, 29) = 8.63$, $p = .006$, $\eta_p^2 = .229$, but not further interaction was observed, $F(5.31, 153.91) = 1.65$, $p = .147$. Yet, for implied motion stimuli, no effects of response set were observed, Fs < 2.60, $p > .118$. As for any influence of time, here a main effect for implied motion stimuli was observed, $F(1, 29) = 6.41$, $p = .017$, $\eta_p^2 = .181$, but no further interactions were once again observed, all Fs < 3.36, $p > .053$. Yet, for continuous motion stimuli, this data pattern was not repeated, as no influence of time was observed, Fs < 0.86, $p > .501$. This indicates no systematic and consistent influence of either variable on Representational Momentum, but these analyses should only be seen as exploratory, as the study was not designed to investigate any of these effect. Please also note the unbalanced amount of participants per group.