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Spatial estimation of accelerated stimuli is based on a linear extrapolation of first-order information

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### Abstract

We examined spatial estimation of accelerating objects (-8, -4, 0, +4, or +8 deg/s<sup>2</sup>) during occlusion (600, 1000 ms) in a spatial prediction motion task. Multiple logistic regression indicated spatial estimation was influenced by these factors such that participants estimated objects with positive acceleration to reappear behind less often than those with negative acceleration, and particularly after the longer occlusion. Individual-participant logistic regressions indicated spatial estimation was better predicted by a first-order extrapolation of the occluded object motion based on pre-occlusion velocity rather than a second-order extrapolation that took account of object acceleration. We suggest a general principle of extrapolation is involved in prediction motion tasks whereby there is a contraction of the variable of interest (i.e., displacement in spatial prediction motion and time in temporal prediction motion). Such an approach to extrapolation could be advantageous as it would offer participants better opportunity to correct for an initial estimation error.

*Key words:* Pursuit; Spatial Estimation; Extrapolation; Prediction Motion, Acceleration

**Spatial estimation of accelerated stimuli is based on a linear extrapolation of first-order information**

There are many situations in everyday interactions within our surrounds that require extrapolation of occluded object motion (e.g., estimating reappearance of a cyclist who is occluded by a passing car, or when a football will reappear from behind the wall of players during a free kick). Extrapolation processes have been extensively studied with temporal prediction motion (TPM) tasks in which participants have to estimate the arrival time of a transiently occluded moving object at a pre-specified target. Numerous studies have shown that a linear relationship exists between estimated and actual arrival-time (e.g., Caird & Hancock, 1994; DeLucia & Liddell, 1998, Schiff & Oldack, 1990). Yakimoff and colleagues (Yakimoff, Bocheva, & Mitrani, 1987; Yakimoff, Mateeff, Ehrenstein, & Hohnsbein, 1993) suggested this relationship can be expressed by the linear equation:  $T_r = \alpha T_a + \theta$ , where  $T_a$  is the actual arrival time of the moving object,  $T_r$  the response time between the occlusion and the response,  $\alpha$  reflects subjective velocity perception, and  $\theta$  represents the participant's state of readiness and anticipation. It has been suggested that the linear model with  $\alpha$  less than unity (i.e., velocity is overestimated) and  $\theta$  greater than zero can explain the finding of overestimation of arrival time for shorter occlusions and underestimation of arrival time for longer occlusions, with a transition point generally occurring around 800-900 ms (Benguigui, Ripoll & Broderik, 2003; Manser & Hancock, 1996; Schiff & Detwiler, 1979; Schiff & Oldak, 1990).

TPM tasks have been also used to identify the information used when estimating arrival-time of accelerating (i.e., negative and positive) objects. Despite being sensitive to acceleration given sufficient stimulus duration (i.e., > 300 ms; Brouwer, Brenner, & Smeets, 2002), arrival time in TPM is underestimated and overestimated for negatively and positively accelerating objects respectively (Kaiser & Hecht, 1995; Rosenbaum, 1975). Benguigui et al. (2003) showed that first-order information corresponding to position and velocity at occlusion accounted for the pattern of temporal estimation errors. This finding was later replicated by Benguigui and Bennett (2010), who provided a detailed analysis of eye movements during occlusion. Rather than maintaining smooth pursuit of the unseen lateral object motion during occlusion, participants made a saccade soon after occlusion that moved the eyes to the vicinity of the target corresponding to the arrival position. Importantly, the timing of the saccade did not predict temporal estimation but still this oculomotor response may have influenced the extrapolation process because the eyes, and thereby overt attention, were directed at the arrival

1 position. For instance, by prematurely halting ocular pursuit of the unseen object there could have  
2 been decay in extra-retinal information regarding the object motion.

3 To avoid participants making a saccade to a known arrival position and instead maintain  
4 better pursuit during occlusion, researchers have used the spatial prediction motion (SPM) task  
5 (Makin & Poliakoff, 2011; Wexler & Klam, 2001). In SPM, participants make an estimation regarding  
6 the reappearance position of an object (after a transient occlusion) that is either behind or ahead of  
7 where it should be given a veridical extrapolation. Importantly, no advance cues are available from the  
8 stimulus display regarding the reappearance location (arrival location in TPM tasks), and thus the  
9 required extrapolation displacement. Also, participants expect the object to reappear and continue  
10 along its motion rather than making contact with a stationary target and potentially coming to an  
11 abrupt halt. Accordingly, participants exhibit more accurate pursuit during SPM than TPM by  
12 extrapolating the occluded lateral object motion using a combination of smooth and saccadic eye  
13 movements (Bennett & Barnes, 2006).

14 Despite maintaining better pursuit of the object in SPM tasks, it has nonetheless been  
15 reported that there is a reliance on first order information with accelerating objects that reappear after  
16 800ms of occlusion (Bennett & Benguigui, 2013). It is thus possible that a similar extrapolation  
17 process is involved in SPM and TPM tasks. To further elucidate this issue, here we extended upon  
18 our previous study by examining spatial estimation over two occlusion durations (600ms, 1000ms) in  
19 an SPM task where the object could undergo negative or positive acceleration (-8, -4, 0, +4, or +8  
20 deg/s<sup>2</sup>). Once again we ensured that object velocity at occlusion was the same irrespective of  
21 acceleration and occlusion duration, and thus did not provide an obvious cue regarding reappearance  
22 position. Therefore, if participants do not account for object acceleration in their extrapolation of  
23 occluded lateral motion, and instead use first-order information corresponding to velocity at the  
24 moment of occlusion, it should follow that object displacement is overestimated and underestimated  
25 for negatively and positively accelerating objects respectively. Consequently, participants should  
26 make more “behind” estimations for negatively accelerating objects and fewer “behind” estimations for  
27 positively accelerating objects. Moreover, it can be expected that the longer duration occlusion  
28 interval should increase the discrepancy between veridical object displacement and extrapolated  
29 occlusion displacement based on pre-occlusion velocity, and thus influence the number of “behind”  
30 estimations if participants do not take account of object acceleration.

## 1 **Method**

### 2 **Participants**

3 Fifteen male participants (mean age: 22 years) volunteered to take part in the experiment.  
4 Participants were instructed that on each trial they would be required to pursue an object that would  
5 undergo transient occlusion and then reappear at a position behind or ahead of where it should be  
6 had the motion properties remained unchanged. They were told the object motion properties would  
7 change from trial-to-trial but they were not given specific detail regarding the levels of acceleration,  
8 occlusion duration or change in reappearance position (i.e., reappearance step). All participants had  
9 normal or corrected-to-normal vision, were healthy and without any known oculomotor abnormalities.  
10 Written consent was obtained before the experiment, and in accordance with the Declaration of  
11 Helsinki, the protocol was approved by the Liverpool John Moores University local ethics committee.

### 12 **Apparatus**

13 Participants sat in a purpose-built dark room, facing a 22" CRT monitor (Iiyama Vision Master  
14 505) located on a workbench at a viewing distance of 0.9 m. The head was supported with a height-  
15 adjustable chin rest that was aligned perpendicular to the screen centre. Experimental stimuli were  
16 generated on a host PC (Dell Precision 670) using the COGENT toolbox implemented in MATLAB  
17 (Mathworks Inc) and displayed on the CRT monitor with a spatial resolution of 1280x1024 pixels and  
18 a refresh rate of 85 Hz. Estimation of reappearance position was determined from the key pressed  
19 (left = behind, right = ahead) on a Lycosa Razr keyboard polling at 1000 Hz.

### 20 **Task and Procedure**

21 Participants were required to make a spatial estimation regarding the reappearance position  
22 of an occluded moving object (Figure 1). Each trial began with the appearance of a green spherical  
23 object (0.6 deg diameter) located at -20 deg to the left of the participant's point of observation as they  
24 faced the monitor. After a fixed duration of 1500 ms the green spherical object changed color to red,  
25 which signalled to the participant that it would soon begin to move. Following a random foreperiod  
26 between 1650 and 1850 ms, the red spherical object moved horizontally for 600 ms from the left to  
27 the right. Initial velocity was either 16.8, 14.4, 12.0, 9.6 or 7.2 deg/s, and was uniquely matched with a  
28 single level of acceleration (-8, -4, 0, +4, or +8 deg/s<sup>2</sup>, respectively) such that object velocity at  
29 occlusion was 12.0 deg/s. With these parameters, object velocity at occlusion did not uniquely specify  
30 reappearance position and velocity, and thus had limited predictive value. However, change in

1 velocity resulting from the outermost levels of acceleration (-8 and +8 deg/s<sup>2</sup>) during the initial 600 ms  
2 of motion was above the accepted 25 % discrimination threshold (Babler & Dannemiller, 1993;  
3 Brouwer et al., 2002). During occlusion the object continued to move, unseen, horizontally across the  
4 screen for 600 or 1000 ms. It then reappeared with a position step that was either behind or ahead (-  
5 5, -3, -1, +1, +3, +5 deg) of the veridical position had the object continued to move with the same  
6 motion properties. Using these parameters, object displacement differed as a function of object  
7 acceleration and occlusion duration (see figure 1). Moreover, the inclusion of a position step resulted  
8 in 36 different reappearance positions (i.e., 6 for the 600 ms occlusion and 30 for the 1000 ms  
9 occlusion), thus minimizing this as a cue to infer occluded object motion properties.

10 Each participant performed a total of 195 trials that were received in a single experimental  
11 session lasting approximately one hour. The first block of 15 trials was used as a familiarization  
12 session and was not included in the analysis. The next 180 trials were received in pseudo-random  
13 order organised into 6 blocks of 30 trials. Each combination of motion parameters was repeated 3  
14 times but never in consecutive order. Participants were instructed to track the moving object with their  
15 eyes for the entirety of the presentation and estimate its reappearance relative to the expected  
16 position had it continued to move with the same motion properties throughout. Object reappearance  
17 was always subject to a position step, hence requiring participants to make a two-alternative, forced-  
18 choice estimation (Wexler & Klam, 2001). No feedback was given regarding estimation error in order  
19 to emphasize use of veridical motion properties and thereby minimize the likelihood of participants  
20 responding based on a learned heuristic.

## 21 **Data Analysis**

22 For each trial, the keyboard data was used to determine whether participants estimated the  
23 actual reappearance position to be behind (left mouse click) or ahead (right mouse click) of the  
24 expected reappearance position. The number of trials estimated as “behind” and “ahead” was then  
25 calculated for each combination of object parameters. Given our data were non-normally distributed  
26 and non-independent due to the repeated measures design, we used R statistical software (R version  
27 3.2.0, 2015) to conduct a multiple logistic regression using a generalized linear mixed model (glmer of  
28 the lme4 package for R: Bates, Maechler, Bolker, & Walker, 2014). Specifically, the estimation data  
29 were fit by maximum likelihood (Adaptive Gauss-Hermite Quadrature with 2 nodes), using a binomial  
30 distribution and log link function. Participants were uniquely identified within the dataset and modelled

1 with a random intercept. The independent variables, reappearance step (-5, -3, -1, +1, +3, +5 deg),  
2 acceleration (-8, -4, 0, +4, +8 deg/s<sup>2</sup>) and occlusion duration (600, 1000 ms), were rescaled to a  
3 similar range, each with a mean of zero and modelled as fixed effects (main and interaction) with an  
4 intercept.

5 To then examine the information used as the basis of spatial estimation by individual  
6 participants, their data were submitted to separate logistic regression analysis (glm of the lme4  
7 package, with a binomial distribution and log link function). Two models were fit in which the predictor  
8 represented a spatial variable available at the moment the object reappeared with respect to either an  
9 extrapolation based on: 1) veridical motion properties including the acceleration (i.e., reappearance  
10 step of -5, -3, -1, +1, +3, +5 deg); 2) or only pre-occlusion velocity without acceleration (see Table 1).

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## Results

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### Spatial Estimation

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Fixed effects parameters for a logistic regression model including all main and interaction effects are shown in Table 2. From the full model it can be seen that reappearance step, acceleration and occlusion duration, as well the interaction between reappearance step and acceleration, and acceleration and occlusion duration, each made a significant contribution to the model. The non-significant 3-way and 2-way interaction terms indicate that the probability of giving a behind estimation as position step progressed from negative to positive was not modified by occlusion duration, irrespective of object acceleration. Akaike Information Criterion (AIC) Bayesian Information Criterion (BIC) for the full model were 1284 and 1328, respectively. For the random effect of participant, the standard deviation of intercepts was 0.85, thus confirming the presence of individual-participant variability. The data were then fitted again by a reduced model that did not include the non-significant terms. Fixed effects parameters for this reduced model are also shown in Table 2. AIC and BIC for the reduced model were 1282 and 1315, respectively. As expected, there was again evidence of individual-participant variability but now with a marginally reduced standard deviation of intercepts equal to 0.84. A comparison of the two models using the likelihood ratio test indicated no difference in the relative quality ( $\chi^2_{(2)} = 1.36, p > 0.5$ ). Removal of additional predictors did not result in an equal fit of the spatial estimation data and thus we accepted the first reduced model described above.



1           According to the reduced model, and as can be seen from observing the group mean data  
2 (Figure 2), participants spatial estimations were broadly consistent with the reappearance position. As  
3 can be expected if participants based their estimation behaviour on the difference between actual  
4 reappearance position and an extrapolation of the occluded trajectory, there was a decrease in  
5 probability ( $\beta = -0.41 \pm 0.02$  SE) of giving a behind estimation for a one unit change in position step  
6 moving from negative to positive (Wald statistic = -21.79,  $p < 0.001$ ). There was also a significant effect  
7 of acceleration, with a decrease in probability ( $\beta = -0.47 \pm 0.02$  SE) of giving a behind estimation for a  
8 one unit change in acceleration moving from negative to positive (Wald statistic = -20.98,  $p < 0.001$ ).  
9 This would not be expected if participants based their estimation behaviour on the difference between  
10 actual reappearance position and a veridical extrapolation of the occluded trajectory. The interaction  
11 between reappearance step and acceleration was significant and associated with a decrease in  
12 probability of giving a behind estimation for negative positions steps when the object had positive  
13 acceleration compared to negative acceleration, and an increase in probability of giving a behind  
14 estimation for positive positions steps when the object had negative acceleration compared to positive  
15 acceleration (Wald statistic = 2.32,  $p < 0.02$ ). Notably, the interaction effect was somewhat marginal ( $\beta$   
16 =  $0.01 \pm 0.01$  SE). As predicted, there was a decrease in probability of giving a behind estimation  
17 after a 1000 ms compared to 600 ms occlusion ( $\beta = -0.47 \pm 0.05$  SE). The effect of occlusion duration  
18 was also influenced by object acceleration (Wald statistic = -7.09,  $p < 0.001$ ). As can be inferred from  
19 Figure 2, there was a decrease in probability ( $\beta = -0.14 \pm 0.02$  SE) of giving a behind estimation after  
20 a 1000 ms compared to 600 ms occlusion when the object had zero or positive acceleration.

### 21 **Information for Spatial Estimation**

22           Given the finding that the group data was influenced by occlusion duration, as well as the  
23 finding of variability in individual-participant intercepts, logistic regressions were conducted separately  
24 for each participant on spatial estimation data for the 600 and 1000ms occlusions. The outcome of  
25 indicated that the inclusion of either predictor resulted in a better fit than the intercept-only model in 53  
26 of the 60 individual-participant logistic regressions. As can be seen in tables 4 and 5, the model  
27 including the difference between object reappearance position and a first-order extrapolation of object  
28 position as a predictor provided the best fit of the estimation data. Nagelkerke's pseudo  $R^2$  was  
29 greater with a first-order than second-order predictor in all participants for the 600ms and 1000ms  
30 occlusion durations. This was confirmed by subtracting the AIC value of the first-order predictor from

1 the second-order predictor, and comparing to the distinguishable difference (i.e.,  $>2$ ) threshold  
2 (Burnham & Anderson, 2002). The criterion threshold was met in 14 of the 15 participants for the  
3 600ms occlusion, and all 15 participants for the 1000ms occlusion. Notably, only P3 exhibited  
4 estimations that were no better fit by the first-order or second-order predictor than the intercept-only  
5 model. The overall performance of this participant was ranked 14<sup>th</sup> with an average number of correct  
6 responses equal to 1.43. Still, the participant who was ranked 15<sup>th</sup> (P2) exhibited spatial estimation  
7 data that was well fit by the first-order predictor. The implication is that P3 based their spatial  
8 estimations on a different predictor, or combination of predictors.

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### Discussion

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The current study examined spatial estimation of accelerating objects to determine whether extrapolation of the occluded lateral motion is: 1) consistent with use of first-order information; and 2) influenced by occlusion duration. Consistent with our previous study (Bennett & Benguigui, 2013), we found that participants estimated objects with negative acceleration to reappear behind the veridical extrapolated position more often than those with positive acceleration. This effect is consistent with a shift from overestimation to underestimation of the extrapolated object displacement, and would be expected if participants did not take account of negative and positive acceleration, respectively (i.e., second-order information). For instance, for an object with positive acceleration it follows that reappearance with negative position step would be estimated behind less often because it would coincide more closely with the underestimated extrapolation. Participants also estimated objects with positive acceleration to reappear behind more often after the shorter occlusion than the longer occlusion. Again, this effect would not be predicted by use of second-order information. Logistic regression on the individual-participant data confirmed that the difference between object reappearance position and a first-order extrapolation of object position (i.e., based on pre-occlusion object position and velocity) was a significant predictor of spatial estimation in almost all cases.

Given that the change in velocity during the initial visible portion of the trajectory was above the reported detection threshold (Babler & Dannemiller, 1993; Brouwer et al., 2002), it is unlikely that participants were unable to perceive the object was accelerating. This being the case, our results are consistent with the suggestion that perception and use of object acceleration for temporal or spatial estimations are somewhat independent (Benguigui et al., 2013). This can be explained by divergence

1 in processing downstream of cortical processing (MT/MST) of visual motion stimuli (Kowler, 2011;  
2 Spering & Montagnini, 2011). It could be interesting in future work to examine whether instructions  
3 and/or knowledge regarding the properties of upcoming object motion influence the use of  
4 acceleration in SPM tasks. Indeed, it has been shown that ocular pursuit is maintained better during  
5 an occlusion when the participant has advance knowledge from repeated presentations (Bennett,  
6 Orban de Xivry, Lefèvre, & Barnes, 2010) regarding object acceleration. Such long-term prediction  
7 (i.e., inter-trial) was minimised in the current study by randomising the motion parameters from trial-to-  
8 trial, and not giving detail regarding the levels of acceleration, occlusion duration or change in  
9 reappearance position (i.e., reappearance step). This was necessary in order to examine unbiased  
10 extrapolation in SPM, and thus permit comparison with previous studies of TPM tasks (Benguigui et  
11 al., 2003; Rosenbaum, 1975) and coincidence-anticipation tasks (Ripoll & Latiri, 1997) with  
12 accelerating objects. However, it may be that advance knowledge regarding the upcoming motion  
13 parameters results in improved pursuit during occlusion of SPM tasks, and thus more accurate spatial  
14 estimations.

15         While there was evidence in the group and individual-participant analysis that spatial  
16 estimation was better predicted by an extrapolation based on first-order rather than second-order  
17 information, we did not find a tendency towards overestimating extrapolated displacement with  
18 increasing occlusion, as could be predicted by findings from TPM tasks. On the contrary, the main  
19 effect of occlusion duration, as well as the interaction between occlusion duration and acceleration,  
20 indicated that participants tended to underestimate extrapolated displacement of the longer occlusion,  
21 although more so when the object had zero or positive acceleration. Previous studies of the SPM task  
22 have reported a general tendency towards underestimating extrapolated displacement of constant  
23 velocity objects with increasing occlusion. Tanaka, Worringham, and Kerr (2009) found that the  
24 tendency to underestimate object reappearance position increased with larger displacements, which  
25 equated to occlusion duration that ranged from 235-941 ms (see also Lyon & Waag, 1995). Wexler  
26 and Klam (2001) found that participants tended to underestimate larger than smaller displacements  
27 (i.e., 30, 60, 90 deg) of a passively moved occluded object (i.e., 490, 970, 1510 ms occlusion  
28 duration) when it had circular motion (experiment 1) or lateral motion (experiment 2). Underestimation  
29 of the extrapolated object displacement was also greater when encouraged to maintain pursuit with

1 the eyes compared to fixation, thus indicating that the typical decay in smooth pursuit during occlusion  
2 might influence spatial estimation.

3         An initial conclusion one might draw is that TPM and SPM tasks do not share the same  
4 extrapolation processes. For instance, while it has been suggested that overestimation of velocity can  
5 explain the findings in TPM tasks (for detailed consideration see Lyon & Waag, 1995), this would not  
6 account for the effects reported in SPM tasks. Wexler and Klam (2001) suggested that velocity  
7 perception is likely modulated by object speed during the initial visible period in accord the properties  
8 of a low-pass filter, and then subsequently decreases during occlusion of the SPM task. While we do  
9 not refute the idea that velocity perception could be differentially modulated by the TPM and SPM  
10 tasks, we contend that a more general principle of extrapolation is involved in these tasks. That is,  
11 despite clear differences in the stimulus features, and thus the potential extra-retinal input, occlusion  
12 of the moving object causes a contraction of the variable of interest (i.e., time in TPM and  
13 displacement in SPM). Such an approach could convey an advantage in the respect that participants  
14 would have better opportunity to correct for the initial estimation error. For example, in a task that  
15 required temporal prediction, a tendency to underestimate occlusion time would mean participants  
16 respond before the object arrives, thus giving opportunity to respond again and not suffer the  
17 consequences of being late (i.e., miss or contact). Similarly in a task that requires spatial prediction,  
18 underestimation of occlusion displacement would result in the participant's response (e.g., pointing or  
19 reaching) being behind the veridical location. This would then require corrections in the direction of  
20 object motion, which are generally more time and energy efficient than movement reversals (Elliott,  
21 Hansen, Mendoza, & Tremblay, 2004). This general tendency to underestimate space and time is  
22 probably an adaptation to the relative inaccuracy of the processes involved in extrapolation and  
23 prediction tasks.

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**Table 1.** Difference (deg) between object reappearance position and a second-order extrapolation that takes into account acceleration (Veridical), or a first-order extrapolation based on pre-occlusion velocity (PreVel – deg/s) irrespective of acceleration.

	Veridical	PreVel -8	PreVel -4	PreVel 0	PreVel +4	PreVel +8
600 ms						
Occlusion						
-5	-5	-6.4	-5.7	-5	-4.3	-3.6
-3	-3	-4.4	-3.7	-3	-2.3	-1.6
-1	-1	-2.4	-1.7	-1	-0.3	0.4
1	1	-0.4	0.3	1	1.7	2.4
3	3	1.6	2.3	3	3.7	4.4
5	5	3.6	4.3	5	5.7	6.4
1000 ms						
Occlusion						
-5	-5	-9	-7	-5	-3	-1
-3	-3	-7	-5	-3	-1	1
-1	-1	-5	-3	-1	1	3
1	1	-3	-1	1	3	5
3	3	-1	1	3	5	7
5	5	1	3	5	7	9



**Table 2.** Fixed effect parameters from multiple logistic regression on group mean spatial estimation. The full model is shown first followed by a reduced model that does not include the non-significant predictors. Estimate is the standardized predictor coefficient and SE is the associated standard error. Z represents the Wald statistic and  $p$  is the associated alpha level.

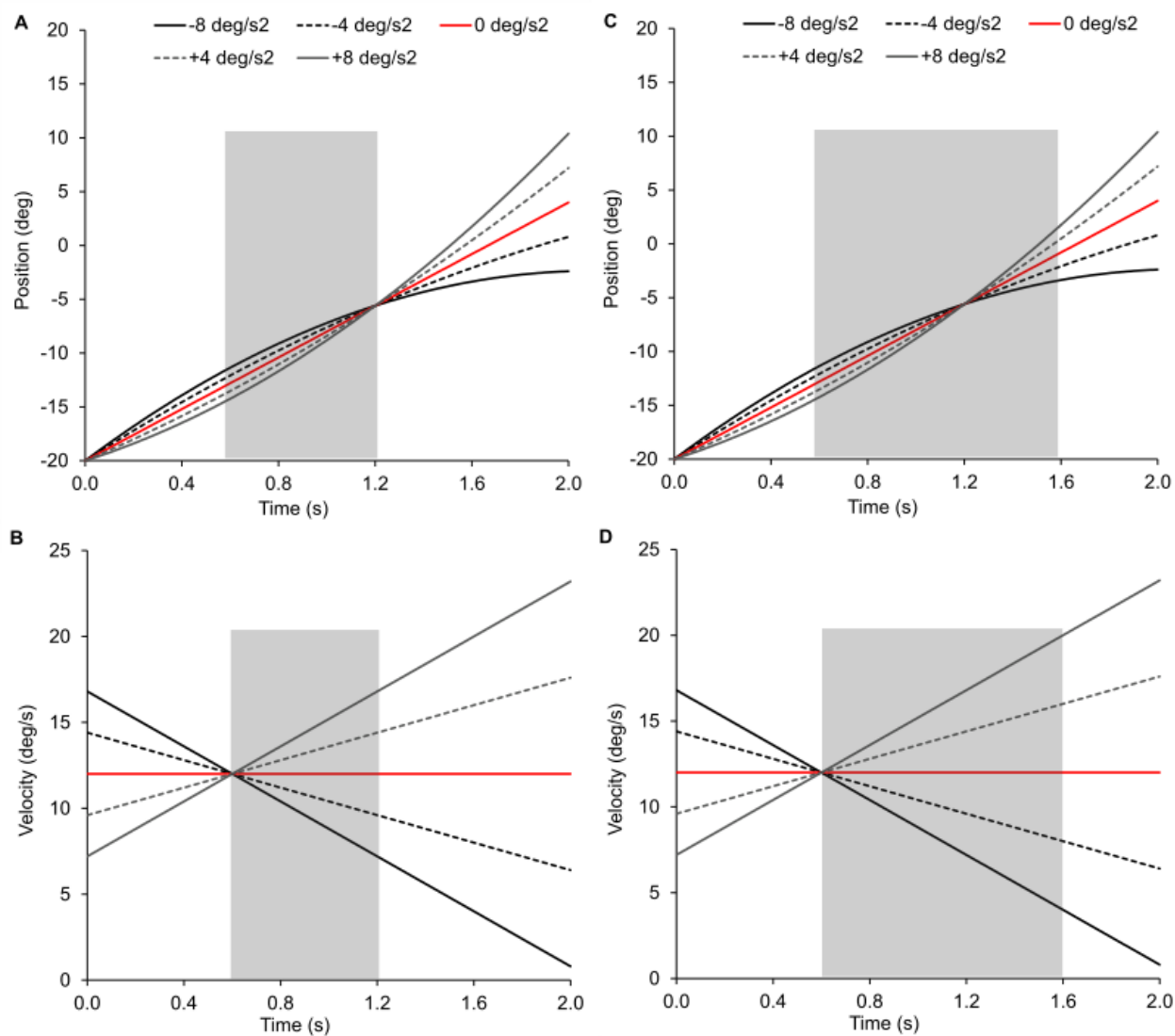
Fixed Effects	Estimate	SE	Z	$p$
<u>Full Model</u>				
Intercept	0.13	0.23	0.56	0.57
Step	-0.40	0.02	-21.51	0.01
Acc	-0.47	0.02	-20.63	0.01
Occlusion	-0.44	0.06	-7.68	0.01
Step x Acc	0.02	0.01	2.45	0.01
Step x Occlusion	0.00	0.02	0.18	0.86
Acc x Occlusion	-0.14	0.02	-6.44	0.01
Step x Acc x Occlusion	0.01	0.01	1.14	0.25
<u>Reduced Model</u>				
Intercept	0.12	0.23	0.53	0.60
Step	-0.41	0.02	-21.79	0.01
Acc	-0.47	0.02	-20.98	0.01
Occlusion	-0.47	0.05	-8.82	0.01
Step x Acc	0.01	0.01	2.32	0.02
Acc x Occlusion	-0.14	0.02	-7.09	0.01

**Table 3.** Results of individual-participant (P1-P15) logistic regression for spatial estimation after a 600 ms occlusion, with the difference between object reappearance position and a second-order extrapolation ( $\Delta Obj-2^{nd}$ ) as the predictor. Estimate is the standardized predictor coefficient and SE is the associated standard error.  $Z$  represents the Wald statistic and  $p$  is the associated alpha level. AIC and  $R^2$  are described in the text.

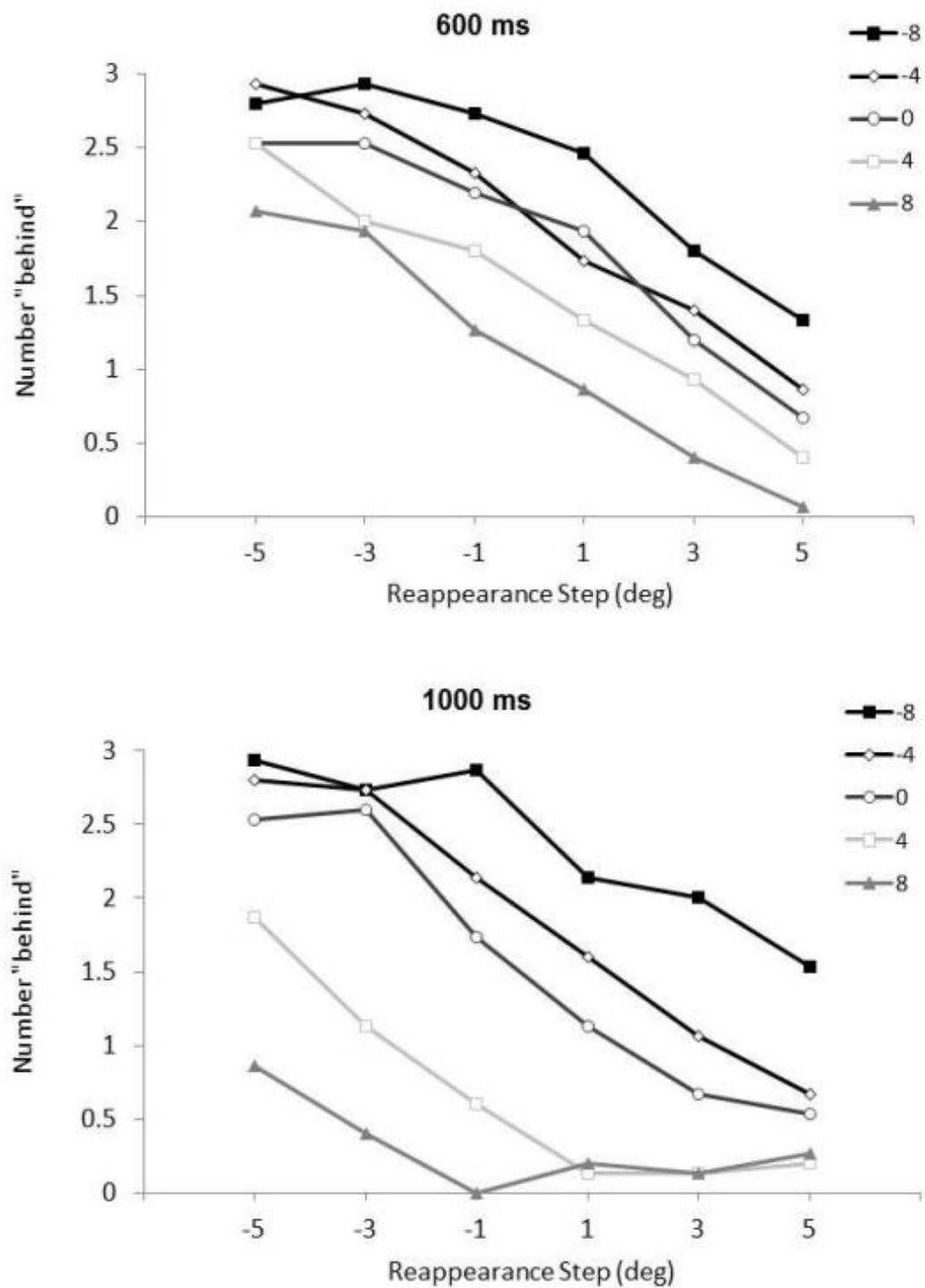
P	$\Delta Obj-1^{st}$						$\Delta Obj-2^{nd}$					
	Estimate	SE	$Z$	$p$	AIC	$R^2$	Estimate	SE	$Z$	$p$	AIC	$R^2$
1	-0.25	0.08	-3.11	0.01	59.54	0.36	-0.20	0.08	-2.56	0.01	63.76	0.24
2	-0.41	0.09	-4.48	0.01	61.96	0.66	-0.31	0.08	-3.86	0.01	72.96	0.49
3	-0.12	0.06	-1.88	0.06	116.31	0.12	0.02	0.06	0.31	0.76	119.88	0.01
4	-0.29	0.08	-3.59	0.01	68.85	0.44	-0.19	0.07	-2.59	0.01	77.51	0.23
5	-0.79	0.16	-4.98	0.01	41.89	0.91	-0.75	0.15	-5.08	0.01	44.97	0.90
6	-0.69	0.14	-4.96	0.01	51.87	0.87	-0.53	0.11	-4.90	0.01	66.26	0.77
7	-0.54	0.11	-4.96	0.01	58.66	0.80	-0.51	0.10	-4.94	0.01	62.49	0.76
8	-0.61	0.23	-2.69	0.01	32.39	0.50	-0.47	0.20	-2.40	0.02	36.87	0.37
9	-1.27	0.30	-4.20	0.01	26.79	0.96	-1.05	0.23	-4.55	0.01	34.52	0.93
10	-1.41	0.35	-4.07	0.01	30.03	0.96	-0.83	0.17	-4.84	0.01	51.80	0.89
11	-0.12	0.07	-1.75	0.08	65.62	0.11	-0.10	0.07	-1.50	0.13	66.47	0.08
12	-0.44	0.09	-4.75	0.01	60.05	0.72	-0.42	0.09	-4.70	0.01	62.78	0.69
13	-1.43	0.38	-3.79	0.01	21.36	0.95	-0.91	0.22	-4.22	0.01	37.05	0.86
14	-0.39	0.09	-4.37	0.01	62.95	0.63	-0.33	0.08	-4.02	0.01	69.57	0.53
15	-0.73	0.15	-4.97	0.01	54.02	0.88	-0.57	0.11	-5.00	0.01	66.67	0.80

**Table 4.** Results of individual-participant (P1-P15) logistic regression for spatial estimation after a 1000 ms occlusion, with the difference between object reappearance position and a first-order extrapolation ( $\Delta Obj-1st$ ) as the predictor. Estimate is the standardized predictor coefficient and SE is the associated standard error. Z represents the Wald statistic and  $p$  is the associated alpha level. AIC and  $R^2$  are described in the text.

P	$\Delta Obj-1^{st}$						$\Delta Obj-2^{nd}$					
	Estimate	SE	Z	$p$	AIC	$R^2$	Estimate	SE	Z	$p$	AIC	$R^2$
1	-0.26	0.07	-3.62	0.01	62.59	0.48	-0.13	0.07	-1.74	0.08	76.76	0.11
2	-0.59	0.12	-4.81	0.01	58.87	0.87	-0.18	0.07	-2.65	0.01	107.98	0.23
3	-0.27	0.07	-4.07	0.01	97.39	0.54	0.05	0.06	0.80	0.42	119.33	0.02
4	-0.20	0.06	-3.48	0.01	78.46	0.41	-0.07	0.06	-1.11	0.27	91.97	0.04
5	-0.70	0.16	-4.49	0.01	36.84	0.89	-0.40	0.10	-4.11	0.01	68.55	0.58
6	-1.38	0.36	-3.86	0.01	25.15	0.97	-0.46	0.09	-4.83	0.01	79.04	0.71
7	-0.90	0.20	-4.50	0.01	36.30	0.94	-0.37	0.08	-4.47	0.01	83.93	0.61
8	-0.56	0.12	-4.81	0.01	52.20	0.86	-0.26	0.07	-3.58	0.01	91.06	0.41
9	-1.01	0.24	-4.30	0.01	30.38	0.95	-0.50	0.10	-4.88	0.01	68.72	0.75
10	-0.88	0.19	-4.53	0.01	43.91	0.94	-0.30	0.08	-3.92	0.01	98.97	0.48
11	-0.39	0.09	-4.62	0.01	62.82	0.74	-0.16	0.07	-2.39	0.02	93.43	0.19
12	-0.35	0.08	-4.52	0.01	60.26	0.70	-0.26	0.07	-3.58	0.01	77.87	0.42
13	-1.08	0.28	-3.91	0.01	31.45	0.93	-0.66	0.15	-4.34	0.01	58.61	0.76
14	-0.42	0.09	-4.70	0.01	65.96	0.76	-0.38	0.08	-4.47	0.01	78.55	0.62
15	-0.32	0.07	-4.39	0.01	75.04	0.64	-0.36	0.08	-4.38	0.01	78.80	0.59



**Figure 1:** Object position (panels A and C) and velocity (panels B and D) as a function of acceleration (see legend) and time. Light grey shaded bars represent occlusion, which was either 600 or 1000ms.



**Figure 2:** Group mean number of trials with reappearance position estimated to be behind expected position for the 600ms (panel A) and 1000ms (panel B) occlusion. Acceleration ( $\text{deg/s}^2$ ) is labelled as follows: -8 = black squares on black line; -4 = white diamonds on black line; 0 = white circles on black lines; 4 = white squares on grey line; 8 = grey triangles on grey line.