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/s²) 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

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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: $Tr = \alpha Ta + \theta$, where Ta is the actual arrival time of the moving object, Tr the response time between the occlusion and the response, α reflects subjective velocity perception, and θ represents the participant's state of readiness and anticipation. It has been suggested that the linear model with α less than unity (i.e., velocity is overestimated) and θ 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 position. For instance, by prematurely halting ocular pursuit of the unseen object there could have been decay in extra-retinal information regarding the object motion.

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

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

Method

Participants

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

Apparatus

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

Task and Procedure

Participants were required to make a spatial estimation regarding the reappearance position of an occluded moving object (Figure 1). Each trial began with the appearance of a green spherical object (0.6 deg diameter) located at -20 deg to the left of the participant's point of observation as they faced the monitor. After a fixed duration of 1500 ms the green spherical object changed color to red, which signalled to the participant that it would soon begin to move. Following a random foreperiod between 1650 and 1850 ms, the red spherical object moved horizontally for 600 ms from the left to 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 single level of acceleration (-8, -4, 0, +4, or +8 deg/s^2, respectively) such that object velocity at occlusion was 12.0 deg/s. With these parameters, object velocity at occlusion did not uniquely specify reappearance position and velocity, and thus had limited predictive value. However, change in velocity resulting from the outermost levels of acceleration (-8 and +8 deg/s²) during the initial 600 ms of motion was above the accepted 25 % discrimination threshold (Babler & Dannemiler, 1993; Brouwer et al., 2002). During occlusion the object continued to move, unseen, horizontally across the screen for 600 or 1000 ms. It then reappeared with a position step that was either behind or ahead (-5, -3, -1, +1, +3, +5 deg) of the veridical position had the object continued to move with the same motion properties. Using these parameters, object displacement differed as a function of object acceleration and occlusion duration (see figure 1). Moreover, the inclusion of a position step resulted in 36 different reappearance positions (i.e., 6 for the 600 ms occlusion and 30 for the 1000 ms occlusion), thus minimizing this as a cue to infer occluded object motion properties.

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

Data Analysis

For each trial, the keyboard data was used to determine whether participants estimated the actual reappearance position to be behind (left mouse click) or ahead (right mouse click) of the expected reappearance position. The number of trials estimated as “behind” and “ahead” was then calculated for each combination of object parameters. Given our data were non-normally distributed and non-independent due to the repeated measures design, we used R statistical software (R version 3.2.0, 2015) to conduct a multiple logistic regression using a generalized linear mixed model (glmer of the lme4 package for R: Bates, Maechler, Bolker, & Walker, 2014). Specifically, the estimation data were fit by maximum likelihood (Adaptive Gauss-Hermite Quadrature with 2 nodes), using a binomial distribution and log link function. Participants were uniquely identified within the dataset and modelled with a random intercept. The independent variables, reappearance step (-5, -3, -1, +1, +3, +5 deg), acceleration (-8, -4, 0, +4, +8 deg/s²) and occlusion duration (600, 1000 ms), were rescaled to a similar range, each with a mean of zero and modelled as fixed effects (main and interaction) with an intercept.

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

Results

Spatial Estimation

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.

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

Information for Spatial Estimation

Given the finding that the group data was influenced by occlusion duration, as well as the finding of variability in individual-participant intercepts, logistic regressions were conducted separately for each participant on spatial estimation data for the 600 and 1000ms occlusions. The outcome of indicated that the inclusion of either predictor resulted in a better fit than the intercept-only model in 53 of the 60 individual-participant logistic regressions. As can be seen in tables 4 and 5, the model including the difference between object reappearance position and a first-order extrapolation of object position as a predictor provided the best fit of the estimation data. Negelkerke's pseudo R^2 was greater with a first-order than second-order predictor in all participants for the 600ms and 1000ms occlusion durations. This was confirmed by subtracting the AIC value of the first-order predictor from the second-order predictor, and comparing to the distinguishable difference (i.e., >2) threshold (Burnham & Anderson, 2002). The criterion threshold was met in 14 of the 15 participants for the 600ms occlusion, and all 15 participants for the 1000ms occlusion. Notably, only P3 exhibited estimations that were no better fit by the first-order or second-order predictor than the intercept-only model. The overall performance of this participant was ranked 14th with an average number of correct responses equal to 1.43. Still, the participant who was ranked 15th (P2) exhibited spatial estimation data that was well fit by the first-order predictor. The implication is that P3 based their spatial estimations on a different predictor, or combination of predictors.

Discussion

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

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

An initial conclusion one might draw is that TPM and SPM tasks do not share the same extrapolation processes. For instance, while it has been suggested that overestimation of velocity can explain the findings in TPM tasks (for detailed consideration see Lyon & Waag, 1995), this would not account for the effects reported in SPM tasks. Wexler and Klam (2001) suggested that velocity perception is likely modulated by object speed during the initial visible period in accord the properties of a low-pass filter, and then subsequently decreases during occlusion of the SPM task. While we do not refute the idea that velocity perception could be differentially modulated by the TPM and SPM tasks, we contend that a more general principle of extrapolation is involved in these tasks. That is, despite clear differences in the stimulus features, and thus the potential extra-retinal input, occlusion of the moving object causes a contraction of the variable of interest (i.e., time in TPM and displacement in SPM). Such an approach could convey an advantage in the respect that participants would have better opportunity to correct for the initial estimation error. For example, in a task that required temporal prediction, a tendency to underestimate occlusion time would mean participants respond before the object arrives, thus giving opportunity to respond again and not suffer the consequences of being late (i.e., miss or contact). Similarly in a task that requires spatial prediction, underestimation of occlusion displacement would result in the participant’s response (e.g., pointing or reaching) being behind the veridical location. This would then require corrections in the direction of object motion, which are generally more time and energy efficient than movement reversals (Elliott, Hansen, Mendoza, & Tremblay, 2004). This general tendency to underestimate space and time is probably an adaptation to the relative inaccuracy of the processes involved in extrapolation and 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	-6.4	-5.7	-5	-4.3	-3.6
	-3	-4.4	-3.7	-3	-2.3	-1.6
	-1	-2.4	-1.7	-1	-0.3	0.4
	1	-0.4	0.3	1	1.7	2.4
	3	1.6	2.3	3	3.7	4.4
	5	3.6	4.3	5	5.7	6.4
1000 ms						
Occlusion						
	-5	-9	-7	-5	-3	-1
	-3	-7	-5	-3	-1	1
	-1	-5	-3	-1	1	3
	1	-3	-1	1	3	5
	3	-1	1	3	5	7
	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*
Full Model				
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
Reduced Model				
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 (*ΔObj-2nd*) 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.

	ΔObj-1st						*ΔObj-2nd*					
P	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 (*ΔObj-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.

	ΔObj-1st						*ΔObj-2nd*					
P	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

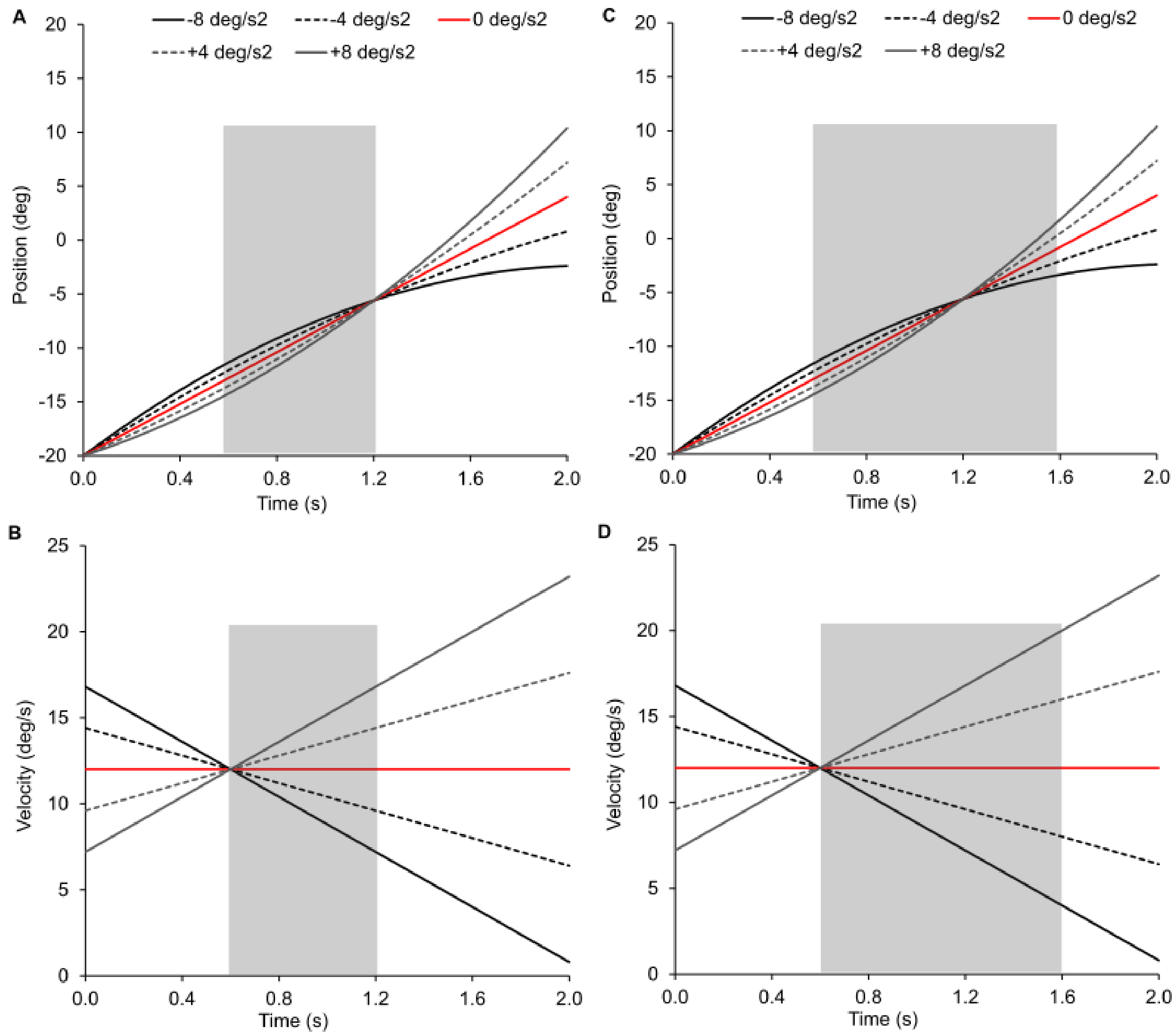

Figure 1: Object position (panels A and C) and velocity (panels B and D) as a function of acceleration (see legend) and time. Light grey shaded bars represent occlusion, which was either 600 or 1000ms.

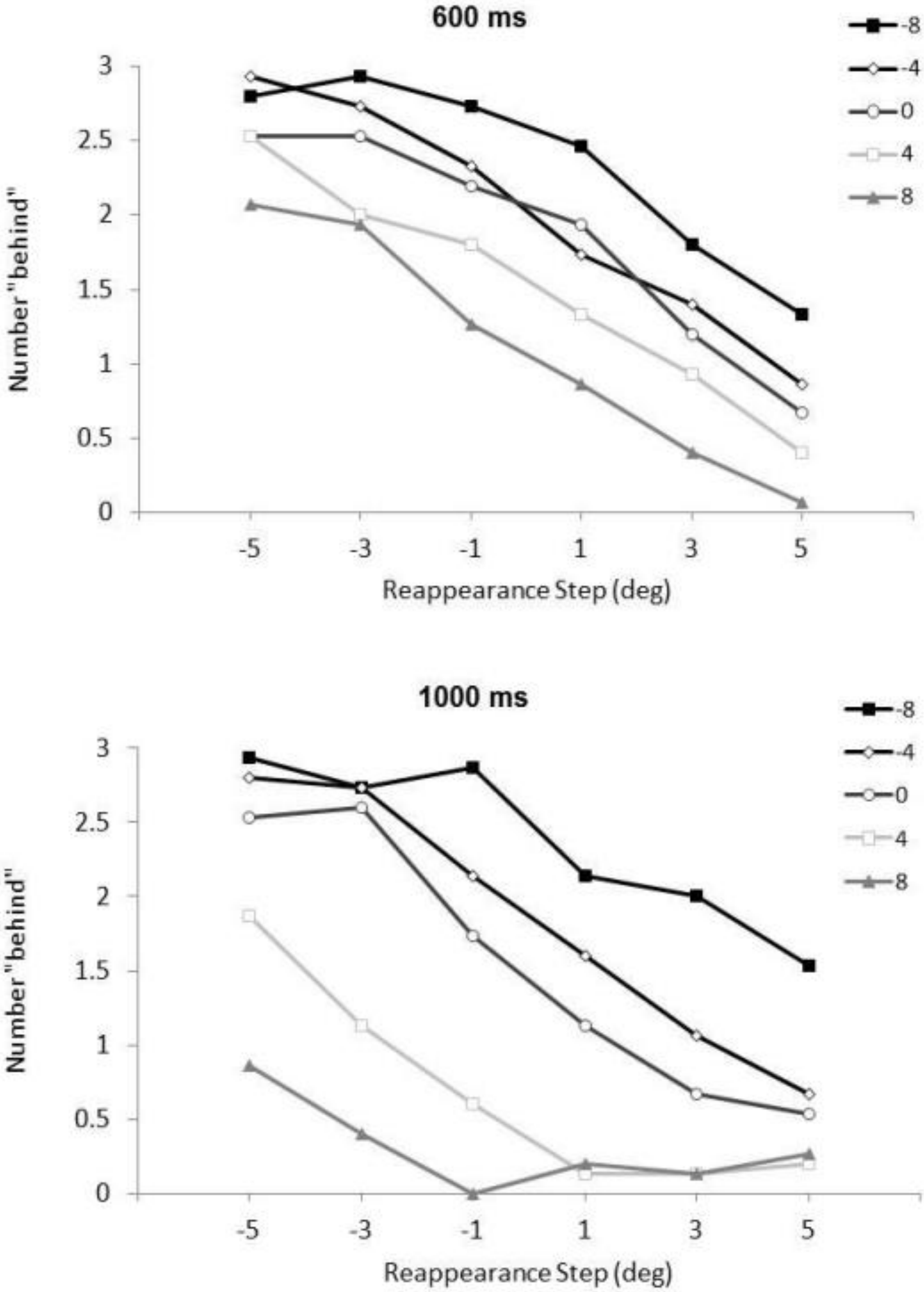

Figure 2: Group mean number of trials with reappearance position estimated to be behind expected position for the 600ms (panel A) and 1000ms (panel B) occlusion. Acceleration (deg/s²) is labelled as follows: -8 = black squares on black line; -4 = white diamonds on black line; 0 = white circles on black lines; 4 = white squares on grey line; 8 = grey triangles on grey line.