Simulated motion blur does not improve player experience in racing game

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Figure 1: *Participants in our study were asked to play the racing game,* ***Split/Second: Velocity*** *(Black Rock Studios, Disney), in the (left) absence and (right) presence of simulated motion blur. We found that the presence of simulated motion blur did not lead to significant improvements in either the objective measures of participants' performance (e.g., time to complete a race) or the subjective measures of player experience (e.g., enjoyment of race). Shown here are stills from the customized Storm Drain track used in our study.*

Abstract

Motion blur effects are commonly used in racing games [Sousa 2008; Vlachos 2008; Ritchie et al. 2010] to add a sense of realism as well as to minimize artifacts due to strobing and temporal aliasing [Glassner 1999]. Typically, motion blur computations are expensive, and for real-time applications, trade-offs are made between the quality of the effects and the computational cost. In this work, we wanted to understand: (i) the practical impact of the motion blur effect on the player experience; and (ii) whether the value gained by including the effect is worth the extra cost in computation, real-time performance, development time, etc. We studied the objective and subjective aspects of the player experience for *Split Second: Velocity* (Black Rock Studios, Disney), a high-speed racing game, in the presence and absence of the motion blur effect. We found that neither objective measures of participants' performance (e.g., time to complete a race) nor subjective measures of the player experience (e.g, enjoyment of a race, perceived speed) were affected, even though participants could reliably detect the presence of the motion blur effect. We conclude that motion blur effects, while useful for reducing artifacts and achieving a realistic 'look', do not significantly enhance the player experience.

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1 Introduction

Motion in video games is often depicted with a blur effect [Sousa 2008; Vlachos 2008; Ritchie et al. 2010]. This effect is intended to mimic the directional blurring, i.e., motion blur, that occurs in individual frames when fast-moving objects are imaged by a film or digital camera. Frame rates used in video games are usually multiples of standard refresh rates such as NTSC 59.94 fps or 29.97 fps, so each rendered frame samples the motion passing under each pixel for approximately 1/60th or 1/30th of a second. These sampling rates are not sufficient for high-speed racing games, and unless motion blur is simulated, artifacts due to temporal aliasing and strobing can occur [Glassner 1999]. Motion blur simulations also add a sense of realism by mimicking natural film [Glassner 1999], and for this reason, simulation parameters are often tuned by game artists to achieve a specific 'look'. At low frame rates (< 30 fps), simulated motion blur improves the jerky appearance of games and reduces the nausea that some players experience. Despite these many benefits, users of gaming forums report that the motion blur effect can be distracting and that it can slow down the game engine.

In this work, we examine the perceptual role and the practical impact of the motion blur effect in racing games. Recent work has considered the perception of motion-blurred renderings [Navarro et al. 2011b], albeit at the level of mechanical rendering features such as object material and shutter speed. We want to understand how and to what degree simulated motion blur affects players' experience of the game. By understanding more precisely which aspects of motion-blurred renderings players care about, one can guide the design of motion blur effects appropriately. This has been performed in an initial form by Navarro *et al.*, but not at the level of overall assessments of the player experience [2011b].

The design of motion blur effects involves a careful balance between physical accuracy, real-time performance, computational complexity, and benefit to players. Advanced features, such as higher-order motion blur [Bowles et al. 2012] and handling of disocclusions [McGuire et al. 2012], enable accurate rendition in real time but at the cost of increased computational complexity. It is useful to understand whether these advanced features benefit players' experience of the game or if they go unnoticed. The tradeoff between physical accuracy and gameplay benefit is hotly debated [Adams 2007; Shelley 2001]; our work addresses this issue directly by measuring the practical impact on player experience.

2 Related Work

We will now briefly review prior work in human vision on the phenomenon of motion blur and in computer graphics on the depiction of motion blur.

2.1 Human perception of motion blur

Humans do not experience motion blur in the same way as cameras because: (i) there is no fixed rate at which the human visual system samples the world; (ii) the visual system analyzes motion by integrating light both in space and time unlike cameras that integrate light only in time [Burr and Thompson 2011]; and (iii) in real life, we actively track moving objects with pursuit eye movements unlike cameras that passively record the scene in front of them. For these reasons, we do not see moving objects as being blurry (although, we do experience motion smears and streaks [Burr 1980; Geisler 1999]). Our experience of the motion blur phenomenon comes mainly from exposure to still photography and films [Glassner 1999], and it is a visual effect that we have come to expect in CG-generated scenes [Rosado 2007].

Most work on the perception of motion-blurred images has considered restricted stimuli like sinusoidal gratings and moving dots [Burr and Thompson 2011]. As a result, little is known about the perception of motion-blurred images that look like scenes in the real world. Recent work by Navarro and colleagues aims to fill this gap in our understanding by studying complex stimuli like checkerboard-patterned spheres [2011b]. Navarro *et al.* tested the influence of rendering features like object material, object speed, shutter speed, and anti-aliasing level for motion-blurred renderings of rolling spheres. Their motion blur effect was simulated by offline, non-interactive distributed ray tracing, and they were able to precisely identify the relationship between the rendering features and the perceived quality of the motion blur effect.

Our work differs from Navarro *et al.*'s in several ways [2011b]. Our goal is to understand how the presence vs. absence of simulated motion blur affects the overall gaming experience rather than how rendering features influence the quality of simulated motion blur. This is why we study motion blur in the context of a racing game, which involves more realistic scenes and object motions, and the primary task for our participants is playing the game, not judging the quality of the motion blur effect. Finally, their motion blur effect is presented non-interactively unlike ours [Ritchie et al. 2010], which makes it harder to compare their findings to ours.

2.2 Motion blur rendering

When rendering motion blur, one must combine contributions from all movements of textured geometry under each pixel for the duration of a frame. In single-frame buffer rasterization rendering on GPU, between 2 to 16 discrete samples have to be processed per pixel to achieve a basic quality motion blur effect [Mitchell 2001]. Advanced techniques have been developed to reuse samples in a fraction of frame time [Bowles et al. 2012]. Such techniques are limited, however, when visibility changes during a frame, and further techniques have been developed to deal with this visibility issue in real time [Yang and Bowles 2012]. A detailed discussion of these various techniques is beyond the scope of this work, and we refer interested readers to an excellent review of state-of-the-art techniques [Navarro et al. 2011a].

The motion blur effect studied in this work is the one published in the video game, *Split Second: Velocity* [Ritchie et al. 2010]. Ritchie *et al.*'s technique for rendering motion blur initially follows standard image space velocity field blur techniques [Rosado 2007]. An efficient coding of rigid body motions enables the representation of motions of multiple objects traveling in different directions. Given the intense geometries and animations in the racing environments of the game, a method for combining image space velocity field with texture space blur [Loviscach 2005] through anisotropic sampling of the texture mip chain in the velocity directions is employed. This method is needed to reduce sample bound blur artifacts common in image space only blur methods. As only a single source sample frame is used, this method is not robust to disocclusions. In practice, the velocity field of a racing game is such that disocclusions occur infrequently, and further measures are applied to mitigate their presence [Ritchie et al. 2010].

3 Experiments

We conducted five experiments to measure the influence of simulated motion blur on the gaming experience. In all experiments, we used high-speed racing scenarios from the game, *Split Second: Velocity* (Black Rock Studios, Disney). Participants were asked to play the game, and objective measures of their performance (e.g., time taken to complete a race) and subjective measures of their gaming experience (e.g., satisfaction with their performance on a race) were recorded. Each participant played a fixed number of races (see Table 1). In Experiments 1, 2, 3, and 5, the independent variable was the presence of simulated motion blur. In half the races, motion blur simulations were used (ON condition) and in the other half, motion blur simulations were not used (OFF condition). In Experiment 4, the independent variable was the straight-line acceleration of the racing car. In half the races, the acceleration was set to the default, as-shipped values (LOW condition) and in the other half, it was set to a higher value to increase the difficulty of the game (HIGH condition).

A total of 68 participants (13 females and 55 males, ages 18-35 years) took part in our study. The gender ratio of our participant pool reflected the demographics of the local student population. All participants gave informed consent, and they were monetarily compensated for their time. We screened our participants for previous gaming experience, and a new set of participants was recruited for each experiment. All experiments took up to an hour to complete, and all experimental procedures were approved by an Institutional Review Board.

Participants were seated in well-lit room in front of a 52-inch SONY KDL-52NX800 television monitor that was connected via an HDMI cable to a Microsoft Xbox 360 development kit. The game was launched using a proprietary build provided by Black Rock Studios, and game settings were controlled by an external computer connected to the Xbox. Participants sat approximately 1.6 m from the monitor ($43.1^\circ \times 27.6^\circ$ visual angle, 29.97 fps), and they were encouraged to assume a comfortable gaming posture. Participants were allowed up to three practice races before each experiment to become familiar with the game. The difficulty level at which the game was played was chosen during the practice and stayed the same for the duration of the experiment. Note that our within-subjects design does not require all participants to play at the same difficulty level. After each race, participants rated their qualitative impressions of the gaming experience (see Table 1). To capture quantitative information about their driving performance, the game was set up to log the speed of the car every five seconds and the time it took to complete each lap. For some of the experiments, the number of crashes and scrapes with the sides of the track were also logged.

	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5
Independent variable	Motion blur	Motion blur	Motion blur	Acceleration	Motion blur
# Participants	8	15	11	11	23
# Races per participant	4	8	12	12	12
# Laps per race	3	3	3	3	3
Track	Airport	Storm Drain	Storm Drain	Storm Drain	Storm Drain
Competitive	✓	✗	✗	✗	✗
Power plays	✓	✗	✗	✗	✗
Straight-line acceleration	0.5	0.09	0.09	0.09, 0.5	0.5
Motion blur setting	Off, Default	Off, Default	Off, Default	Off	Off, Default
Post-race question about enjoyment of race	✓	✓	✓	✗	✓
Post-race question about satisfaction with performance	✓	✓	✓	✗	✓
Post-race question about focus during race	✓	✓	✓	✗	✓
Post-race question about motion blur	Realism	Image Quality	Blurriness	Blurriness	Blurriness
Post-race questions about perceived speed	✗	✓	✓	✓	✓
Post-race question about ease of handling	✗	✗	✗	✓	✓
Post-experiment question about blur consistency	✗	✗	✓	✓	✓
Per-race position (e.g., 1^{st}, 2^{nd})	✓	✗	✗	✗	✗
Per-race highest speed	✓	✓	✓	✓	✓
Per-race completion time	✓	✓	✓	✓	✓
Per-race number of crashes	✗	✓	✓	✓	✓
Per-race number of scrapes	✗	✗	✗	✓	✓

Table 1: *Experimental settings, subjective measures of gaming experience, and objective measures of performance used in our study*

3.1 Experiment 1

We started by testing the influence of simulated motion blur under standard settings of gameplay. Participants were asked to play four races each on the Airport track, as shown in Figure 2a. This track included competing cars, which were simulated by the game AI, as well as 'power plays' that allowed track alterations (e.g., short cuts, obstacles) during the race. In addition, the Airport track included visual effects such as shadows and particles and visual clutter in the form of on-screen text displays (e.g., position in race, power levels) and colliding objects (e.g., a taxiing airplane, a falling crane). In half the races, the motion blur settings were set to default values (ON), and in the other half, the motion blur settings were disabled (OFF). The order of ON and OFF races was counterbalanced between participants.

Eight participants (1 female) completed Experiment 1. After each race, participants answered questions about their enjoyment of the race, satisfaction with their performance, focus during the race, and the realism of the visuals using 5-point scales. Higher ratings corresponded to positive experiences (e.g., 5 = very enjoyable / very satisfied / very focused, 1 = very unenjoyable / very unsatisfied / very unfocused) and realistic visuals (e.g., 5 = very realistic, 1 = very unrealistic). The first three questions were designed to capture overall impressions whereas the fourth question was designed to reveal participants' perception of the motion blur effect. Although the visual appearance of the track behind the car was noticeably different in the ON and OFF races, we did not want to draw attention to that fact in our questioning. Therefore, we asked a general question about the realism of the visual environment. To obtain objective measures of performance, we recorded the position at the end of the race and the completion time.

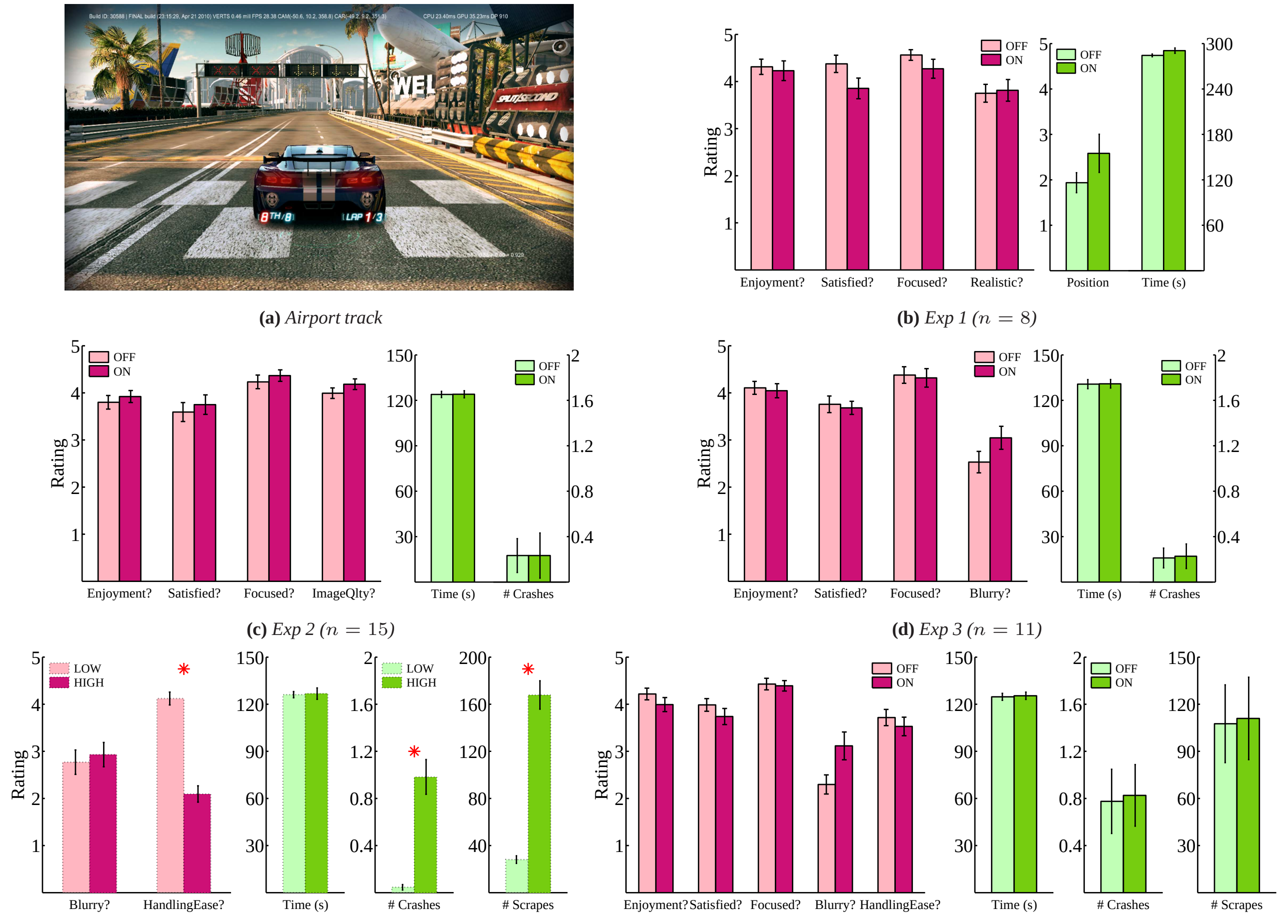
The ratings and performance measures for Experiment 1 are plotted in Figure 2b. A repeated measures MANOVA test was conducted with one within-subjects factor, motion blur setting, and six dependent variables: four ratings and two performance measures. The results showed that there was no significant difference in the dependent variables for the ON and OFF races ($F(6,2) = .78, p = .66, \eta^2 = .7$). Univariate tests also indicated that there was no effect of the motion blur setting on enjoyment ($F(1,7) = .12, p = .74, \eta^2 = .02$), satisfaction ($F(1,7) = 2.53, p = .16, \eta^2 = .27$), focus ($F(1,7) = 1.72, p = .23, \eta^2 = .2$), realism ($F(1,7) = .1, p = .76, \eta^2 = .01$), position ($F(1,7) = 2.75, p = .14, \eta^2 = .28$), and completion time ($F(1,7) = 3.41, p = .11, \eta^2 = .33$).

3.2 Experiment 2

Next, we tested the influence of simulated motion blur under reduced settings of gameplay. It is plausible that under default settings, there are too many distractions for the participants to notice the motion blur effect. To test this reasoning, we created a reduced version of the game by customizing the Storm Drain track, as shown in Figure 1. We chose this track for its simple design; it is a short, oval closed loop. We removed the competitive aspect of the game by disabling all other cars on the track. In addition, we reduced visual clutter by disabling shadows, particles, colliding objects, and on-screen text displays. The only text visible during the race was a brief message informing participants of the lap they were in. This message was displayed after each lap and disappeared after 3 seconds. Finally, all game sounds were disabled to allow participants to focus on the visual gaming experience.

Fifteen participants (0 females) completed Experiment 2. They were asked to play eights races each. As in Experiment 1, motion blur settings were disabled (OFF) in half the races and set to default values (ON) in the remaining races. The order of OFF and ON races was counterbalanced between participants. After each race, participants used 5-point scales to answer questions about their enjoyment of the race, satisfaction with their performance, focus during the race, image quality during the race, the highest perceived speed during the race, and the highest perceived speed of the current race relative to the previous race. The first three questions were identical to those used in Experiment 1. The fourth question was modified from Experiment 1 to draw attention to the simulated motion blur. The last two questions were designed to reveal the influence of simulated motion blur on the perception of speed in the game [Rosado 2007]. There were three objective measures of performance: completion time, the number of crashes during the race, and the highest speed during the race. Note that gravity in the game differs from that in the real world, and therefore, ratings of perceived speed (in mph) cannot be directly compared to actual speeds in the game (in game speed unit).

The results of Experiment 2 are shown in Figures 2c, 3, and 4. A repeated measures MANOVA was conducted with one within-



(a) *Airport track* **(b)** *Exp 1 ($n = 8$)* **(c)** *Exp 2 ($n = 15$)* **(d)** *Exp 3 ($n = 11$)* **(e)** *Exp 4 ($n = 11$)* **(f)** *Exp 5 ($n = 23$)*

Figure 2: *Participants played the game in either (a,b) the Airport track with default game settings or (c-f) the Storm Drain track with reduced game settings. Subjective measures of gaming experience (pink bars in b,c,d & f) did not differ significantly for the two motion blur settings that were tested. Higher ratings correspond to positive responses to the questions (e.g., 5 = very satisfied, 1 = very unsatisfied). Objective measures of performance (green bars in b,c,d & f) also did not differ significantly for the two settings. (e) When we tested two settings of acceleration in the absence of motion blur, we found significant effects for both subjective measures of gaming experience and objective measures of performance. Error bars correspond to 1 s.e.m.*

subjects factor, motion blur setting, and eight dependent variables: five ratings and three performance measures. There was no significant difference in the dependent variables for the ON and OFF races ($F(8,7) = .44, p = .86, \eta^2 = .33$). Univariate tests also indicated that there was no effect of the motion blur setting on enjoyment ($F(1,14) = .85, p = .37, \eta^2 = .06$), satisfaction ($F(1,14) = .48, p = .5, \eta^2 = .03$), focus ($F(1,14) = 1.37, p = .26, \eta^2 = .09$), image quality ($F(1,14) = 1.53, p = .24, \eta^2 = .1$), highest perceived speed ($F(1,14) = .09, p = .76, \eta^2 = .01$), completion time ($F(1,14) = 0.03, p = .86, \eta^2 = .002$), number of crashes ($F(1,14) < .001, p \approx 1, \eta^2 < 0.001$), and actual highest speed ($F(1,14) = 1.2, p = .29, \eta^2 = 0.08$).

3.3 Experiment 3

Ratings of realism and image quality in previous experiments did not reveal whether participants noticed the visible changes caused by the presence of simulated motion blur. To address this issue, we repeated Experiment 2 with slight modifications: (i) after each race, participants rated the blurriness of the track behind the car on a 5-point scale; and (ii) at the end of the experiment, participants were asked if the track behind the car had been consistent in its visual appearance. By drawing participants' attention to the regions where the influence of simulated motion blur was most visible, we wanted to ensure that participants were aware of the experimental manipulation.

Eleven participants (3 females) completed Experiment 3. They played twelve races each, and as in the previous experiments, motion blur was turned on for half the races (ON) and off for the rest (OFF). The order of ON and OFF races was counterbalanced between participants. The results of Experiment 3 are shown in Figures 2d, 3, and 4. A repeated measures MANOVA was conducted with one within-subjects factor, motion blur setting, and eight dependent variables: five ratings and three performance measures. There was no significant difference in the dependent variables for the ON and OFF races ($F(8,3) = .24, p = .95, \eta^2 = .39$). Univariate tests also indicated that there was no effect of motion blur setting on enjoyment ($F(1,10) = .31, p = .59, \eta^2 = .03$), satisfaction ($F(1,10) = .22, p = .65, \eta^2 = .02$), focus ($F(1,10) = .22, p = .65, \eta^2 = .02$), blurriness of the track behind the car ($F(1,10) = 2.79, p = .13, \eta^2 = .22$), highest perceived speed ($F(1,10) = .12, p = .74, \eta^2 = .01$), completion time ($F(1,10) = .17, p = .69, \eta^2 = .02$), number of crashes ($F(1,10) = .04, p = .84, \eta^2 = .004$), and actual highest speed ($F(1,10) = .91, p = .36, \eta^2 = .08$). While there was no signif-

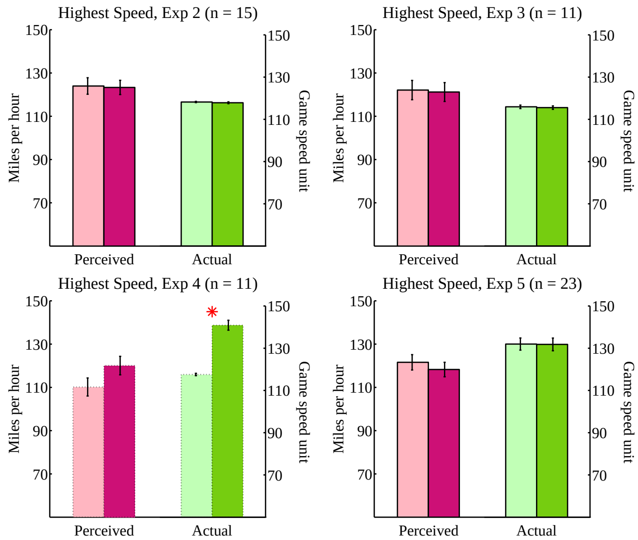


Figure 3: *In Experiments 2 through 5, participants rated the highest perceived speed during the race on a 5-point scale. Their speed ratings (pink bars) did not differ significantly for the two settings of the independent variable – motion blur in all experiments (OFF = lighter bar, ON = darker bar) except Experiment 4 (LOW = lighter bar, HIGH = darker bar). The objective measure of the highest speed during a race (green bars) also did not differ significantly for the two settings in all experiments except Experiment 4. Error bars correspond to 1 s.e.m.*

icant effect of the motion blur manipulation on per-race blurriness ratings, 10 out of 11 participants said that they noticed inconsistencies in the visual appearance of the track behind the car during the experiment. This result indicates that participants were aware of the experimental manipulation even if they could not pinpoint the races where the motion blur was on vs. off.

3.4 Experiments 4 & 5

Despite being aware of the experimental manipulation, participants in Experiment 3 did not experience the game differently or perform differently in the two motion blur settings. It is plausible that the measures we used were not the right ones; perhaps, the presence of motion blur does not affect broad impressions of enjoyment or highest speed, but it might affect participants' ability to control the car. In Experiments 4 and 5, we measured the ease of handling the car in the following way. We increased the straight-line acceleration of the participant's car to make it easier to achieve higher speeds at which it is harder to control the car. In Experiment 4, we tested two settings of acceleration, 0.09 (the value used in Experiments 2 and 3) and 0.5, to establish the increased difficulty of navigating the Storm Drain track. In Experiment 5, we used the higher value of acceleration, 0.5, to study the influence of simulated motion blur on the ability to control the car.

Eleven participants (2 females) played twelve races each in Experiment 4. The acceleration was set to 0.09 (LOW) in half the races and to 0.5 (HIGH) in the rest. The motion blur effect was disabled for all races. After each race, participants rated the blurriness of the track behind the car, highest perceived speed, highest perceived speed relative to the previous race, and the ease of handling the car using 5-point scales. As in Experiment 3, they answered the question about the consistency of track appearance at the end of the experiment. The objective measures of performance comprised completion time, the number of crashes, the number of scrapes with the sides of the track, and actual highest speed during the race.

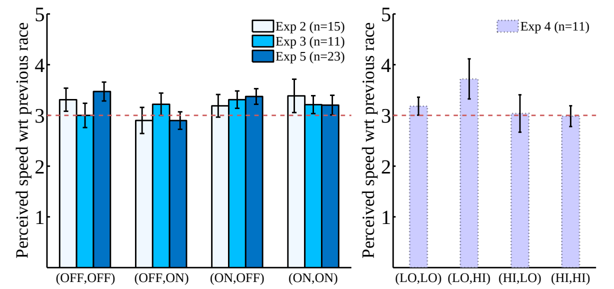


Figure 4: *In Experiments 2 through 5, participants rated the highest perceived speed in the current race relative to the previous race on a 5-point scale. Their relative speed ratings are shown for all combinations of (left) motion blur and (right) acceleration settings for the previous and current races (e.g., OFF,ON indicates OFF$_{prev}$,ON$_{curr}$). Higher ratings indicate faster relative to previous race (i.e., 5 = much faster, 1 = much slower). If there was an influence of the independent variable, then the ratings when the setting did not change from previous to current race would differ from the ratings when the setting did change. As one can observe, the ratings did not differ significantly from the 'neither faster nor slower' level in all cases. Error bars correspond to 1 s.e.m.*

The results of Experiment 4 are shown in Figures 2e, 3, and 4. A repeated measures MANOVA revealed a significant effect ($F(7, 4) = 170.8, p < 0.001, \eta^2 = .997$) of the acceleration setting on seven dependent variables. Univariate tests indicated: (i) a significant effect of the acceleration setting on the ease of handling ($F(1, 10) = 118.6, p < 0.001, \eta^2 = .92$), the actual highest speed ($F(1, 10) = 140.4, p < 0.001, \eta^2 = .93$), the number of crashes ($F(1, 10) = 35, p < 0.001, \eta^2 = .78$), and the number of scrapes ($F(1, 10) = 165.2, p < 0.001, \eta^2 = .94$); (ii) a trend towards significance for blurriness ($F(1, 10) = 7.57, p = .02, \eta^2 = .43$); and (iii) no effect on highest perceived speed ($F(1, 10) = 1.34, p = .08, \eta^2 = .27$) and completion time ($F(1, 10) = 2.34, p = .74, \eta^2 = 0.01$). At the end of the experiment, only 5 out of 11 participants said that they noticed inconsistencies in the track appearance behind the car. These results establish that the higher acceleration setting made it significantly harder to control the car. Although the outcome of Experiment 4 is not surprising, it validates the use of the higher acceleration setting in Experiment 5.

Twenty-three participants (7 females) completed Experiment 5, which used the higher acceleration setting from Experiment 4 and the design of Experiment 3. Participants answered one additional question in Experiment 5 regarding the ease of handling the car, and one additional measure of performance, the number of scrapes, was recorded. The results of Experiment 5 are shown in Figures 2f, 3, and 4. A repeated measures MANOVA found no effect of the motion blur setting on eight dependent variables ($F(8, 15) = 1.3, p = .31, \eta^2 = .41$). Univariate tests indicated: (i) a trend towards a significant effect on blurriness ($F(1, 22) = 9.88, p = .005, \eta^2 = .31$) and enjoyment ($F(1, 22) = 6.56, p = .02, \eta^2 = .23$); and (ii) no effect on satisfaction ($F(1, 22) = 3.34, p = .08, \eta^2 = .13$), focus ($F(1, 22) = .28, p = .6, \eta^2 = .01$), ease of handling ($F(1, 22) = 3.18, p = .09, \eta^2 = .13$), completion time ($F(1, 22) = 2.4, p = .14, \eta^2 = .1$), number of crashes ($F(1, 22) = .36, p = .56, \eta^2 = .02$), and number of scrapes ($F(1, 22) = .45, p = .51, \eta^2 = .02$). At the end of the experiment, 15 out of 23 participants reported noticing inconsistencies in the track appearance behind the car. Taken together, these results indicate that participants were aware of the motion blur manipulations, but their performance and their experience of the game, in particular, their ability to control the car, did not depend on the motion blur setting.

4 Discussion

We examined the influence of simulated motion blur under standard and reduced settings of gameplay, under low and high settings of acceleration, and under direct and indirect questioning about motion blur. We found that the motion blur effect in *Split Second: Velocity* has no significant influence on overall impressions of the race, assessed in terms of reported enjoyment, satisfaction, and focus, or on participants' performance, assessed in terms of completion time, number of crashes, and the highest speed attained in a race. The motion blur effect is noticeable only by its presence or absence; participants can reliably detect the visual changes associated with the effect.

In fast-paced racing games like *Split Second: Velocity*, there are many forceful imaging effects (e.g., explosions) and visual cues (e.g., receding landscape on the sides of the track) that can overwhelm a player with information s/he needs to proceed in the game. In this scenario, motion blur is a supplementary effect that does not determine the outcome of a race. It is possible that visual behavior is modified in the presence of the motion blur effect, but such measurements (e.g., fixation locations, fixation durations) are beyond the scope of the present study. Perhaps, a scenario that includes the awareness of eye movements in the rendering loop would yield a fundamental validation of the motion blur effect. Such a scenario would require a display device that can measure eye movements precisely, which is beyond current hardware capability.

We recorded participants' responses after an entire race of interactive play. We leave it to future work to examine the influence of the motion blur effect on individual actions during a race, such as braking, overtaking, and accelerating round a curve. Studying the gaming experience and participants' performance at the level of individual actions may yield different results than our study. Certain game genres that require extreme reaction times (e.g., *Super Hexagon* by Terry Cavanagh) may reveal a significant role of motion blur in determining participants' performance. Of course, one can contrive gameplay where judging speed by looking at the length of motion blur streaks is necessary to achieve a precise motor bike jump. *Blockade* (Gremlin) and *Tron Light Cycles* (Bally Midway) may be viewed as primitive and exaggerated forms of this proposal where motion trails integrate directly with gameplay mechanics. When the motion blur effect is an essential element of game design, variations in the blur/trail effect are likely to be significant to the player.

It is interesting to consider the case of high frame rate ($>$ 100 fps) capable display standards [Salmon et al. 2011]. It has been suggested that higher frame rates may require more perceptual accuracy in the rendering of motion blur because the higher sampling rates are consistent with the duration of motion smears that are experienced by humans [Burr 1980]. It is plausible that the role of simulated motion blur will be greater at these higher frame rates than at standard frame rates. Finally, it is important to note that the commercial competitiveness of visual effects can often warrant their inclusion in a game independent of their contribution to gameplay. A visual effect like motion blur contributes to game aesthetics, and the aesthetic criterion may be sufficient for deciding whether to include it in a game.

5 Conclusion

We tested if the presence of simulated motion blur [Ritchie et al. 2010] affects the overall player experience for *Split Second: Velocity*. Our findings show that the motion blur effect is not essential to the *Split Second: Velocity* experience, but they do not preclude a significant role for simulated motion blur in other gaming scenarios.

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