Effects of View, Input Device, and Track Width on Video Game Driving

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ABSTRACT

Steering and driving tasks – where the user controls a vehicle or other object along a path – are common in many simulations and games. Racing video games have provided users with different views of the visual environment – e.g., overhead, first-person, and third-person views. Although research has been done in understanding how people perform using a first-person view in virtual reality and driving simulators, little empirical work has been done to understand the factors that affect performance in video games. To establish a foundation for thinking about view in the design of driving games and simulations, we carried out three studies that explored the effects of different view types on driving performance. We also considered how view interacts with difficulty and input device. We found that although there were significant effects of view on performance, these were not in line with conventional wisdom about view. Our explorations provide designers with new empirical knowledge about view and performance, but also raise a number of new research questions about the principles underlying view differences.

KEYWORDS: View, driving perspective, game design, steering.

INDEX TERMS: H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

1 INTRODUCTION

Many games, simulations, and desktop virtual environments involve tasks where users must maneuver a vehicle, avatar or a pointer along a path. In a racing game, for example, the user steers a car around a track, going as quickly as possible without leaving the roadway.

Games and other systems support steering tasks by providing visual feedback – the visual representation of the vehicle and/or roadway – through images presented on a screen in front of the user. Unlike driving in the real world or in virtual reality simulations, there are many possible views of the environment that can be presented: first-person views, as would occur in a real car; third-person views from behind the car; or overhead views, which look down on the car from above. Different video games have used various views (see Figure 1), and there exists conventional wisdom that suggests certain views are better for certain scenarios. For example, Wikipedia states that for realistic racing simulator-type games, "driving views […] are arcade [i.e., third-person]. This softens the learning curve for the difficult handling characteristics of most racing cars [26]." In many games of other genres, like the first-person shooter series *Halo,* avatars are controlled (steered) in first-person view, while the game switches to a third-person view for vehicle driving elements. These examples suggest that for steering a vehicle, third-person view is best. However, in other games, such as *World of Warcraft*, players are provided with several preset camera positions or have fine control over camera position. This allows the player to select their preferred view for steering their avatar. This suggests that designers may not be clear on whether there is a 'best' view for steering and driving in different game scenarios.

Namco *Monaco GP*, 1979 | Sega *Pole Position*, 1982

Sony *Gran Turismo*, 1998 | Sony *Gran Turismo 5*, 2007

Figure 1. Driving games with different views.

The video game industry is now extremely large, with sales over $10 billion per year in the US alone (starting in 2008). Racing games, which typically involve driving a vehicle around a track, account for roughly 7% of all sales [23]. Although view is an important design choice in many different video game genres, there is little empirical research comparing different view types. To gain a basic understanding of how view affects performance, and how view interacts with other important factors in video game driving, we carried out three studies.

We compared the effects of view type (first-person view, third-person view, and overhead view) on performance in a simple driving system. In the first study, we tested the effects of view with different road widths (which make the driving task more or less difficult). In the second study, we examined whether performance with different views is influenced by input device (steering wheel, mouse, or game controller). In the third study, we examined the effect of a view's *visible forward distance* as an underlying performance principle. In addition to collecting performance and preference data, we used an eye tracker to determine where on the screen people were looking. Results show that view is an important factor in driving performance, but these effects are not always in line with the conventional wisdom that third-person view is best for driving vehicles in games.

Seven main findings provide a foundation for understanding view in steering games:

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- Performance with overhead views is significantly worse than with first-person or third-person views.
- We found no performance differences between first-person and third-person views, in any study.
- There is a minor interaction between view and track width: the disadvantage of overhead views increases for narrower tracks.
- There are significant performance differences between the input devices used to control steering; surprisingly, the steering wheel was *not* the best device.
- We found a strong interaction between view and input device: performance with the game controller's thumbstick was much less affected by view than the other devices.
- There were significant differences in the way that participants rated the views and the input devices, but these did not correlate strongly with performance.
- The amount of a view's forward distance was *not* found to be a main cause of the performance differences between overhead and other views, and eye-tracker analysis shows that people do not make use of increased forward distance in overhead views.

These results provide a valuable empirical foundation for thinking about view in steering-based games. In addition, our studies also raise a number of new research questions about why there are performance differences between views, the perceptual effects of different views, the physical characteristics of input devices for steering, and the eye gaze behavior in different views.

2 RELATED WORK

We review three areas of related research: steering (in the real world and in 3D environments), views, and controls.

2.1 Driving and Steering

Our review of the literature has not shown a clear distinction between the acts of 'steering' and 'driving'. However, steering has more generally referred to guiding the movement of any object (e.g., a cursor), whereas driving has been used for describing the control of vehicle movement (most often a real or virtual car).

2.1.1 Models of Steering and Driving

Initial HCI research into steering control was carried out by Accot and Zhai, who showed that Fitts' Law [13] models crossing-based gestures in which users must pass through a 1D target [1]. They extended this idea to a tunnel steering task (moving along a constrained-width path), showing that the task can be modeled as an infinite number of single crossing tasks. The steering law [1] is defined as:

$$MT = a + b \times \frac{A}{W} \qquad (1)$$

with movement time *MT*, *a* and *b* empirically determined constants, the length of the track *A* (amplitude), and the width of the track *W*. The difficulty of the steering task, referred to the *index of difficulty* (ID), is described by the ratio of the amplitude divided by width. The steering law has since been used to model selection times for different input devices [2] and for cascading pull-down menus [3]. Researchers have also used the steering law to model performance of simulation driving, demonstrating that first-person views in VR driving adheres to the steering law [29].

Two driving models [7][18], which predate work on the steering law, predict performance as functions that include track width and angular accuracy of movement. They differ in that one [18] models instantaneous maximum safe driving speed, and includes car dimensions and the driver's reaction time as model components, while the other [7] predicts the time to complete a track and includes factors for track length, sampling interval, and a safety constant.

2.1.2 Eye Gaze in Driving

Work on human factors in real-world driving and in simulators has found that where a driver looks affects their ability to perform. Land and Lee found that drivers "rely on the tangent point on the inside of each curve [11]." Wilkie and Wann [27] found that drivers fixate mostly on the center of the road, and that they performed better without a fixed gaze point. Land and Horwood [12] experimented with the forward distance available to drivers, finding that drivers make rapid and discrete steering movements, rather than smooth continuous ones, with short view distances. Salvucci and Gray [21] proposed a two-point model of steering, where drivers focus on a far point (10-20m) to predict upcoming turns, and on a near point (0-8m) to stay within their lane. In a simulated driving study, it was found that participants reported they looked farther ahead on the road with wider tracks and closer to the car with narrower tracks [29].

2.2 Views

A *view* of a 3D world is the 2D projection of the world presented to the user. It is entirely defined by the camera's location, angle, and field of view (FoV). A first-person view places the camera where the user's eyes would be in the virtual environment. A third-person view moves the camera away from the object of control (e.g., the avatar or car), and often increases the angle of the camera to reduce occlusion. View affects many aspects of interaction, but there has been relatively little research into the effects of view on locomotion in 3D environments.

Effective 3D workspace navigation has been well investigated (e.g., [8][14][24]). These techniques attempt to support effective movement through a 3D world, often using only a first-person view. Navigation of real-world tele-operated vehicles can be improved by widening the FoV [17]; however, when this is not possible, providing a third-person view may facilitate certain aspects of navigation.

Research has shown that males and females navigate differently in both real and virtual worlds, with males outperforming females. This difference can be mitigated by providing a larger FoV [5], which increases women's performance without negatively affecting men's. Other research [25] showed that optical flow better supported 3D virtual world navigation, and provided users with more support for building a mental map of the environment. Rouse [19] argued that first-person perspectives provide a better sense of player immersion because players can associate more closely with the character (in a sense, they *are* the character). Salamin et al. [20] showed in an augmented reality experiment that different views better support certain tasks. For example, manipulations occurring near the participant are better supported by first-person perspectives, whereas displacement and interactions with moving objects are better supported by third-person perspectives. None of this prior research, however, investigates the effects of view and related factors in video game driving performance.

2.3 Controls

Hinckley describes an input device as the combination of a physical sensor, feedback, design, and the hardware and software that comprises the interaction technique [9]. Important factors of an input device include the resolution, the sampling rate, the control-to-display ratio, and the number of dimensions sensed by the device, among others. Another important aspect of an input device is that of the type of motion: for example, whether the input device provides linear or rotary input, as described by Jacob [10].

Driving a car on a track has two main control components: speed and direction. There are two main approaches for directional control: controlling the rate of turn of an object (*turn rate*); or by controlling *absolute direction* (each position of an input maps directly to an absolute heading of the object on the screen). Devices are controlled by different limbs, and each limb enables a different rate of information throughput (also called ‘bandwidth’, measured in bits/second). Balakrishnan and MacKenzie showed that unsupported fingers provide 3.15 bits/s, the wrist 4.08 bits/s, and the forearm 4.14 bits/s [4], which is substantially lower than previous research.

We use three car steering devices in this paper: thumbstick, mouse, and steering wheel. These devices differ by the muscle groups required (thumb, wrist, or entire arm), their resolutions, the number of dimensions sensed, the type of motion (rate or absolute), and whether they are *self-centering* (i.e. whether they return to the middle of their range when the control is released).

3 METHODS

3.1 Apparatus

We built a custom 3D environment to test steering performance in a simple driving task. The environment positioned a simple car model (1m wide by 2m long) on a 360m S-shaped track (Figure 2). The system allowed us to manipulate the camera position, while keeping the driving task the same. We could also manipulate other factors of interest, such as input device and task difficulty (by adjusting track width). The game was built in Python using a modified version of VPython (vpython.org), a 3D graphics module. PyGame (pygame.org) was used to interface with different input devices. The system ran on an Intel quad-core i7 machine with a 24” Tobii T60XL monitor and eye tracker.

3.1.1 Track

Previous studies of steering models used either straight tracks or circular tracks with a constant curvature [29]. All of our studies used the same S-shaped track, to provide a more representative task. The track was dark grey in a large green field. To help provide feedback on car speed, conical green trees were set at regular intervals around the contour of the track, and a dashed green line down ran down the track center. The line was colored green rather than the traditional yellow or white to reduce negative transfer effects from real-world roads that may be associated with yellow or white lines. The track was 360m long, and consisted of a 100m straight section, a 30m right-hand curve (resulting in a 90° turn), another 100m straight section, a 30m left-hand curve (another 90° turn), and a final 100m straight section.

3.1.2 Speed Control

Car speed was controlled via the right pedal of a Logitech MOMO Force pedal set. To simplify the controls, the brake pedal was unused; the absolute speed of the car was controlled by the level of depression exerted on the pedal. If the pedal was depressed all the way the car would travel at its full speed instantly, and if the pedal was released, the car would instantly stop. While this was a non-traditional control scheme, it proved simple for participants to control and in pilot tests participants had no trouble learning and using it. We set the maximum speed to 540km/h in all conditions; in pilot studies, we found this maximum speed to be out of the range used by participants, meaning there was no system-imposed limit to completing the task.

3.1.3 Views and Camera Behaviour

We used four views that have been used in different video games with 3D environments (Figure 2):

- *first-person*: camera positioned inside the car;
- *third-person-low*: a third-person view positioned at a low angle (~15°), 19m behind the car;
- *third-person-high*: a third-person view positioned at a high angle (~60°), 19m behind the car;
- *overhead*: a third-person view positioned directly above the car, 19m up.

Views placed the car as close to the bottom of the screen as possible. In all cases the camera stayed aligned with the direction of the car’s forward trajectory (i.e., it rotated with the car), and did not otherwise move or adjust position. In all views except the overhead view, the full extent of the track could be seen from the starting position. In the overhead view, users could see 11.1m of track in front of the car. The on-screen size of the car was the same in all views (except in the first-person view, where users only saw the car’s hood).

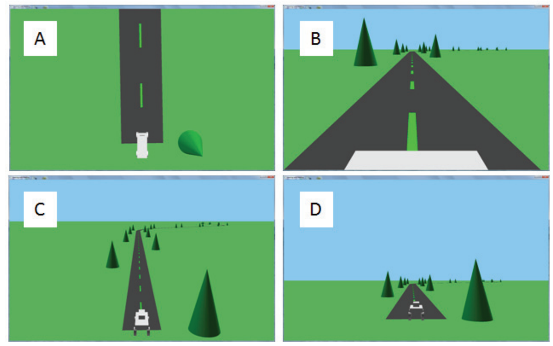

Figure 2. The four views: A) overhead, B) first-person, C) third-person-high, D) third-person-low

3.1.4 Steering Devices

We selected three commonly used steering input devices for controlling the car’s angular turning speed (i.e. for controlling the car’s in-system steering wheel):

- Steering wheel (Logitech MOMO Force),
- Thumbstick (left-hand stick, Xbox 360 controller),
- Mouse (Logitech G5 Laser Mouse).

Table 1. Summary of input devices.

Input range	Self-center	Limb used	Usage
Thumbstick			
[-256,256]	Yes	Thumb	L-R motion → turn angle
Comments: steering movements could be made quickly. Participants often used rapid taps to the stick’s full extent to navigate turns.			
Steering Wheel			
[-1024,1024]	Yes	Arms	Rotation (±210°) → turn angle
Comments: relatively large physical movements were required to achieve the required turn radius. Pilots showed that users would typically start by under-steering, but quickly adjusted.			
Mouse			
[-1024,1024]	No	Wrist	L-R motion → turn angle
Comments: the mouse is very sensitive (2000dpi), so only small movements were required (10cm of left-right motion). Users quickly learned that the mouse did not self-center. Users were all able to complete tasks despite the mouse being non-typical for driving in video games; it is a typical for steering avatars in genres such as FPSs and MMORPGs.			

Differences between devices were controlled where possible (Table 1). For example, the turning capability of the car was mapped to the maximum range for each input device. This approach highlighted the differences between the natural reporting space and physical movements required for manipulating each of the devices. Video games would instead seek to minimize these differences [15].

During piloting, we found that the thumbstick was too sensitive to effectively complete the task – small device movements resulted in large turns, causing an unacceptable number of errors. This is because the device reports values for very small movements. We found that in practice, video games handle this issue by providing a ‘dead zone’ [8]. Dead zones ignore the values reported close to the resting position. With piloting we found that a 'dead zone' equivalent to 15% of the device's total physical input space substantially increased the ability to perform the task with the thumbstick. The remaining 85% of the input space was mapped to the allowable turn radius. For consistency, the dead zone was also applied to the steering wheel and the mouse.

3.2 Task

The task in each study was to traverse the track as quickly and accurately as possible. To successfully complete a trial the participant needed to steer the car through the entire length of track. If at any time, any part of the car exited the extent of the track (i.e. they drove onto the grass around the track) the trial was considered an error and was repeated. Success in five trials was required to progress through the experimental conditions. Each track traversal was completed by driving through the end of the track. Each block consisted of five successfully completed trials, where the first two trials were considered training.

3.2.1 Measures

Performance. Our main measure was completion time. We felt this would provide the most robust measure of performance given different strategies to complete the task. During training participants quickly refined their strategy to accommodate the speed/accuracy tradeoff. Our pilot studies showed marked differences in the participants' tolerance for errors (in games, high speed crashes can be fun), resulting in noisy data from other measures, such as errors and deviation from the center line. A successful trial took 20-30 seconds, and restarting a trial after an error took only a moment.

Measures of Perceived Performance and Preference. We also collected questionnaires asking participants about their perceived performance and subjective preferences of the conditions. These included nine (5-point) Likert-scale questions: one on enjoyment for the condition, six for the NASA TLX work load metric (http://human-factors.arc.nasa.gov/groups/TLX/), two relating to the ease of driving quickly and accurately, and two free text questions collecting comments on the conditions and on the participant's gaze direction while driving.

Eye Tracking. In order to better understand the strategies participants might employ under the different experimental conditions we captured eye-gaze data. This follows previous work that reported difficulty trying to make sense of visual attention without reliable eye tracking information [30].

3.3 Data Analyses

Performance data were gathered from computer logs. For studies 1 and 2, main effects were tested with a repeated-measure factorial ANOVA. Machauly's test was used to test for violations of sphericity. When sphericity assumptions were violated Huynh-Feldt corrections were used. Pairwise comparisons were made using Bonferroni corrections. For Study 3, a one-way ANOVA was used. Post-hoc tests were conducted using Tukey's HSD. Survey results were analyzed using Friedman's ANOVA for related samples; pairwise comparisons used Wilcoxon Signed Ranks Tests for 2-related samples. For all tests, α was set at 0.05. Eye gazes were aggregated for all participants over different conditions. We used heatmaps, generated from the Tobii Studio analysis software, as post-hoc support tools to explore differences in gaze points when performance differences were observed.

4 STUDY 1 – EFFECTS OF VIEW & WIDTH INTERACTION

To answer our main question about whether or not view can affect the ability to perform a steering task in a 3D environment, we conducted a study which compared the four views described. We knew from previous work that varying the difficulty of the task (by manipulating the track width) should affect performance regardless of the view; however, we were uncertain if view and track width would interact. We fully crossed each view with four widths. Our study used a 4x4 (view by width) within-subject design, with view as the outer conditional block. The presentation of width was randomly ordered. The steering wheel was used as the input device.

Participants first completed a demographics questionnaire and then completed each view block. Eye tracker calibration occurred before each view block. After each view block, participants completed a questionnaire, which included the NASA TLX questionnaire and subjective experiences using the view. All participants completed the study in less than 1.5 hours.

4.1 Study 1: Participants

We recruited 12 participants (mean age 27.9, 4 female). All were undergraduate or graduate students (10) or university employees (2). Four stated they did not typically play video games, while six reported playing from 0-3 hours/week, two 3-6 hours/week, and one more than 10 hours/week. Three participants had played car racing games. Participants reported having used a keyboard (8), gamepad (3), mouse (2), and steering wheel (1) as input devices for games. A new participant pool was used for each study.

4.2 Study 1: Performance Results

There was significant main effect of view on completion time, $F_{3,33}$=50.39, p<.001. Pairwise comparisons indicated that the overhead view performed significantly worse than the other views (p <.001), and that there was no significant difference between any of the other views (all p = 1.0).

There was a significant main effect of width on completion time, $F_{3,33}$=33.05, p<.001. Pairwise comparisons showed that completion time was significantly higher for the two narrower track widths (both p<.01), but that there was no significant difference between the two narrowest track widths (p=.20) or the two wider track widths (p=.34).

The assumption of sphericity was violated for the interaction effects of view by width (χ^2(44)=85.05, p<.01). After corrected estimates of sphericity were used (ε=.777), there was a significant interaction effect of View x Width, ($F_{7.0,\,76.97}$ = 32.92, p<.05) with relatively large cross width differences for overhead view in comparison to first-person and third-person views. See Figure 3.

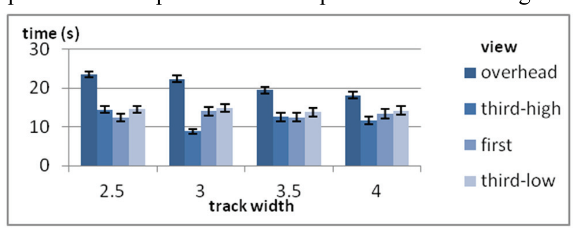

Figure 3. Completion time by view, grouped by track width.

4.3 Study 1: Questionnaire Results

Our questionnaires were designed to obtain subjective impressions of the views. We report participants' ratings of their enjoyment, their work load (TLX), and how fast and accurate they felt they could drive with each of the views. See Table 2.

Did participants enjoy using certain views more than others? Participants rated their enjoyment significantly differently depending on the view they used (χ^2(3)=25.47, p<.000). Pairwise comparison showed that with the exception of the difference between third-person-high and third-person-low, participants rated their enjoyment significantly differently between all views (p<.05), with the first-person view rated the highest and the overhead view rated the lowest.

Did participants rate their overall workload differently between views? Participants rated their overall workload (by answering questions along six dimensions of the NASA TLX) significantly differently between views ($\chi^2(3)=17.76$, $p<.001$). Post-hocs revealed that participants felt first-person view required significantly less workload than third-person-high ($p=.017$), and overhead view required significantly higher workload than all other views (all $p<.05$).

Did participants feel they could drive faster with particular views? Participants felt they could drive faster depending on which view they were using ($\chi^2(3)=16.60$, $p=.001$). Again first-person view and third-person (high and low) views were perceived as significantly faster than overhead view. First-person view was also thought to be faster than third-person-low ($p< .047$).

Did participants feel they could steer more accurately with certain views? Participants felt they could keep the car on the track better with certain views ($\chi^2(3)=23.79$, $p<.001$). Overhead view was seen as significantly less accurate for steering than first-person and third-person views (all $p<.05$). First-person view was thought to be more accurate than third-person-low ($p<.031$).

Table 2. Mean ratings (±SE), 5-point scale. Higher is better.

	First-Person	Third-High	Third-Low	Overhead
Enjoyment	4.5 (.20)	3.75 (.33)	3.5 (.31)	1.9 (.40)
TLX Load	3.53 (.33)	2.47 (.26)	2.56 (.26)	1.47(.33)
Drive Fast	4.17 (.241)	3.67 (.36)	3.25 (.37)	2.25 (.43)
Steer. Accy.	4.25 (.22)	3.75 (.33)	3.42 (.31)	1.92 (.38)

4.4 Study 1: Eye-Tracking Results

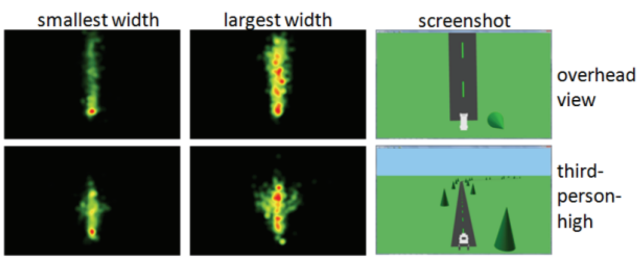

Figure 4. Heat maps from Study 1 for two views; the user's gaze moves away from the car as the track gets wider.

Figure 4 shows heat maps of participant focus points in the smallest width and the largest width tracks, for the overhead and third-person-high views. These images demonstrate two trends that can be seen throughout the images. First, participants looked farther ahead in the larger track than they did in the narrower track. This was also observed in interview results provided in previous steering work [30]. Second, participants seemed to keep their eyes on the road just in front of them, and did not focus on any other features in front of the car.

4.5 Study 1: Interpretation of Results

Our study confirmed that there is a significant effect of view upon driving performance, with first-person view being preferred but performing roughly equivalently to the third-person views (third-high or third-low). The overhead view performed worst of all, and was consistently rated as significantly worse by all participants. There is also a small interaction effect between view and width, which does suggest that some views allow different performance characteristics under different task difficulty conditions (track widths). Figure 3 shows that the completion of the overhead view has a clear downward trend as tracks widen, while other views do not seem to have this clear improvement. Overall, track widths demonstrate the expected effect that completion time decreases with increased width (although much of this improvement may be attributed to the overhead view).

Participants seem to consistently prefer first-person, but this view did not perform significantly better than the third-person views; overhead view was perceived as the worst in all dimensions and performed the worst. We have also confirmed a previous observation that suggests that eye gaze moves forward from the object being steered as track width increases. As the task gets easier the car can move faster, and the eye gaze moves up the path. It is not clear whether the shift in eye gaze is a consequence of increased speed, or a prerequisite for increased speed.

5 STUDY 2 – VIEW & DEVICE INTERACTION

To explore our second question about the interaction effects of device and view, we conducted a 3x3 within-subject study. As previously described, we compared steering wheel, thumbstick, and mouse. We eliminated the third-person-low view condition, as it did not perform differently from either the first-person or the third-person views. We used a single track width of 3.5m.

5.1 Study 2: Participants

The nine participants were all graduate or undergraduate students (mean age 27.6, 1 female). Two participants reported not playing video games, two 0-3 hours/week, one 3-6 hours/week, and four reported 6 or more hours/week. Six had previously played car racing games. Participants commonly used the following input devices for games: keyboard (4), gamepad or thumbstick (6), mouse (6), and steering wheel (1).

5.2 Study 2: Performance Results

Study 2 results were consistent with those of Study 1. There was a significant main effect of view on completion time, $F_{2,12}=53.48$, $p<.001$. Pairwise comparisons indicated that the overhead view performed significantly worse than the other views ($p<.001$), and that there was no significant difference between the other views (both $p=1.0$).

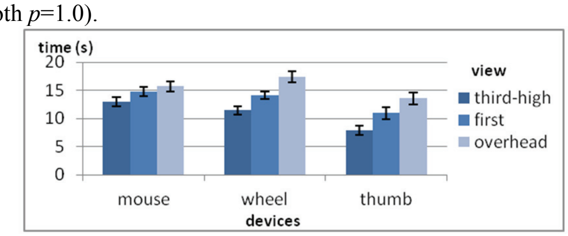

Figure 5. Performance results for device by view.

There was a significant main effect of device on completion time, $F_{2,16}=8.05$, $p=.003$. Pairwise comparisons showed that thumbstick performed significantly better than the steering wheel ($p=.035$) and the mouse ($p=.011$), but no other differences ($p=1.0$).

There was a significant view by device interaction, $F_{2.16,17.28} = 6.60$, $p<.01$ (corrected for sphericity violation), caused by particularly poor performance with the mouse and steering wheel in the overhead view condition (see Figure 5).

5.3 Study 2: Questionnaire Results

For Study 2, questionnaires were provided to participants after every View-Device combination block (9 total). However, because participant responses had been analyzed for view-specific ratings in Study 1, in this study we were mainly interested in participants' perceptions of devices.

Did participants rate devices differently? Unlike view, which showed significant main effects for all dimensions, there was only one significant main effect, for ratings of enjoyment ($\chi^2(3)=6.20$, $p=.045$). Pairwise comparisons showed that enjoyment ratings for steering wheel (mean=3.54, sd=.53) were significantly higher (p=.03) than the mouse (mean=2.42, sd=.97), and that ratings for the thumbstick (mean=3.46, sd=.64) were also higher than for the mouse (p=.04).

No differences were found between device ratings for accuracy of steering ($\chi^2(3)$=4.87, p=.088), ability to drive fast ($\chi^2(3)$=3.16, p=.206), or TLX Load ($\chi^2(3)$=3.16, p=.206).

5.4 Study 2: Eye-Tracking Results

Figure 6 shows heat maps of participant focus points for each device in the overhead view. Participants had two focus points with the thumbstick: the first, similar to the other two devices, is on the car, and the second farther ahead on the road. The focus points ahead of the car seem to be more prominent as the device performs better.

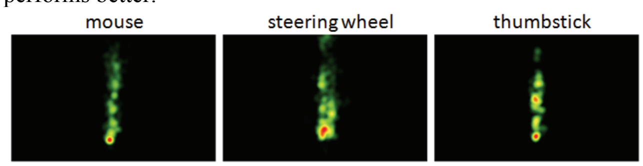

Figure 6. Eye tracking results for the three tested devices, for all participants in the overhead view condition.

5.5 Study 2: Interpretation

The performance results show that the course was completed significantly faster with the thumbstick. Also, there was a significant interaction effect between device and view. While the overhead view performed consistently worse with all devices, the thumbstick did not suffer as badly, and performed close to the level of the mouse with the best performing view (third-high).

The eye-tracking results of Study 2 showed a similar trend as those from Study 1, suggesting that focusing farther ahead seems to coincide with better performance. This also suggests that task difficulty may predict participant ability to move their gaze forward along the path; the better-performing devices make the task easier, allowing people to look farther ahead and drive faster.

It is also interesting to note participant preference (enjoyment ratings) for the steering wheel. These did not match the performance results of the devices, as the thumbstick performed significantly better than the steering wheel. Participants' preference did not seem to bias their ratings of device performance and load, though, as there was no difference between devices.

The main effects of view stayed consistent with those of Study 1, with the overhead view performing significantly worse than the other views. This raises the question, 'What exactly is the difference between the overhead view and the other views?' In considering this question, we feel the most apparent difference that can be seen between overhead and other views is the distance visible in front of the car (*forward distance*). In the third- and first-person views, the extent of the entire track can be seen from the starting position. This is not so in the overhead view; because the camera is pointing straight towards the ground, only a limited distance of the track can be seen in front of the car.

6 Study 3: Controlling Forward Distance

Due to the fact that the overhead view was performing consistently and significantly worse than other views, we conducted a third study to investigate the major difference between the overhead view and the other views. Specifically, we hypothesized that the amount of track that is visible ahead of the car, or the *forward distance*, would account for most of the performance differences between the overhead and other views.

We therefore conducted a study that controlled how far ahead participants could see in each of three views (overhead, third-person-high, and first-person). To do so, we inserted an opaque wall into the first-person and third-high views so that visible road distance ahead of the car matched that in the overhead view. We also included a fourth view condition, *overhead-far*, that increased the camera height, such that the distance visible in front of the car was doubled (from 11.1m to 22.2m). Otherwise overhead-far was identical to the original overhead view. We added the new overhead-far view to check the hypothesis that performance was due to the visible distance in front of the car. If this were true, then we should see performance equalized between the views with the wall (i.e. third-person-high and first-person) with the overhead view, as forward distance was equalized. By increasing the distance in overhead-far we could check for performance gains afforded by increased forward distance.

The visible distances we tested align closely to those studied by Salvucci and Gray [21] who showed that drivers used two forward regions (near: 0-8m and far: 10-20m). This work focused on how the regions were used for navigating turns in real world driving.

6.1 Study 3: Participants

We recruited 9 participants (mean age 25.6, 2 female). Seven were undergraduate or graduate students, one was a tradesperson, and the other did not identify. Two stated they did not typically play video games, while three stated playing from 0-3 hours/week, one stated playing 3-6 hours/week, two stated playing 6-9 hours/week, and one stated they played more than 10 hours/week. Three participants had played car racing games. Participants reported having used a keyboard (6), gamepad (7), and mouse (6) as commonly used input devices for games.

6.2 Study 3: Performance Results

The studied views provided a significant main effect on completion time, $F_{3,83}$=3.61, p=.017. Post hocs showed that third-person-high was completed significantly faster than the overhead view (p=.016). There were no other significant differences between views (p>.05). See Figure 7.

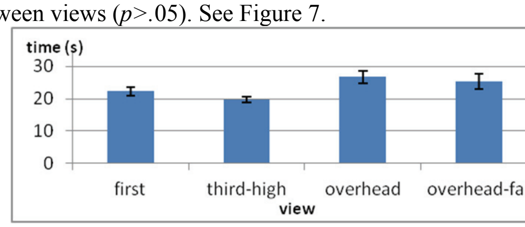

Figure 7. Completion times for view (distance controlled).

6.3 Study 3: Questionnaire Results

With controlled forward distance, participants did not rate the views significantly differently for task load ($\chi^2(3)$= 6.34, p=.096), performance in steering accurately ($\chi^2(3)$=4.26, p=.235), driving quickly ($\chi^2(3)$=3.574, p=.311), or enjoyment ($\chi^2(3)$=5.63, p=.131).

6.4 Study 3: Eye-Tracking Results

Figure 8 shows heat maps of participant focus points for the two overhead views. We compared the overhead view from the first two studies to the zoomed-out version, overhead-far. Overhead-far doubled the amount of "track-ahead" information available for participants by extending the distance in front of the car that is visible, but users did not seem to make use of it (note that in Figure 8, the larger focus area of the regular overhead view corresponds to the same amount of track as the smaller focus area in the overhead-far view).

6.5 Study 3: Interpretation

The performance results from Study 3 suggest that there is more to steering performance than forward distance. While the first-person view with a controlled forward distance did not allow significantly better completion times, third-person-high (also with the forward distance control) did provide significantly faster completion times, staying consistent with results from the previous two studies. Interestingly, overhead-far (which had doubled the visible distance ahead of the car as the other views and had the same view perspective as overhead) did not see significantly better performance times than any other view.

Participants did, however, change their assessment of the different views from Study 1 with the view-distance controls added. There was no preference for any of the views and none were rated as better in terms of ability to perform or task load.

These results are counter to our expectations – we assumed that the poor performance of the overhead view could be attributed to the limited amount of information provided in the overhead view; however, the results presented from the eye-tracker (Figure 8) suggest that there is something further that is yet unaccounted for.

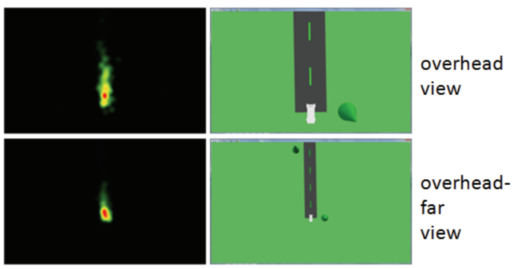

Figure 8. Heat maps from Study 3, far and near overhead views, showing that participants did not use the extra distance.

7 Discussion

Our three studies revealed several main results:

- There were differences between views, but in many cases, these were not what we expected;
- The overhead view was always worse than the first- or third-person views, and got worse with narrower tracks;
- There were no differences between first- and third-person views (which is where we expected differences);
- There was a significant interaction between view and device, with the thumbstick not as affected by the overhead view as the other input devices;
- People preferred thumbstick and steering wheel to the mouse;
- Reducing the forward distance of the views did not equalize first- and third-person with overhead (the third-person view was still faster than the overhead view);
- There was no difference between the normal and zoomed-out overhead views, even though the latter showed twice the forward distance.

7.1 Explanation of Results

Why no difference between 1st-person and 3rd-person views? Our expectations were that the third-person views would be better than the first-person view, particularly as tracks got narrower. This is what conventional wisdom [26], and even prior studies [5][17], have suggested. However, we found no difference between these two views in any of our three studies. In addition, ratings of these views showed that participants preferred the first-person view, and also felt that they could perform better with the first-person view.

The main difference between these two views is the size of the image of the road (much bigger in first-person) and the view of the car (much more complete in third-person). The size of the road in the first-person view may have influenced participants – it appears that one can see more of the road in the first-person view, even though the forward distance is the same. Other than these differences, however, the two views provide much the same information to the driver, and so it is perhaps not surprising that they led to similar performance. However, it is also possible that our simulation did not exercise the factors that would separate these two views.

In particular, the controllers and the mappings of inputs to car movement in our system led to a car that was not overly sensitive to input; it is possible that when it is more critical to make fine adjustments to the car's position or direction at higher speeds, being able to see more of the car on the road will still be valuable. We will consider this issue in future studies.

Why was the overhead view worse, and why was the thumbstick less affected by this view? The overhead view was clearly more difficult for participants to use. There are three possible reasons for the difference. First, it is possible that this view makes it more difficult for people to perceive the tightness of the upcoming curves; perhaps the movement of objects toward the driver in the first- and third-person views allows better perception of upcoming turns than the movement of the road underneath the driver in the overhead view.

Second, people are also very experienced at judging turns in the real world from a first-person view – although we use overhead views for maps, we do not have to use them for steering. Therefore, simple experience could also be a factor in the difference between these views. Finally, it is possible that there are perceptual effects of being high up (in the overhead view); for example, these may lead to underestimation of the size of control action necessary to negotiate a turn.

It is perhaps interesting, as a future investigation, that performance changed suddenly as the view angle rose. In Study 1, the third-person-low view was at an angle of 15°, and the third-person-high view was at 60°, a difference of 45° – and there was no performance difference. The difference between the 60° view and the overhead view, however, was only 30°, and yet there was a dramatic difference. It will be interesting to see how view angles between 60° and 90° affect performance, and to see whether there is a specific angle at which performance degrades sharply.

An additional issue with the overhead view is the question of why the thumbstick dealt with this view better than the steering wheel or the mouse. From our observations of the sessions, it appears that the way in which the thumbstick was used for steering reinforces the above suggestion that people were less able to judge the curves in the overhead view. People used what might be called 'flick steering' – quickly pushing the stick to its maximum extent and letting go (which zeroed the stick). This allowed people to steer in an almost discrete fashion. These observations are echoed by Land and Horwood [12], who also experimented with forward distance. They found that people made rapid-discrete steering movements with shorter viewing distances, rather than smooth continuous movements for larger viewing distances.

Flick steering is very different to the continuous control required for the steering wheel and the mouse – people could perhaps better adjust the direction of the car to the road in the overhead view, since it was easy to see whether the car was oriented correctly to the road, and since quick adjustments were easier to make with the thumbstick.

Why did forward distance not affect performance? In Study 3, we compared the overhead view from Study 1 and 2 to a zoomed out overhead view (Figure 8). The zoomed-out view doubled the amount of forward distance available for participants. However, this manipulation did not improve performance – we had assumed that the poor performance of the overhead view could be attributed to the limited amount of information provided, but this does not appear to be the case.

The eye-tracking data also suggests that people did not use the extra track information – their eyegaze was primarily focused around the car, not down the track. This suggests that it is not the amount of forward distance that makes the overhead views perform poorly. Salvucci and Gray [21] suggested that both a near-region and far-region are needed for controlled steering around turns. The zoomed-in overhead view only provided the near-region. Our forward distance in the overhead-far view included the far-region, yet it did not improve performance. This suggests that there may be other factors affecting driving.

7.2 Lessons for designers

Our studies provide several usable lessons for designers of games and other systems that involve steering tasks.

- View can have a substantial impact on performance and user satisfaction, and so designers should think carefully about these issues when choosing views.
- Overhead views are likely to give lower performance, and simply providing a more zoomed-out view is unlikely to change this disadvantage.
- Reducing the forward distance of a first- or third-person view will compromise performance, but not to the point where these are as bad as overhead views.
- The choice between first-person and third-person view may not be critical for performance, at least for systems where the vehicle is not overly sensitive to input.
- There are strong user preferences for these two views, however, so providing both types is likely to be the best design solution for most gaming situations.

8 Conclusion and Directions for Future Work

Steering tasks are common in many games and 3D environments. Different systems provide users with different views, but little empirical work has been done to understand the effects of view on driving performance. To establish a foundation for view in the design of driving games, we carried out three studies that explored the effects of different view types on driving performance, and the interactions of view with track width and device. Although there were several significant effects of view on performance and preference, many of our results were not in line with conventional wisdom about view, which held that third-person views would perform best. Our studies provide designers with empirical knowledge that can be used to make design decisions about view and performance, but also raise a number of new research questions about the principles underlying view differences.

In future work, we plan to carry out several extensions that will more fully explore the effects of view and the underlying reasons for performance in different views. First, we will investigate the differences between first-person and third-person in actual driving games, to see whether our results can be replicated in these other environments. Second, we will investigate views between the third-person-high view (at 60°) and the overhead view (at 90°) to look for sudden changes in performance. Third, we will test the hypotheses described above in a deeper exploration of the difference between views – in particular, the way in which a view leads a driver to judge both the radius of a curve and the size of control actions needed to negotiate the turn. Finally, we will investigate user preference for first- over third-person views, in light of first-person not providing performance benefits.

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