The social psychology of traffic situations: Collision avoidance by drivers and pedestrians

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1 Abstract

Two virtual reality simulation studies of traffic-based situations are presented. Both are simulations of real-world social situations involving two parties, with one party computer controlled and the other party the experimental participant. The first study investigates the relative merit of a fractional rate braking control system compared to a traditional linear braking control system in the context of vehicle following. With a fractional rate braking system, deceleration is proportional to current velocity, whereas deceleration in a linear braking system is independent of velocity. It was found that fractional rate control led to more accurate maintenance of headway to a lead vehicle and lower workload over the duration of a single braking episode. When the gap maintenance task was extended to include multiple braking, constant speed and acceleration episodes however, no difference in performance or workload was found between fractional rate and linear control modes. Further research is required to determine how braking profiles produced with a fractional rate braking system differ from those produced with a linear braking system. The second study investigates a pedestrian road-crossing situation in which the participant was committed to crossing the road in front of an oncoming vehicle. The virtual environment was displayed through a head mounted display that was updated via head tracking equipment as the participant crossed the road. The relative safety of road-crossing events were scored using the ratio of the time taken to cross to a safe position divided by the time available in which to cross (termed the safety ratio). It was found that participants crossed the road more safely when there was more time available in which to cross, and also when the vehicle started closer to them (and there was the same time available to cross as when the vehicle started further away and travelled faster). Future experiments should investigate whether road-crossing performance is affected by the time available to cross when varied independently of distance to the vehicle (i.e. different vehicle speeds). The two studies project toward a system in which a pedestrian and driver can interact in the same virtual environment.

2 General introduction

The research presented in this work seeks to investigate two common traffic situations – vehicle following and pedestrian road crossing. The first experiment, involving vehicle following, investigates a traffic situation from the perspective of a driver whereas the second experiment, involving road crossing, investigates a traffic situation from the perspective of a pedestrian. Both experiments are simulation studies that make use of virtual reality (VR) equipment. In Experiment 1, the participant controls their driving behaviour using a joystick and is informed of the state of the simulation via a computer monitor (sometimes termed 'desktop virtual reality'). Experiment 2 is a fully immersive virtual reality simulation that uses a head mounted display (HMD) to present the state of the simulation and head tracking equipment to monitor the participant's behaviour. Both experiments have novel aspects to their design. Although driving simulation studies are now commonplace, the fractional rate control mode in Experiment 1 has not previously been studied in a driving context. Various methods have been used to study road-crossing behaviour, but it has not previously been studied using a virtual reality simulation as in Experiment 2. The experiments are therefore preliminary in nature. Part of their purpose is to determine the feasibility of their designs and to discover potential problems that may be addressed in follow-up experiments. Taken together, the two experiments point towards further research in applied social problems in the domain of traffic safety.

The experiments are motivated from the perspective of ecological psychology (Gibson, 1979). The idea for the fractional rate controller studied in Experiment 1 was based on the premise that the information acquired by perception and the information controlled by action must be the same. Because fractional change in velocity is the functional variable for perception of change in self-velocity (see Section 3.1), performance should be improved if people are given direct control over fractional change in velocity. The ecological approach to perception holds that animals perceive affordances. An affordance is the functional utility of a set of environmental properties taken with reference to the action capabilities of the animal. Affordances are therefore relative to the individual. In Experiment 2, the level of the functionally important variable for the road-crossing events (time-to-arrival of an oncoming vehicle) is scaled relative to the participant's abilities in the same way that other affordances are relative to the individual. This means that the affordance for road-crossing is set to the same levels for each participant, as opposed to using absolute levels of time-to-arrival that would result in different levels of safety (or risk) for different participants. The safety ratio used in Experiment 2 as the primary performance measure also captures an affordance, i.e. an environmental property scaled relative to a property of an individual.

A central tenet of ecological psychology is that perception and action are cyclically linked, and this means they should not be studied independently. Experiments that attempt to study ‘pure’ perceptual phenomena, for example, are typically highly constrained with artificial task demands. The problem with such studies is that they have low ecological validity and their findings may not generalize well to real-world reference situations. The present study examines two applied traffic problems using simulation technology. Because the constraints imposed in the simulations match the constraints ordinarily encountered by drivers and pedestrians, the tasks have high ecological validity. A simulation methodology allows manipulation of the information available for perception, and uses objective performance measures (action) as the dependent variables (as opposed to subjective measures), therefore the results should be generalizable to real-world traffic situations. It is acknowledged however that the use of a simulation (with its limitations) raises questions regarding ecological validity and generalization of findings, and this is discussed further in Section 5.1.

3 Experiment 1: Vehicle following

3.1 Introduction

Systems that control braking in road vehicles have traditionally been entirely mechanical in nature, and necessarily constrained by their mechanical properties. However, the advent of electronically controlled braking systems allows for the possibility of alternative control designs. It is predicted that hydraulic braking systems will eventually be fully replaced by electrical systems (Bannatyne, 1999). There are already a number of electronic enhancements designed to assist in the control of braking and steering such as Anti-lock Brake Systems (ABS), Electronic Stability Programs (ESP), and Integrated Vehicle Dynamics (IVD). An alternative braking control system made possible by the development of electronic control is investigated in this study.

A good brake has generally been considered one that gives a linear response, free of fade or grab (Spurr, 1965). A linear braking system produces a constant deceleration for a given pedal position, regardless of velocity. However, this may not be the optimal type of braking control from the perspective of the human operator. Research by Owen (1984, 1990) found that fractional change in velocity $(\ddot{x}/\dot{x})$ was the functional variable for perception of change in self-velocity, where $\ddot{x}$ represents deceleration, the time derivative of velocity $\dot{x}$. It was also found that observers are sensitive to fractional changes in altitude $(\dot{z}/z)$, rather than linear changes in altitude $(\dot{z})$, where $\dot{z}$ represents change in altitude, the time derivative of altitude z (Owen, 1990). These two examples are converging evidence of Fechner's principle (1860 / 1966) at work in ecological optics (Gibson, 1961): Successive equal-ratio increments in an event variable $(\ddot{x}/\dot{x})$ or $(\dot{z}/z)$ give rise to equal-increment improvements in performance (measured by reaction times and accuracy). This has important implications for the visually guided control of road vehicles. When performing a braking action, a driver cycles between sampling the information available and regulating control such that deviations from the desired optical conditions are minimized. This perception-action cycle is ongoing, with the action component pausing only when adequate optical conditions have been achieved. Consequently, the information acquired by perceiving and the information controlled by acting should be in the same units. If humans are sensitive to fractional loss in velocity then it might be better if they are given control over fractional loss in velocity. In fact, in traditional braking systems the driver has control over linear loss in velocity ($\ddot{x}$), not fractional loss in velocity ($\ddot{x}/\dot{x}$). By using a computer in the loop (i.e. electronically based control), drivers can be given direct control over fractional loss in velocity. In this way, the perceptual sensitivities of the person are matched to the action properties of the person-vehicle system, thus creating a direct or 'natural' control system.

A simulation study by Owen (1993) investigated the merit of a natural control system in the context of linear flight path landing approaches in rotorcraft. In this case pilots were given direct control over the fractional variable ($\dot{s}/z$), where $\dot{s}$ is velocity along a path of locomotion, and z is altitude (eye height). This type of control was compared with the standard control over velocity along a path ($\dot{s}$). A number of different performance measures were taken, and the fractional control type was found to be superior for all of them. For example, controller workload was lower for the fractionally based control, in terms of both number of control episodes and total zero-control durations (time off the control). A lower workload frees the pilot's attention for other tasks, which should result in simplified training and increased safety under difficult conditions. The mean distance to touchdown at termination of the 25-s trials was found to be larger with the fractional rate controller, indicating a more conservative approach to landing that was closer to the 'ideal' approach. It is predicted that these sorts of performance improvements will also apply to the fractional rate control of braking in road vehicles ($\ddot{x}/\dot{x}$), and the goal of Experiment 1 is to investigate this possibility.

Now consider how a fractional rate braking system might work. A braking control system consists of a pedal connected in some way to brakes that produce vehicle deceleration. The relationship between pedal position and vehicle deceleration can be modelled by Equation 1:

$$\text{deceleration} = \text{pedal position} \times (a \times \text{current velocity} + b). \qquad (1)$$

The parameters a and b can be varied to produce different types of controller. A traditional linear braking controller has $a = 0$, and b equal to some non-zero value, so that Equation 1 reduces to Equation 2:

$$\text{deceleration} = \text{pedal position} \times b. \tag{2}$$

Vehicle deceleration is linearly related to pedal position by some constant factor b, irrespective of vehicle velocity. Conversely, a fractional rate controller has $b = 0$, and a equal to some non-zero value, producing Equation 3:

$$\text{deceleration} = \text{pedal position} \times a \times \text{current velocity}. \tag{3}$$

In this case vehicle deceleration is related not only to pedal position and a constant factor, but also the current velocity of the vehicle. This can be termed 'fractional' control as pedal position is proportional to a fractional term as shown in Equation 4:

$$\text{pedal position} \propto \frac{\text{deceleration}}{\text{current velocity}} = \frac{\ddot{x}}{\dot{x}}. \tag{4}$$

Figure 1 shows the deceleration profiles obtained for a constant pedal position for each type of controller. Figure 2 shows the corresponding velocity profiles. The graphs are in arbitrary units as magnitude is dependant on both pedal position and the values of the parameters a and b. Note that a third type of controller based on Equation 1 is also possible, one in which a and b are both non-zero. This type of controller would be a sort of hybrid, having properties part way between a purely linear or purely fractional controller. A hybrid type of controller is not investigated in this study.

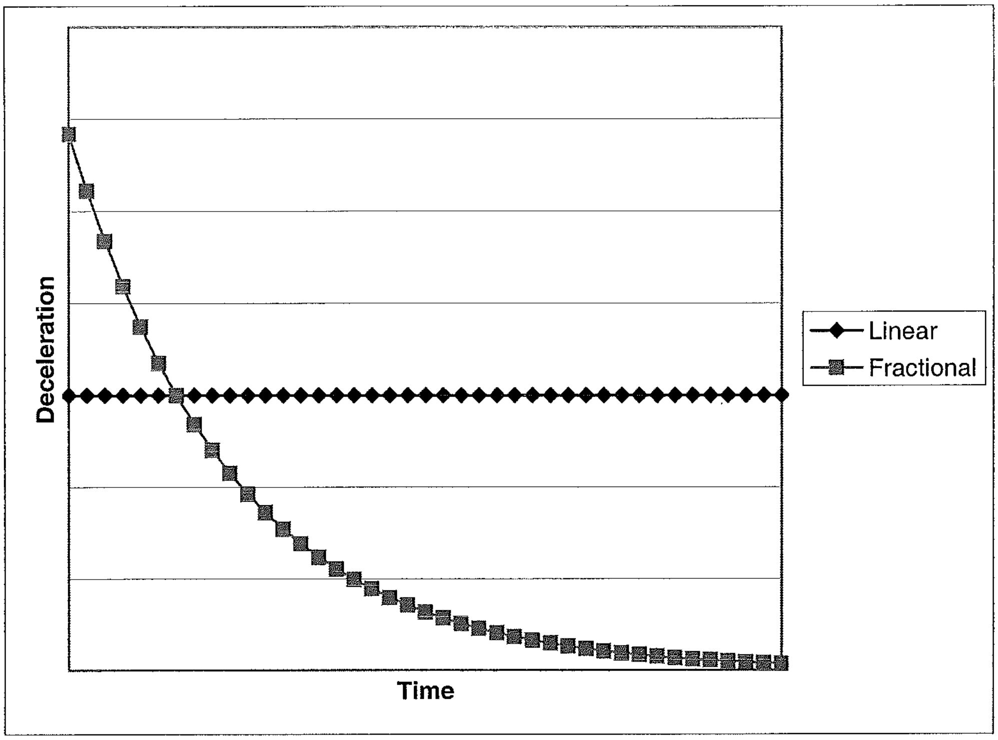

Figure 1. Deceleration profiles of linear and fractional controllers for a given pedal position. The linear profile is constant over time, whereas the fractional profile starts high and curves to a zero asymptote (as velocity decreases over time).

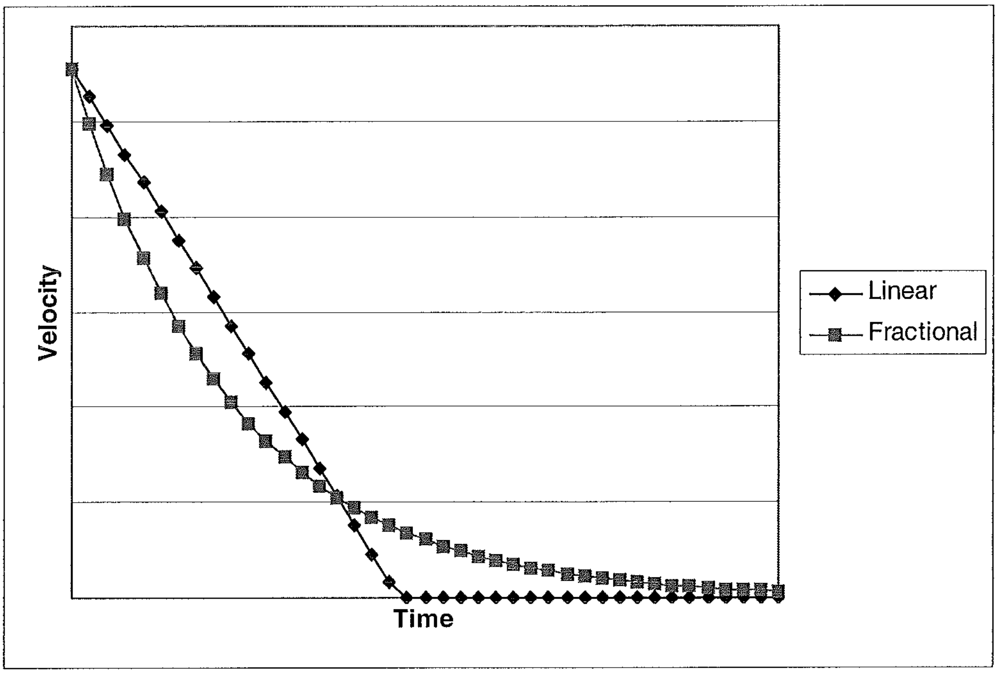

Figure 2. Velocity profiles of linear and fractional controllers for a given pedal position. The linear controller shows a constant slope profile, whereas the fractional controller shows a curved profile. Velocity for the fractional profile tends toward, but never reaches zero.

Note that a purely fractional controller would be impractical at lower speeds as in theory velocity asymptotically approaches zero (disregarding friction from other sources such as air resistance and engine braking). To overcome this drawback a minimum velocity threshold could be used. Once velocity dropped below a certain relatively low value, control would change to linear, allowing any level of deceleration up to the maximum. An emergency braking threshold could also be included for the fractional type controller. Once pedal position exceeded a certain near maximum value, the control type would change to linear. This would ensure drivers could attain the highest levels of deceleration possible in an emergency, regardless of their velocity. Fuzzy logic could be used to determine when the control type should be changed, in much the same way as it has been successfully applied to the problem of gear changing in automatic transmissions.

3.2 Experiment 1a: Gap maintenance during a single braking episode

3.2.1 Introduction

A gap maintenance driving simulation experiment was devised in order to investigate the potential of a fractional rate braking control system. Each trial of the experiment began with the participant driving behind a bus. After a few seconds the bus began to brake, and the participant's task was to try to maintain the same (initial) separation distance behind the bus. The participant was able to slow down or speed up by pulling back or pushing forward on a small joystick. In one session the joystick was programmed to act as a fractional rate braking controller, while in the other it acted as a linear braking controller. Measures of gap maintenance performance and participant workload were recorded per trial.

It is predicted, in line with the theory, that vehicle following performance will be superior with the fractional control system than with the traditional type of braking system. Specifically, it is predicted that gap maintenance will be superior and workload less with the fractional rate controller than with the linear controller.

3.2.2 Method

3.2.2.1 Participants

Seven females and eight males between the ages of 18 and 51 (mean 24.5, median 20, mode 20) from the University of Canterbury took part in the experiment.

3.2.2.2 Materials and apparatus

3.2.2.2.1 The virtual environment

The virtual environment consisted of a straight, flat section of road, sky (non-textured), roadside grass (non-textured), and a bus. The road was marked with continuous white edge lines and dashed white centre stripes that divided the road into two lanes each 4 m in width. The posts and road stripes were evenly spaced in all conditions: posts 14 m apart, stripes 10 m apart. The camera height (i.e. participant viewing position) was 1 m above the road surface, similar to a driver's eye height in an average size car. The participant viewing position and bus were both centred in the middle of the left lane. Lateral driver position in the real world will of course vary depending on the driver, vehicle and road conditions. Centring both bus and driver is a reasonable approximation and has the additional advantage of making optical expansion and contraction of the bus symmetrical. Figure 3 shows one frame of a typical view of the virtual environment. The bus was mainly white in colour and the texture on the rear was taken from a digital photograph of a real bus. The dimensions of the large size bus were based on measurements of a real bus and the small bus was scaled by a factor of 0.75 in all dimensions (see Table 1). The brake lights illuminated (i.e. increased in brightness) at times when the bus was decelerating. The virtual environment was developed as a Windows application using the C programming language and OpenGL graphics libraries. The scene was updated and the joystick sampled approximately 45 times per second. The monitor was refreshed 70 times per second.

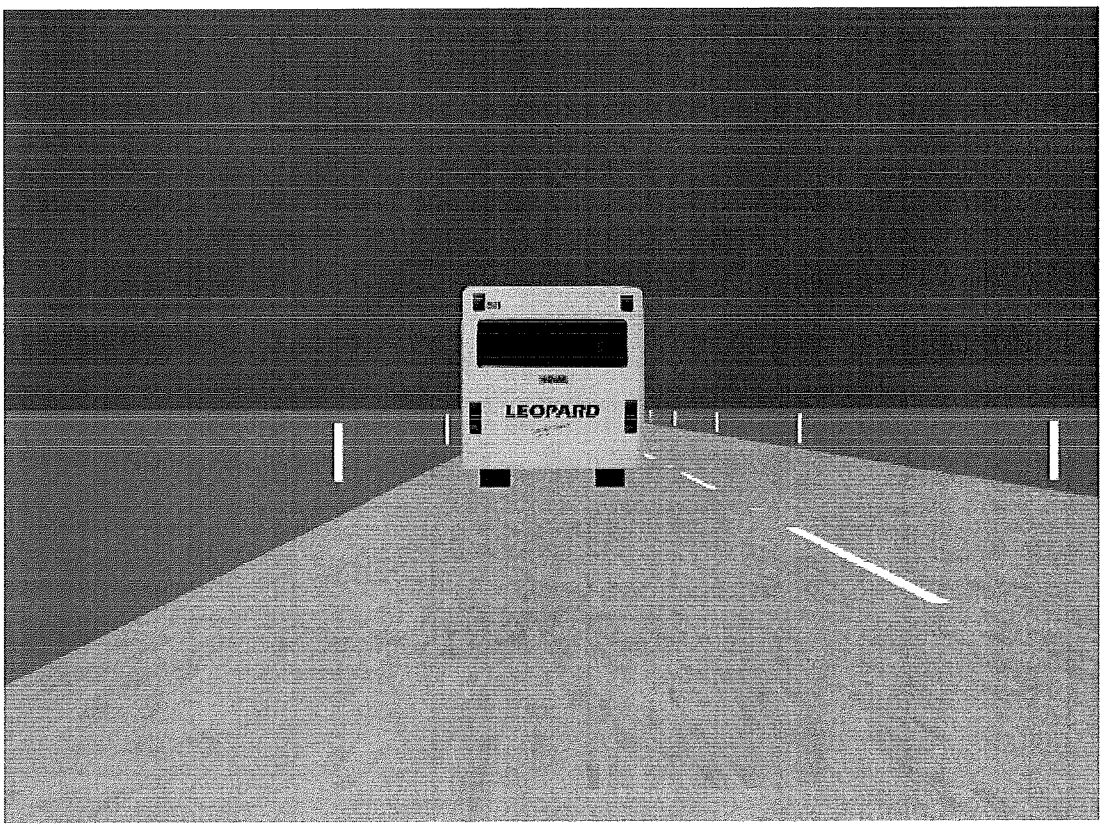

Figure 3. A screenshot of the virtual environment.

3.2.2.2.2 Hardware

Twelve workstations allowed up to 12 participants to be tested concurrently. The virtual environment was generated on 550-Mhz Pentium III PC's with 128-Mb of RAM and 32-Mb Riva TNT2 3D graphics accelerator cards. The environment was displayed in full screen on 17-inch ViewSonic monitors. Input was via RS 162-984 contactless joysticks that were sampled by the PC software through Advantech PLC-818L Input/ Output boards. The joysticks were return-to-centre spring loaded, and for 10 of the 12 workstations were mounted in the desktop to the right of the monitor, keyboard and mouse. The remaining two joysticks were mounted in sturdy wooden boxes that could be positioned on the desktop for either left or right handed operation.

3.2.2.3 Design

Each trial commenced with the participant driving behind a bus. A bus was chosen as the lead vehicle because it was easy to model using only three surfaces: a square rear and two rectangular wheels. In addition, because a bus is a large vehicle that obstructs the following driver's view of the road, this made the spontaneous braking of the bus for no discernable reason more plausible. The bus would start braking at a randomly selected time between 2.5 and 5.5 s after the start of the trial, providing the participant left the joystick in the centred position. If the participant moved the joystick before the start of bus braking, then the bus would not begin to brake until 2.5 to 5.5 seconds after the joystick had been returned to the centred position. The joystick had a 'dead zone' around the centred position of ±3% of its total movement range. Within the dead zone the joystick was considered to be centred, with acceleration equal to zero. The dead zone was included because joystick position samples from the I/O board contained some error variance, and it was necessary to determine when the joystick was centred in order to initiate the bus braking. When the joystick was pulled back it acted as a braking controller (see Table 1), and when pushed forward it acted as an accelerator (i.e. velocity controller). The dynamics did not model any friction, meaning the same velocity would be maintained if the joystick was left in the centred position. At the end of each trial the RMS distance error (see Table 2), a measure of gap maintenance performance, was displayed. This gave the participant feedback on how well they were doing, making the repetitive braking task more of a challenge.

The experiment was divided into two sessions that differed only in controller type. Half of the participants used the linear controller first, while the other half used the fractional controller first. Participants were told the only difference between sessions were properties of the controller, but were not told in what way the properties differed. They were advised to take a short break between trials or sessions if they felt their concentration was lapsing. The first six trials of each session were considered training trials and data were not recorded from them. These six trials were sampled from the total trial pool and represented all the levels of the independent variables. The following 36 trials in each session were the combinations of the levels of initial distance, size, braking rate and braking type as shown in Table 1. The order of these trials was random.

Table 1. Independent variables for Experiment 1a.

Variable	Description	Number of Levels	Levels	Unit
Initial Distance	Separation between the bus and participant's eye when trial starts	3	5, 10, 15	m
Size	Bus size (horizontal by vertical of rear)	2	2.46×2.50, 1.845×1.875	m
Braking Rate	Deceleration rate of the bus	3	2, 3, 4	m/s^2
Braking Type	Whether the bus brakes in a linear or fractional fashion	2	Linear, Fractional	-
Controller Type	Whether the joystick acts as a linear or fractional deceleration controller	2	Linear, Fractional	-

Figure 4 illustrates the six deceleration profiles of the bus arising from the combination of the three braking rates and two braking system types. A linear braking type means that the bus decelerates at a constant rate throughout the trial, as indicated by the straight lines in Figure 4. A fractional braking type means that the deceleration rate is proportional to (i.e. a fraction of) the current velocity of the bus. This results in a decreasing rate of deceleration as speed reduces throughout the trial, as indicated by the curved lines in

Figure 4. The two braking types were included to study the implications of introducing a road vehicle with a fractional rate braking system into existing traffic.

The *maximum* participant braking profiles using the two types of controller are also shown in Figure 4. The fractional type controller means that the participant's deceleration is based on current speed, whereas deceleration with the linear type controller is independent of speed. The curves shown are the participant braking profiles that would result from pulling the joystick fully back for the duration of the trial. It can be seen that the fractional braking profile allows for a higher theoretical maximum deceleration (a steeper slope on the graph). In order to make an unbiased comparison between fractional and linear controllers, the maximum deceleration of the fractional controller was limited to that of the linear controller. This was also a reasonable ecological limitation as the maximum linear controller braking rate was $8 m/s^2$, which is approximately equal to the emergency braking rate of an actual car (c.f. Tignor (1966) cited in Jarvis (undated), states that car decelerations of more than $10 m/s^2$ may be attained under optimal conditions).

The crossing of controller type with braking type allows the four possible lead and following vehicle braking system pairings to be investigated. In trials where controller type and braking type were matched – fractional controller with fractional bus braking, or linear controller with linear bus braking – perfect performance could theoretically be achieved by holding the joystick in one position throughout the trial. In practice this would not be possible as the participant has to wait until after the bus initiated braking before the joystick could be moved. The participant then has to react to the bus braking and compensate for the relative change in velocities by trying to re-establish the initial separation of bus and self. In the trials where controller type and braking type are not matched – fractional controller with linear braking, or linear controller with fractional braking – the participant's task is further complicated by having to adjust the position of the joystick throughout the trial in order to match the deceleration rate of bus and self, thus maintaining the initial separation. When using the fractional controller, the joystick must be pulled back an increasing amount throughout a linear braking trial in order to match the deceleration rate of the bus, since braking rate decreases as the participant's speed decreases. Alternatively, using the linear controller for a fractional braking trial means the participant must decrease the deflection of the joystick throughout the trial in order to match the decreasing deceleration rate of the bus.

The duration's of the linear braking type and fractional braking type trials were matched to allow a fair comparison of performance measures. The gains of the two types of controller were also matched. This means that the three linear braking profiles were the same proportions of the maximum linear braking profile as the three fractional braking profiles were of the maximum fractional braking profile. The fastest bus braking profile for each braking type, for example, was half that of the corresponding maximum participant braking profile. This means these two profiles could be achieved by holding the joystick half way back for the duration of the trial, using the corresponding controller type. The gain of the controllers was matched in this way so that a comparison of joystick movement with the two controller types would be unbiased. Figure 4 also shows that the initial speeds of the participant and bus were 27.778 m/s (100 km/hr), and the trials ended when the bus speed slowed to below the cut-off of 5 m/s (18 km/hr) or collision occurred. This lower cut-off speed was used because deceleration with the fractional controller tends to zero as velocity tends to zero (see Section 3.1).

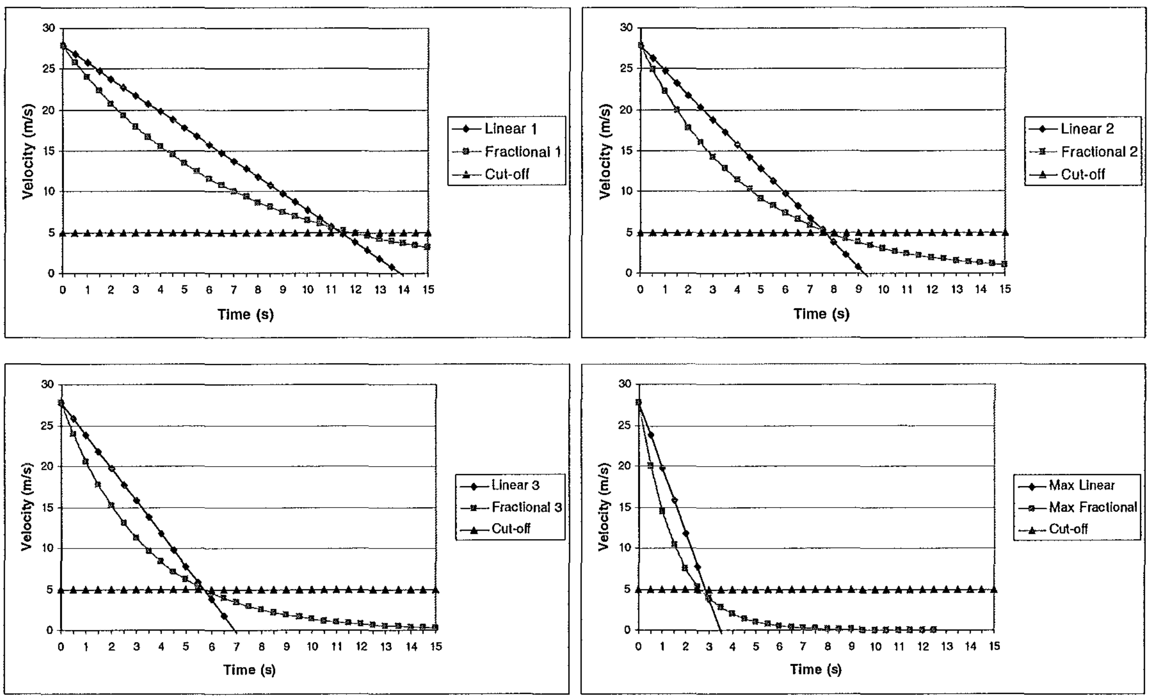

Figure 4. Graphical illustration of the six different braking profiles along with the maximum braking profile for each controller type.

The variables recorded per trial are shown in Table 2.

Table 2. Dependant variables for Experiment 1a.

Variable	Description	Unit
Root Mean Squared Distance Error	Measure of the change in distance between bus and participant throughout the trial relative to the initial distance	m
Root Mean Squared Joystick Velocity	Measure of joystick velocity throughout the trial	Full deflections/s*
Collision	Whether the participant collided with the bus	-

* The proportion of a full joystick deflection per second. If the participant were to move the joystick from centre position to halfway backward in one second, the RMS joystick velocity would be 0.5 full deflections/s.

Root mean square (RMS) is a measure that takes account of both the mean and standard deviation of a variable:

$$\text{RMS} = \sqrt{\text{mean}^2 + \text{standard deviation}^2}. \qquad (5)$$

The RMS distance error is therefore a measure of how well the participant maintained the initial separation distance throughout the trial. Good performance corresponds to low RMS error and poor performance to high RMS error. The RMS joystick velocity is a measure of participant workload. If the RMS joystick velocity is high, the participant has moved the joystick rapidly throughout the trial while trying to maintain the initial separation. Note that RMS distance error and RMS joystick velocity were calculated from the portion of the trial after which the bus began braking and the participant gained control over their own speed (i.e. the initial constant speed interval was ignored).

3.2.2.4 Procedure

Participants were tested together in groups. They were given time to read the instruction sheet (Appendix A), followed by a verbal explanation of the experiment. At the end of each trial, a black inter-trial screen with white text displayed the participant's RMS distance error. The participant initiated the next trial by pressing the keyboard space bar with their non-control hand.

3.2.3 Results

3.2.3.1 RMS distance error

A 6-way (2 controller types × 2 braking types × 3 braking rates × 3 initial distances × 2 sizes × 2 genders) ANOVA with repeated measures on the first five factors was performed on the RMS distance error data. This revealed significant main effects of all variables excluding gender, as well as five significant 2-way interactions: controller type by braking type, controller type by braking rate, distance by braking type, distance by braking rate, and braking type by braking rate.

Figure 5 shows the interaction of controller type and braking type[1]. The interaction shows that the two controller types were essentially equivalent when following a linearly braking bus, but that the fractional controller was superior when following a bus that was braking in a fractional fashion. The main effect of controller type, $F(1,13)=14.95$, $p<.0019$ can be seen and shows that participants maintained the initial distance more accurately with the fractional controller. The main effect of braking type however, $F(1,13)=72.11$, $p<.0000$, shows that participants performed better in the vehicle following task when following a bus that was braking in a linear rather than fractional fashion.

Figure 6 shows the interaction of controller type and braking rate. The interaction shows that the difference between controllers was more pronounced at the highest rate of braking than at the lower levels. The main effect of braking rate, $F(2,26)=59.44$, $p<.0000$, can be seen and shows that participants maintained the initial distance more accurately the lower the rate of braking.

[1] Note that the same scale has been used on the RMS distance error axes in Figures 5 – 9 so that visual comparisons are meaningful.

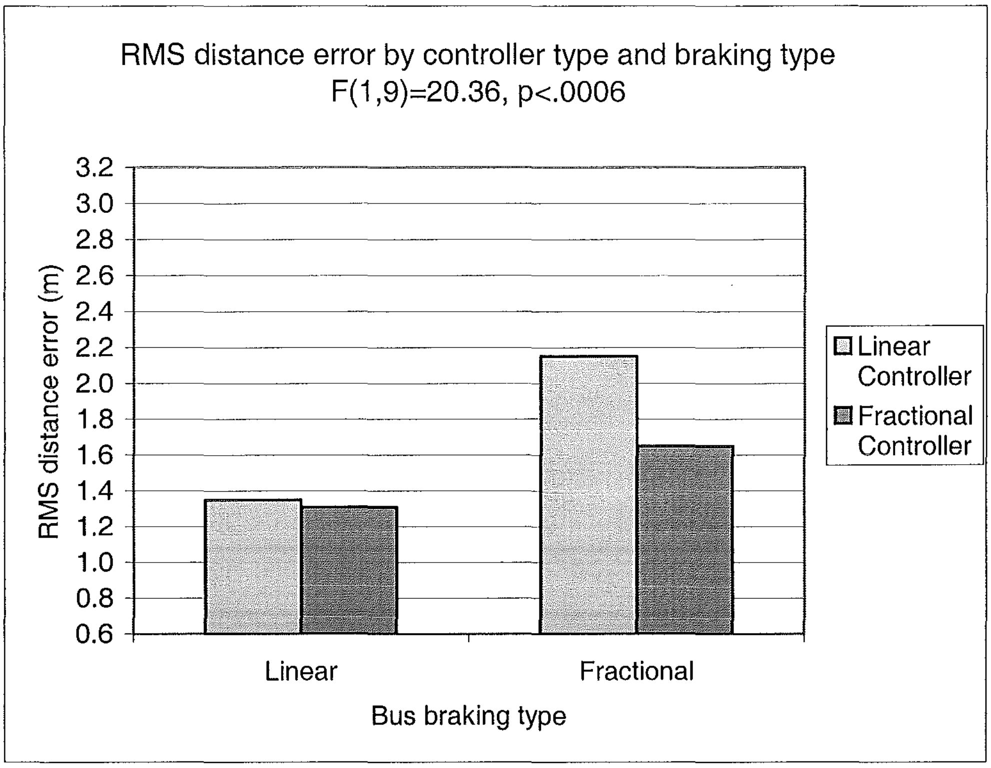

Figure 5. Interaction of controller type and braking type as indexed by RMS distance error.

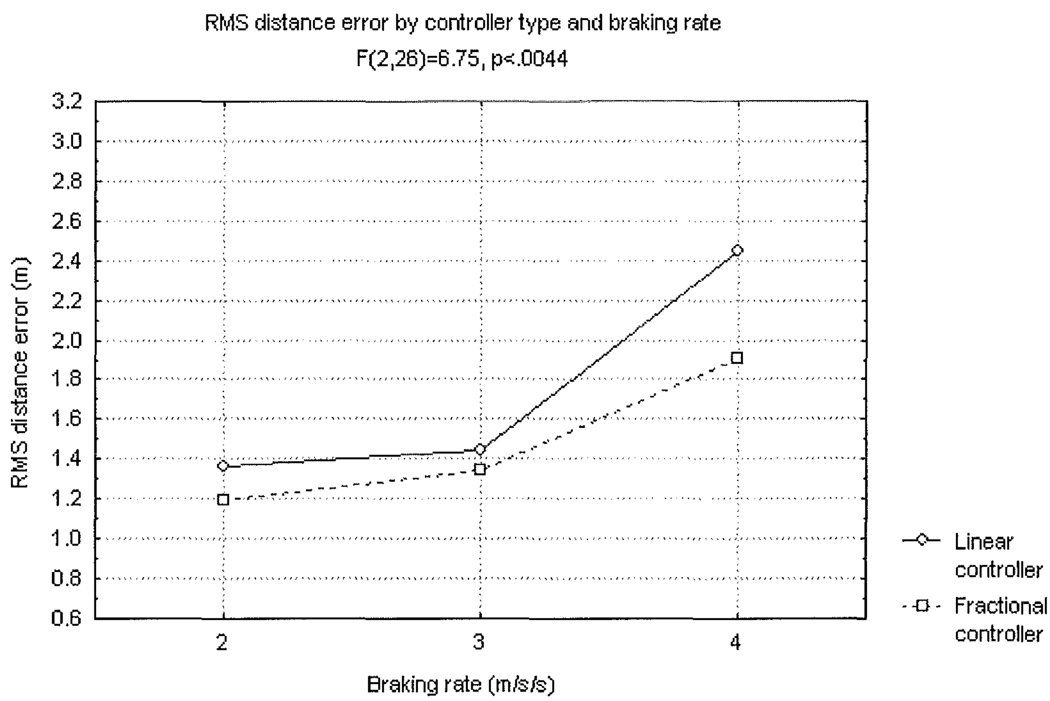

Figure 6. Interaction of controller type and braking rate as indexed by RMS distance error.

The interaction of braking type and initial distance is shown in Figure 7. The interaction shows that at the closest distance the difference between braking types is relatively less than at the further distances. This is likely due to a floor effect whereby performance is approaching a limit making the difference between braking types less pronounced at the 5-m distance. The main effect of initial distance, $F(2,26)=30.20$, $p<.0000$, can be seen and shows that participants maintained distance more accurately the closer the initial separation distance.

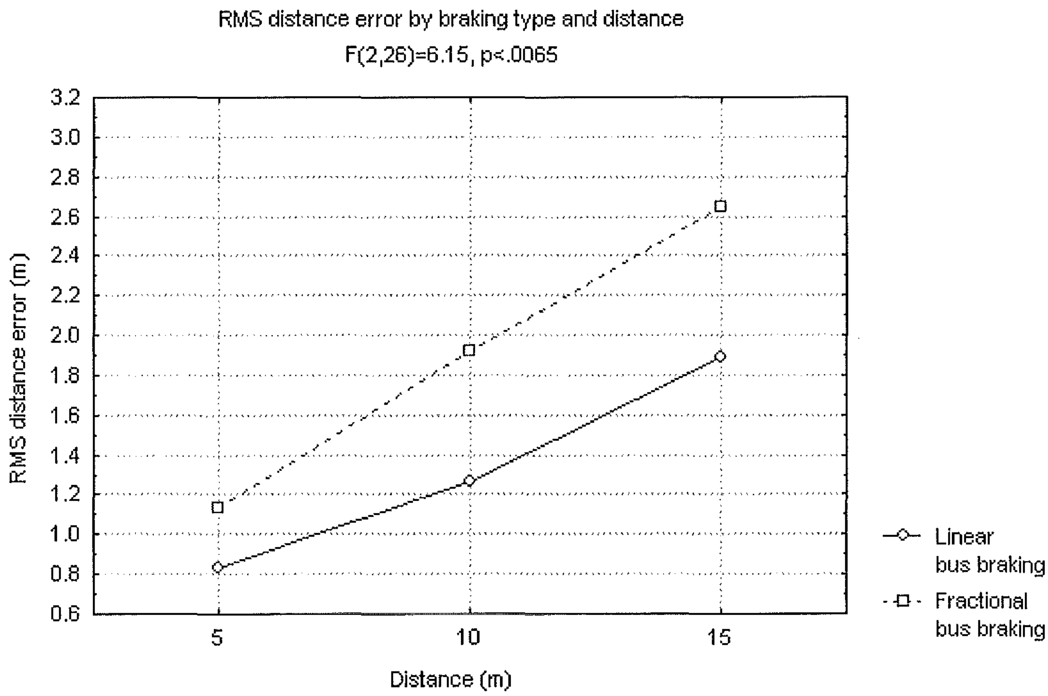

Figure 7. Interaction of braking type and distance as indexed by RMS distance error.

Figure 8 shows the interaction of initial distance and braking rate. It appears the same sort of floor effect may be operating whereby the performance difference between braking rates is reduced at the closest distance.

The interaction of braking type and braking rate is shown in Figure 9. The graph shows that the level of bus braking makes relatively little difference to performance providing braking is linear, but if braking is fractional then the higher the braking rate the worse the gap maintenance.

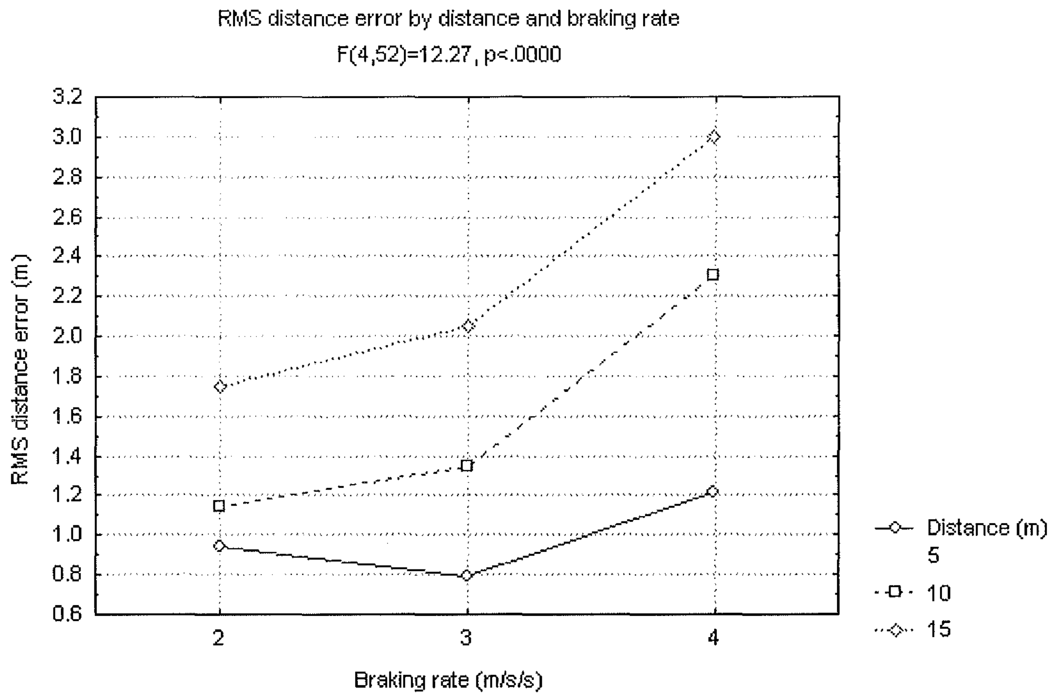

Figure 8. Interaction of distance and braking rate as indexed by RMS distance error.

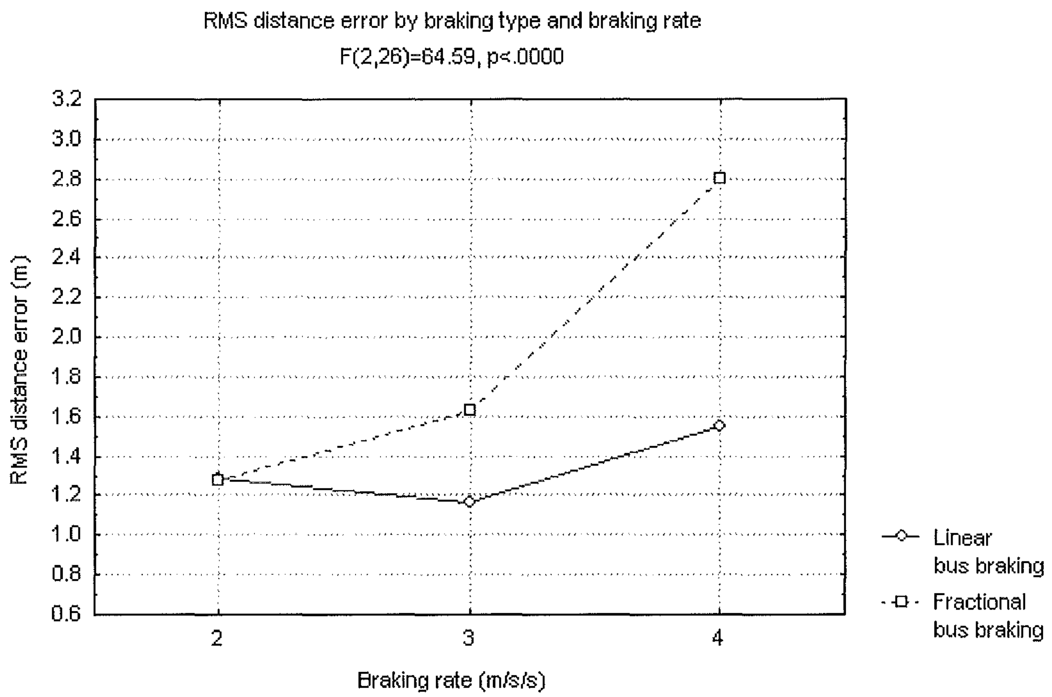

Figure 9. Interaction of braking type and braking rate as indexed by RMS distance error.

The main effect of size, $F(1,13)=8.55$, $p<.0118$, shows that participants maintained the initial distance more accurately when following the larger bus with 1.56 and 1.67 m RMS distance error at the large and small bus sizes respectively.

3.2.3.2 RMS joystick velocity

A 6-way (2 controller types × 2 braking types × 3 braking rates × 3 initial distances × 2 sizes × 2 genders) ANOVA with repeated measures on the first five factors was performed on the RMS joystick velocity data. This revealed significant main effects of braking rate, initial distance and size. Controller type was marginally significant, with braking type and gender not significant.

The marginally significant main effect of controller type, $F(1,13)=3.43$; $p<.0867$, shows that participants performed less work with the joystick when using the fractional controller with 2.25 and 2.09 deflections/s with the linear and fractional controllers respectively. The main effect of braking rate, $F(2,26)=8.54$, $p<.0014$, shows that participants performed less work with the joystick as braking rate decreased with 2.28, 2.20 and 2.03 deflections/s at 4-, 3- and 2-m/s^2 braking rates respectively. The main effect of initial distance, $F(2,26)=38.89$, $p<.0000$, shows that participants performed less work with the joystick as initial separation distance increased with 2.52, 2.06 and 1.93 deflections/s at 5-, 10- and 15-m initial distances respectively. The main effect of size, $F(1,13)=20.41$, $p<.0006$, shows that participants performed less work with the joystick when following the smaller bus with 2.23 and 2.11 deflections/s for the large and small bus sizes respectively. Overall then, participants had lower workload in conditions of lower braking rate, larger distance and smaller bus size, with the fractional controller proving slightly less demanding than the linear controller.

3.2.3.3 Collisions

Out of a total 540 trials with each controller type, there were five collisions with the linear controller compared with only one collision with the fractional rate controller. Two of the collisions occurred with a linearly braking bus, four collisions with a fractional braking type bus. Although these results reflect the RMS distance error trends, the low overall incidence of collisions excludes any meaningful statistical analysis.

3.2.3.4 *Summary*

The results for controller type show that gap maintenance performance with the fractional rate controller was superior with (marginally significant) less workload. Further analysis reveals that the fractional controller was superior only when following a fractional braking type bus (Figure 5), and that the difference between controllers was more pronounced at the highest braking rate (Figure 6). Gap maintenance performance was worse when following a fractional braking type bus. The difference between braking types became more pronounced the higher the level of braking rate (Figure 9).

Combining the results for braking rate shows that the lower the braking rate the lower the workload and the better the gap maintenance performance. Workload and performance were negatively correlated indicating the task was genuinely easier at lower braking rates. Combining the results for initial distance it can be seen that the closer the initial distance the higher the workload and the better the gap maintenance performance. Because workload and performance are positively correlated, it cannot be said that one level of distance is necessarily harder or easier than another, rather that participants appeared to work harder at closer distances to achieve better results. Similarly, workload was higher and gap maintenance performance better when following the larger size bus.

3.2.4 Discussion

The findings in terms of evaluating the relative merit of fractional versus linear braking are not clear cut. Although, as predicted, performance with the fractional rate controller was superior overall and workload was less, this positive finding is moderated by the fact that overall performance was in fact worse when following a vehicle braking in a fractional fashion.

The results suggest that it may be more difficult to follow and maintain a safe distance behind a vehicle with a fractional braking system. However, it must be noted that virtually *any* type of braking profile may be achieved with either type of controller. The braking profiles of the bus were those that would be achieved if the brake pedal was held in one position for the duration of a braking episode (instantaneously reaching the given position which would not be possible in practice). This was thought to be a reasonable first approximation to the sort of braking profiles that might be produced with each controller type. However, a real-world braking study by Spurr (1969) suggests that this assumption may not be well founded. In this study, drivers were instructed to bring a car to rest at nominated points, and their deceleration profiles measured. Spurr found not only that deceleration profiles can be quite irregular, especially for less experienced drivers, but that the majority of braking profiles were in fact convex in shape (i.e. the opposite curvature to the fractional braking type profiles). These braking profiles were generated with a real-world (approximately linear) braking system. It is not known in what way, if at all, typical braking profiles produced with a fractional rate braking system would differ. In this light then, the finding that the fractional rate braking type was harder to follow must be treated with caution. Further research is required to determine what typical braking profiles are like with a fractional braking controller (see Section 3.4.1).

The results showed that the higher the braking rate, the harder it is to maintain a constant distance behind the bus. This result was to be expected as matching a higher braking rate demands more joystick movement (i.e. more deceleration), and the change in distance (if nothing is done) is more rapid than at lower braking rates meaning RMS distance error is likely to be higher. Because more work is required at higher braking rates, the difference between controller types is effectively increased. Also, because distance changes more rapidly, the difference between bus braking types is increased. This explains why the differences between controller types and braking types were more pronounced the higher the braking rate.

One explanation for higher workload at closer distance is that participants were more motivated to accurately maintain distance as given a deviation is more likely to result in collision than the same deviation at a further distance. In the real world, drivers will tend to be more alert to changes in inter-vehicle distance when closely following a lead vehicle than when a large distance behind the lead vehicle. Another explanation for this finding is that changes in distance are more apparent the smaller the distance. When the bus is closer, the same change in distance results in a larger change in optical angle subtended. If changes in distance are more salient at closer distance, then the participant can react to and correct for distance changes more quickly and frequently, thus increasing joystick workload and improving performance. The findings for bus size are similar to those for distance with the larger bus size giving rise to higher workload and better performance. The same explanation in terms of salience applies, with changes in distance being easier to detect for the large bus as they correspond to larger changes in optical angle.

In simulation experiments the update of the virtual environment scene should ideally be synchronised with the refresh rate of the display device. In the current experiment this was not the case (see Section 3.2.2.2.1), and this drawback is addressed in Experiment 1b (see Section 3.3.2.2.1). The spacing of roadside posts and eye height of the driver in the virtual environment were estimated in this experiment. In Experiment 1b they are based on Land Transport Safety Authority regulations (1992).

3.3 Experiment 1b: Gap maintenance during multiple braking, constant speed and acceleration episodes

3.3.1 Introduction

The present experiment seeks to build on Experiment 1a to determine whether the favourable results for the fractional rate braking controller are also applicable to a more complex driving task. Instead of a just single braking episode, the gap maintenance task is expanded to cover a number of braking, constant speed, and acceleration episodes.

The procedure and virtual environment are very similar to those used in Experiment 1a, with some minor modifications. Three different colours of bus have been introduced, primarily to increase variation between trials in an attempt to reduce participant boredom in performing a repetitive task. It will also be possible to investigate figure-ground contrast effects. Three initial distances are again used, however instead of using arbitrary distances they are this time calculated by applying the '2-second rule'[2] to three common vehicle speeds (see Section 3.3.2.3). This means there are three corresponding initial speeds of the bus and participant. Inclusion of this co-variable will allow the fractional rate controller to be tested over a range of common real-world speeds, and allow investigation of whether there is any differential performance between the two controllers at different speeds. It is important to test the fractional controller over a range of speeds, as it is the relationship between speed and corresponding deceleration that makes the controller different from a linear one. The RMS distance error feedback at the end of each trial was removed. Because the gap maintenance task is more complex and includes more variation (bus colour and speed), it was felt that the feedback should be removed as it is not realistic and was no longer deemed necessary to alleviate boredom. The two bus braking types have again been included, although it is acknowledged that these braking profiles may not be representative of the type of profiles actually generated with the two different controller types (see Section 3.2.4)

[2] Learner drivers are taught to maintain a 2-second headway between themselves and a lead vehicle in normal driving conditions (Land Transport Safety Authority, 1999).

It is predicted that the same trends will be found with regard to controller type and braking type as in Experiment 1a. However, because only a proportion of the trial will involve bus braking (and presumably controller braking), it is predicted these effects will be smaller. The same trends with regard to initial distance should also be found, with closer distances corresponding to higher workload and better performance. It is predicted that better performance will be obtained when following the white bus. It should be easier to detect optical expansion and contraction against the mainly blue background of the sky for the white bus than for the blue or purple buses. There is no reason to expect an interaction of controller type with distance (speed), although it is important to show that this is the case (i.e. that the fractional controller works at least as well as the linear controller over a range of speeds).

3.3.2 Method

3.3.2.1 Participants

Six females and five males between the ages of 20 and 38 (mean 24.1, median 22, mode 20) from the University of Canterbury took part in the experiment.

3.3.2.2 Materials and apparatus

3.3.2.2.1 The virtual environment

The virtual environment consisted of a straight, flat section of road, sky (non-textured), roadside grass (non-textured), and a bus. The road was marked with continuous white edge lines and dashed white centre stripes that divided the road into two lanes each 4 m in width. Dimensions of the road markings, posts, and participant viewing position (eye height) were based on those specified in the Land Transport Safety Authority regulations (1992). The posts were 100m apart, stripes 10m apart and the viewing position was 1.15m above the road surface, similar to eye height in an actual average size car. The rear of the bus was 2.46 m in width and 2.5 m in height. The participant viewing position and bus were both centred in the middle of the left lane. The brake lights illuminated (i.e. increased in brightness) at times when the bus was decelerating. The virtual environment was developed as a Windows application using the C programming language and OpenGL graphics libraries. The scene was updated and the joystick sampled 75 times per second, synchronized with the refresh rate of the monitor.

3.3.2.2.2 Hardware

The hardware was identical to that used in Experiment 1a (Section 3.2.2.2.2).

3.3.2.3 Design

Each trial of 60-s duration began with the participant driving behind a bus which went through a number of braking, constant speed and acceleration episodes (see Figure 10). Friction was modelled as a deceleration of 1 m/s^2, meaning the participant's velocity would decrease at a rate 1 m/s^2 if the joystick was left in the centred position, or was pushed forward at a displacement that specified a target velocity less than the current velocity. Deceleration due to friction in the real world will of course vary depending on the vehicle, environmental conditions (road surface and slope, wind) and the transmission gearing relative to the current speed (c.f. Spurr, 1965, found out of gear deceleration to be approximately 0.3 m/s^2). The joystick had a 'dead zone' around the centred position of $\pm 1\%$ of its total movement range. The dead zone was reduced from that used in Experiment 1a as maintenance of a centred joystick position was not used as the criterion to start the trial. An emergency braking band was also included for the fractional rate controller, such that if the joystick was pulled back 95% or more of its range of movement, then the braking rate was set to the maximum. This allowed participants to achieve maximum braking with the fractional controller, regardless of velocity (see Section 3.1).

The experiment was divided into two sessions that differed only in controller type. Half of the participants used the linear controller first, while the other half used the fractional controller first. Participants were told the only difference between sessions were properties of the controller, but were not told in what way the properties differed. They were advised to take a short break between trials or sessions if they felt their concentration was lapsing. The first three trials of each session were considered training trials and data were not recorded from them. These three trials were sampled from the total trial pool and represented all the levels of the independent variables. The following 18 trials in each session were the combinations of the levels of initial speed, braking type, and bus colour as shown in Table 3. The order of these trials was random.

Table 3. Independent variables for Experiment 1b.

Variable	Description	Number of Levels	Levels	Unit
Initial Distance [Speed]	Initial separation of the bus and participant when the trial started [Initial speed of both]	3	27.8, 37.1, 55.6 [50, 66.7, 100]	m [km/h]
Bus Colour	The main colour of the rear of the bus	3	Blue, Purple, White	-
Braking Type	Whether the bus brakes in a linear or fractional fashion	2	Linear, Fractional	-
Controller Type	Whether the joystick acts as a linear or fractional deceleration controller	2	Linear, Fractional	-

The initial speeds of the bus and participant were calculated by applying the 2-second rule (using the initial separation distance):

$$\text{initial speed} = \text{initial distance} \div 2. \tag{6}$$

The initial speeds of the bus and participant were therefore 50, 66.7 and 100 km/h at 27.8, 37.1, and 55.6 m respectively. Note that the three initial separation distances (and three initial speeds) do not appear to be evenly spaced, i.e. halfway between 27.8 m and 55.6 m is 41.7 m (and halfway between 50 km/h and 100 km/h is 75 km/h). This is because the initial separations were evenly spaced in the optical domain, rather than the domain of kinematics. The horizontal optical angle subtended by the bus at a given point in time can be calculated using some basic trigonometry:

$$\text{optical angle} = \tan^{-1} (\text{bus width} \div 2 \times \text{separation distance}). \tag{7}$$

The initial optical angles were therefore 1.29, 1.93, and 2.58 degrees at 50, 66.7 and 100 km/h respectively (bus width = 2.46 m), which is an even spacing of angles. Note also that the upper and lower speeds (and corresponding distances) were chosen to match the common New Zealand traffic speed limits of 50 (urban) and 100 km/h (open road).

The bus completed a number of cycles of travelling at a constant initial speed, slowing down, travelling at a constant lower speed, and then speeding up to the initial speed during each trial. These cycles can be clearly seen in Figure 10 which shows the bus velocity throughout an example of a trial. Note that Figure 10 illustrates a linear braking type trial, as evidenced by the straight lines in segment d. A fractional braking type trial would have curves in segment d. Some parameters of the bus velocity cycle were randomly selected within certain bounds, so that participants could not predict the behaviour of the bus. The parameters and their ranges are detailed in Table 4. The variables recorded per trial are shown in Table 5.

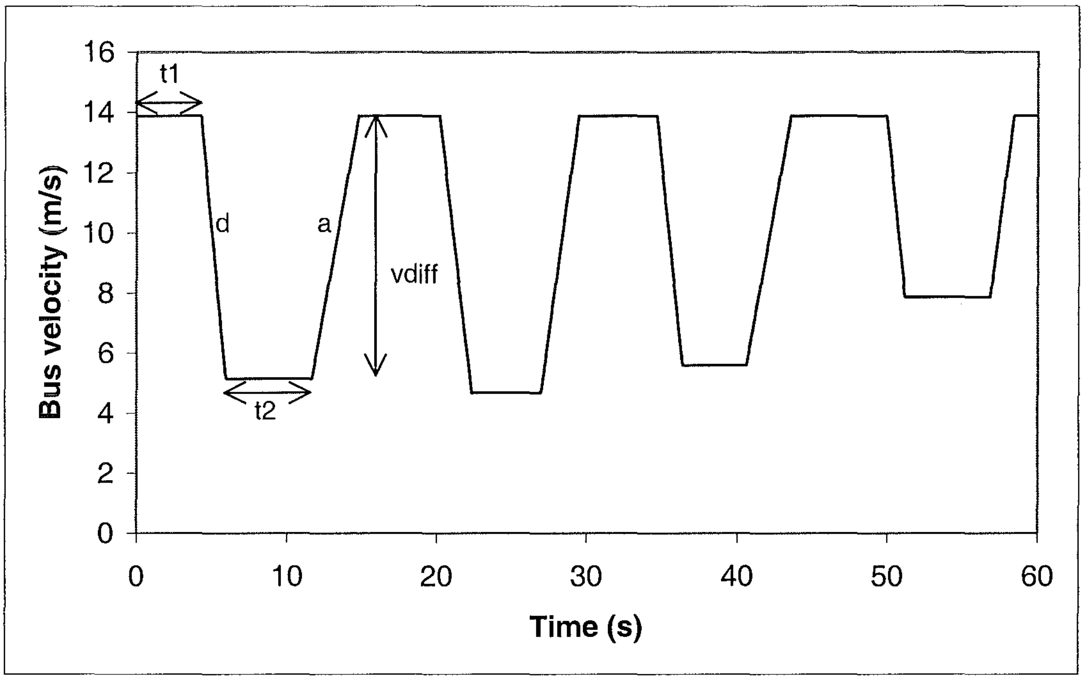

Figure 10. Illustration of bus velocity throughout a linear braking type trial.

Table 4. Parameters that define the bus velocity cycle.

Parameter	Description	Range
t1	Time spent at the initial value of constant speed	3-7 s
t2	Time spent at the lower value of constant speed	3-7 s
d	Deceleration rate	2-6 m/s^2
a	Acceleration rate	2-4 m/s^2
vdiff	Difference in speed from initial to lower value	4.17-9.72 m/s (15-35 km/h)

Table 5. Dependent variables for Experiment 1b.

Variable	Description	Unit
Standard Deviation of Distance Error	Measure of the change in distance between bus and participant throughout the trial relative to the mean maintained distance	m
Velocity Correlation	Correlation between the velocity of the bus and velocity of the participant over the duration of the trial	-
Root Mean Squared Joystick Velocity	Measure of joystick velocity throughout the trial	Full deflections/s
Collision	Whether the participant collided with the bus	Frequency

Note that the standard deviation of distance error is used as the measure of gap maintenance performance instead of RMS distance error, which was used in Experiment 1a. In Experiment 1a, trials were of short duration and it made sense to take account of both the mean and standard deviation components of the distance error (see Equation 5). In the present experiment however, trials were of 60-s duration, meaning participants were unlikely to accurately remember the initial (target) separation distance for the duration of the entire trial. It is likely that participant's perception of the target maintenance distance drifted over the course of the trial. This being the case, participants would attempt to maintain a separation distance that was offset from the initial distance. However, we are more interested in how well participants maintained their target distance, rather than by how much their target distance was offset from the initial distance (as the offset should not be related to controller type or braking type). We are therefore interested in the standard deviation component of the distance error, rather than the mean component. As with RMS distance error, a low value of standard deviation in distance error corresponds to good performance.

An alternative way to measure vehicle following performance is to perform a correlation of the lead and following vehicle's velocities at each point in time. This measure (termed *coherence*) was used in a vehicle following task that was part of a driving simulation study investigating the effects of alcohol and antihistamines on driving performance (Weiler et al, 2000). If the velocities of the bus and participant are well matched, their correlation will be high, and the standard deviation of distance error will tend to be low. In the present study, it was found that coherence and standard deviation of distance error were significantly negatively correlated ($r = -0.77$, $p<.05$). As analysis revealed the same general pattern of results with these two variables, the results for velocity correlation are not reported.

3.3.2.4 Procedure

Participants were tested together in groups. They were given time to read the instruction sheet (Appendix B), followed by a verbal explanation of the experiment. At the end of each trial, a black inter-trial screen with white text instructed the participant to initiate the next trial by pressing the keyboard space bar with their non-control hand.

3.3.3 Results

3.3.3.1 Standard deviation of distance error

A 5-way (2 controller types × 2 braking types × 3 initial distances × 3 bus colours × 2 genders) ANOVA with repeated measures on the first four factors was performed on the standard deviation of distance error data. This revealed significant main effects of initial distance, bus colour and gender as well as a marginally significant interaction of controller type and gender.

Figure 11 shows the interaction of controller type and gender. The main effect of gender, $F(1,9)=5.37$, $p<.0457$, can be seen and shows that males maintained less deviation in the separation distance than females. The interaction shows that gap maintenance performance for males was relatively better with the fractional controller, whereas performance was relatively better with the linear controller for females.

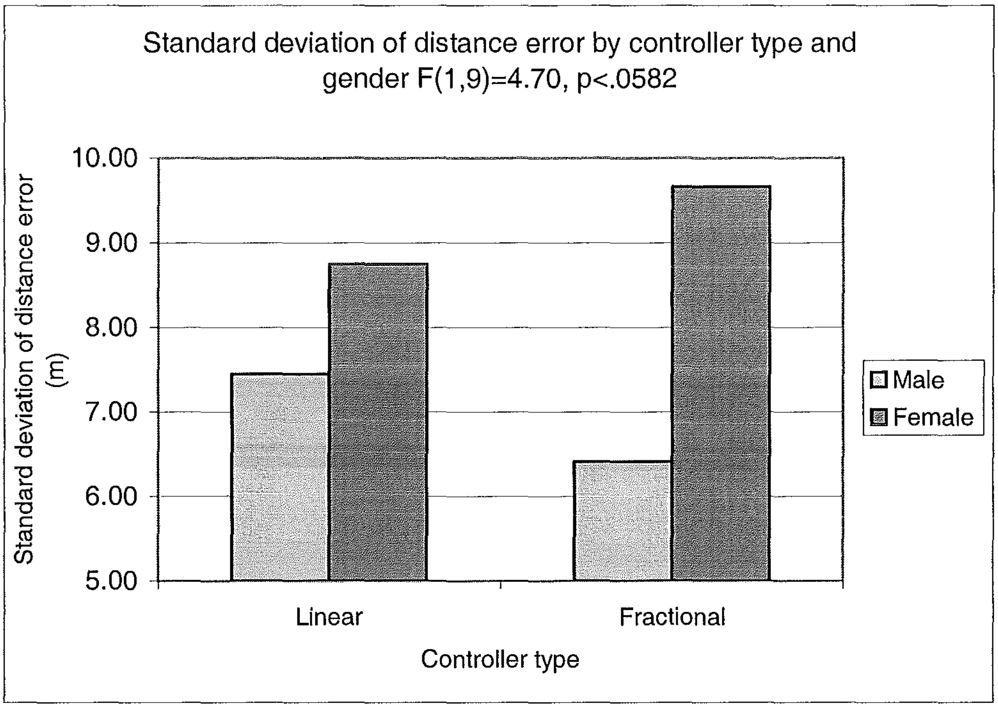

Figure 11. Interaction of controller type and gender as indexed by standard deviation of distance error.

The main effect of initial distance, $F(2,18)=65.68$, $p<.0000$, shows that participants maintained less deviation in the separation distance as distance decreased, with 11.84, 7.32 and 5.05 m of standard deviation in distance error at 55.6, 37.1 and 27.8 m respectively. The main effect of bus colour, $F(2,18)=5.40$, $p<.0146$, shows that participants maintained less deviation in the separation distance for the white bus, with 8.64, 8.47 and 7.10 m of standard deviation in distance error for the purple, blue and white buses respectively.

3.3.3.2 RMS joystick velocity

A 5-way (2 controller types × 2 braking types × 3 initial distances × 3 bus colours × 2 genders) ANOVA with repeated measures on the first four factors was performed on the RMS joystick velocity data. This revealed a marginally significant main effect of initial distance and a marginally significant interaction of controller type and gender.

Figure 12 shows the marginally significant interaction of controller type and gender. The interaction shows that males performed less work with the joystick than females with the linear controller, whereas females performed less work with the joystick than males with the fractional rate controller.

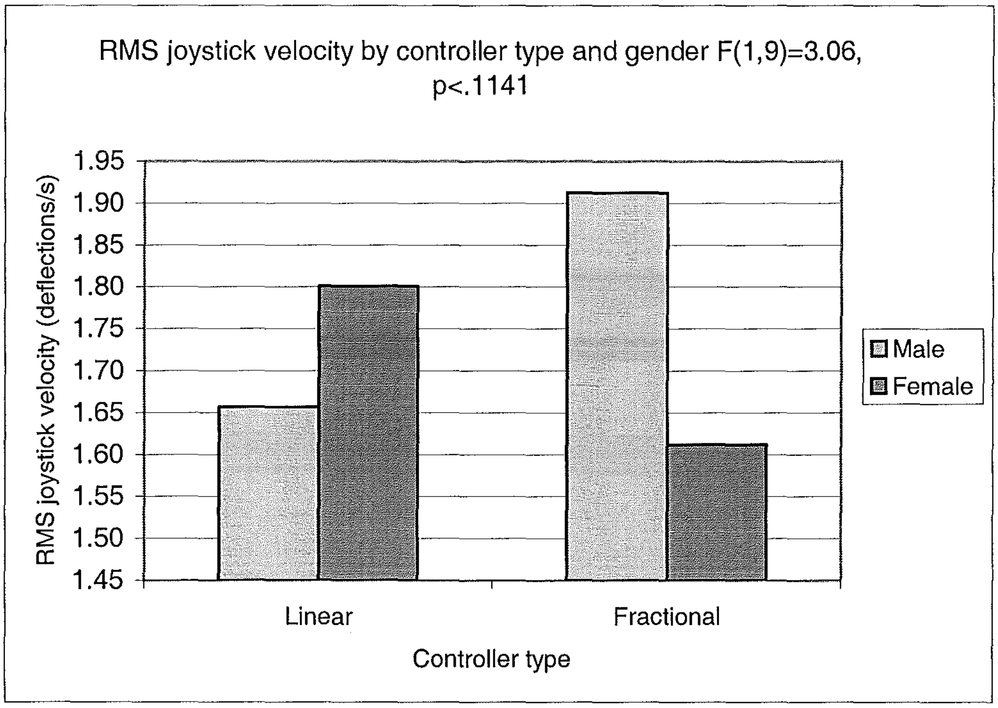

Figure 12. Interaction of controller type and gender as indexed by RMS joystick velocity.

The marginally significant main effect of initial distance, $F(2,18)=3.47$; $p<.0531$, shows that participants performed less work with the joystick as initial separation distance increased, with 1.65, 1.75 and 1.84 deflections/s at 27.8, 37.1, and 55.6 m respectively.

3.3.3.3 Collisions

Out of a total 198 trials with each controller type, there were six collisions with the linear controller compared to three collisions with the fractional rate controller. One of the collisions occurred with a linearly braking bus, eight collisions with a fractional braking type bus. These results reflect the RMS distance error and collision trends from Experiment 1a, although the low overall incidence of collisions excludes any meaningful statistical analysis.

3.3.3.4 *Summary*

It was found that males maintained less deviation in distance error than females. Furthermore, males worked harder and achieved better performance with the fractional type controller relative to the linear controller. Conversely, females worked harder and achieved better performance with the linear type controller relative to the fractional controller.

Taken together, the results for initial distance show that the closer the distance the more the work and the better the separation distance maintenance. This finding is the same as that from Experiment 1a and can be explained in terms of either greater motivation at closer distance or easier detection of change in distance (see Section 3.2.4). It was also found that gap maintenance was considerably better when following the white bus relative to the blue or purple buses.

3.3.4 Discussion

Unlike Experiment 1a, there were no significant differences between controller types or between braking types. It was predicted that these effects would be reduced because of the design of the experiment, but it was expected they would still persist in the more complex task. The absence of controller type and braking type effects can be explained by considering the design in more detail. The bus went through a number of constant speed, deceleration and acceleration cycles throughout a trial (see Figure 10). Taking the average duration of the cycle components, braking in fact only lasts for 12.4% of a trial (an average of 1.74 s out of a total 14.1 s, see Table 4). Over the duration of an entire trial then, the difference between braking types was fairly minimal. Although the proportion of time that the participant spent braking may well have been higher than this, it would still have only been some subset of the trial length. Performance measures were calculated over the duration of the trial, but as shown above only relatively small proportions of the trial were in fact influenced by the difference in braking type or controller type. This suggests that a larger number of participants may have been required to detect the effects of these variables. An additional analysis of performance was conducted whereby the trial was divided into braking, acceleration and constant speed segments. Performance measures were calculated per segment, however no additional results of interest were found through this analysis. A further factor that may have contributed to the absence of significant controller or braking type effects was the introduction of random elements. Because the velocity profile of the bus was regulated by random variables, no two trials of the same type were the same. This effectively increases variability and reduces the chance of finding significant effects.

It was important to check that performance with the fractional rate controller was at least as good as the linear controller over a range of different speeds. There was no interaction of initial distance and controller type, showing participants performed equally well with either controller type at the three levels of initial speed (distance). This result must be taken with caution however, as the design may not have been sensitive enough to detect differences between controller types (see above).

The effects of gender were not predicted as they were not found in Experiment 1a. However, gender differences have been found in other simulation studies involving oncoming objects. For example, females were found to underestimate time-to-contact by a greater amount than males when object velocity is low (Manser & Hancock, 1996) and when object size is small (Caird & Hancock, 1994). In the present study it was found that females worked harder with the linear controller to achieve better performance, whereas males worked harder with the fractional controller for better performance. Because workload and performance were positively correlated, these results do not show that one controller type was necessarily more suited to males and the other type to females. Rather, it appears that for some reason females just *tried harder* when using the fractional controller, and males with the linear controller. It is not clear why this should be the case. Note that the gender interactions were only marginally significant and that a larger number of participants would be required before any firm conclusions regarding gender effects could be reached.

The main effect of colour was as predicted. The greater difference in contrast between the white bus and the (mainly blue) surroundings made detection of optical expansion and contraction easier than for the blue and purple buses.

3.4 Discussion

Overall, more research is needed to determine whether fractional rate braking is a viable alternative to linear braking. Results from the single braking episode task in Experiment 1a showed some support for the fractional rate controller. When the task was extended to involve multiple braking, constant speed and acceleration episodes in Experiment 1b however, there were no controller type or braking type effects found. Gender effects suggesting overall superior performance by males, and interactions of gender with controller type were found in Experiment 1b, but no gender effects were found in Experiment 1a. A consistent and robust effect of initial distance was detected in both experiments where closer initial distance led to superior performance.

The next two sections detail possible extensions to the design and technical aspects that could be used in future experiments.

3.4.1 Design extensions

Investigation into the typical braking profiles produced with a fractional rate controller is required (see Section 3.2.4). An experiment in which participants brake to a stop at nominated points (e.g. stop sign, traffic lights) could be used for this purpose. Controlling the time at which a traffic light changed colour during the participant's approach would allow investigation of different braking rates. The understanding gained from this study could then be used to more accurately model braking profiles of a lead vehicle in vehicle following situations. The implications of introducing a fractional rate braking system into existing traffic could then be revisited, without the assumptions and approximations used in Experiment 1. A more complex but potentially superior approach would be to have two participants interact in the same simulation (see Section 5.2 for further elaboration of this idea). One participant would control the lead vehicle while the other controlled the following vehicle. No modelling or approximation of braking profiles would be required with this type of design.

In Experiment 1, the participant's task was to maintain a constant distance in *space* behind a lead vehicle. In the real world, drivers are taught to maintain a (minimum) distance in *time* behind a lead vehicle. At higher speeds a greater separation in space is required to maintain the same level of safety. In Experiment 1b the 2-second rule was used to set up the initial distance-speed pairings. The participant's task however was to maintain a distance in space, so if distance was correctly maintained there would be a 2-second headway only when travelling at the initial speed. The experiment could be changed so that the task is to maintain a constant 2-second separation distance. The dependant measure of performance would be error in time headway rather than error in distance headway. Training trials could be included to teach the participant how to maintain the 2-second headway at various speeds, making use of roadside objects such as posts. A minimum level of performance in the training trials could be used as a criterion to initiate the experimental trials. Not only is the maintenance of a distance in time more realistic, but the participant would not have to remember what initial distance (or corresponding optical size) they had to maintain during each trial. Instead, the participant would have to maintain the same 2-second headway in each trial, and would be able to determine when their time headway was too long or too short by using the technique taught in the training trials.

Both Experiment 1a and 1b revealed some results that were marginally significant. As preliminary experiments, participant numbers were relatively low. Future experiments may benefit from larger numbers of participants and the corresponding increase in statistical power. Experiment 1b was suggestive of some gender effects. If these were to be investigated in more detail then a balanced number of male and female participants would be desirable.

3.4.2 Technical extensions

A number of technical extensions could be made to increase the realism of the simulation. The extensions suggested here are those that could be achieved with a minimum outlay of programming effort and equipment expenditure. Foot pedals could be used as the control device instead of a joystick. This would allow the reaction times and dynamics of shifting the foot from brake pedal to accelerator and vice versa to be captured. Participants may have a tendency to associate joysticks with computer games. In computer games, players typically have little regard for what would be the corresponding real-world consequences of their actions (for example, the rapid and uncomfortable changes in velocity that would result from high rates of braking or acceleration). The use of foot pedals instead of a joystick may promote more realistic participant behaviour.

Objects such as the roof, bonnet, and window struts that affect a driver's forward view from a car could be modelled. A head mounted display and head tracking equipment (see Section 4.2.2.2) could also be used to more accurately model the driver's visual experience of the environment. Depth perception information from motion parallax and (with stereoscopic imagery) binocular disparity would be made available to the perceiver.

4 Experiment 2: Pedestrian road crossing

4.1 Introduction

A number of studies have investigated participant performance in road-crossing situations. Many of these studies have focussed on the road-crossing ability of young children (c.f., Connelly, Isler, Parsonson, 1996; Demetre & Gaffin, 1994; Demetre, Lee, Grieve, Pitcairn, Ampofo-Boateng & Thomson, 1992, 1993; Lee, Young, & McLaughlin, 1984). The highest incidence of pedestrian fatality is associated with young children and the elderly. In New Zealand, the most fatalities during 1991-1998 were in the 5-9 year age group, followed by the 10-14, 15-19 and 70+ age groups respectively (Land Transport Safety Authority, 1998). There is a need for fundamental research into the perception of safety in road-crossing situations, and such research may also explain children's over-representation in accident statistics.

Many previous studies of road-crossing situations have been performed in the real world. Because of the physical dangers involved when crossing a real road, this approach has inherent limitations. One real-world method is to perform observational studies of people crossing the road (Oudejans, Michaels, van Dort & Frissen, 1996). Although observational studies can yield insights, they have limited control over the functional variables. Another technique is to modify the road-crossing task so that participants do not actually cross the road. At least three such modifications have been used: the pretend road task (Lee, Young, McLaughlin, 1984; Demetre, Lee, Grieve, Pitcairn, Ampofo-Boateng & Thomson, 1993), and the shout and two-step tasks (Demetre, Lee, Pitcairn, Grieve, Thomson, & Ampofo-Boateng, 1992). In the pretend road task, participants stand one road width away from the actual road, and cross the 'pretend road' up to the edge of the actual road. One problem with this approach is that the available optical information is altered by the change in vantage point. The two-step task and the shout task are similar in that participants are not required to actually cross the road, but instead take two steps or shout when they think it would be safe to do so. Although in this case the vantage point is typical, the task is not. Participants may not behave in the same way when they know they do not actually have to cross in front of traffic, but merely indicate when they could cross. Furthermore, there is no opportunity for participants to reassess the situation part way through crossing the road and decide to change their speed, or for the researcher to record such behaviour. A further drawback with these three real-world methods is that a number of experimenters and other resources may be required to set up the desired traffic flows and to record participant behaviour.

A virtual reality simulation of a road-crossing situation offers a solution to some of these problems. Firstly, there is no need to modify the road-crossing task because there is no danger of physical injury from virtual traffic. The simulation allows participants to cross a virtual road in the same way they would cross an actual road, but without the real-world dangers. This allows investigation of high-risk situations and the possibility of 'virtual collisions', which cannot be studied in the real world. The use of a computer-controlled simulation also allows precise definition and manipulation of road-crossing characteristics, including such properties as the number of vehicles, their positions and speeds, the road width, and the presence or absence of occluding or distracting objects. Another advantage is that extremely precise spatial and timing performance measures can be made using VR equipment.

To study safety and risk in road-crossing situations, a relevant measurement system must be devised. The theory of affordances developed by J. J. Gibson (1977, 1979) holds that animals directly perceive what objects and events offer to support action. An affordance is the functional utility of a set of environmental properties taken with reference to the action capabilities of the animal. Affordances are therefore relative to the individual. It follows that tests of affordance theory require measurements that are relative to the individual. Affordance theory has suggested a number of measures that have proved useful for studying applied situations. For example, an affordance analysis of the human activity of stair climbing was conducted in terms of riser height relative to leg length (Warren, 1984). Another example is an analysis of object graspabilty in terms of object size relative to hand span (Hallford, 1984). However, all previous affordance analyses have been applied in the geometric domain. The analysis of road-crossing performance requires a measure that is sensitive to temporal event properties. To study safety and risk, a measure that parses the temporal continuum into safe and risky regions is required. The time available to cross safely relative to the time taken to cross (called herein the *safety ratio*) is such a measure (described in detail in Section 4.2.3). Experiment 2 therefore seeks to examine the applied problem of road crossing using a VR methodology, and to test the applicability of affordance theory to this domain.

Experiment 2 is a road-crossing simulation in which the participant must cross one lane of a road in front of an oncoming vehicle. The procedure is designed such that the participant is committed to crossing the road in front of the vehicle, and must determine how quickly they need to walk in order to cross safely. This type of situation occurs in the real world when pedestrians are in a hurry or when they distractedly begin crossing a road before assessing the proximity of traffic. The design allows for precise control over the speed, distance and time-to-arrival of the oncoming vehicle, and for precise recording of road-crossing performance during each trial. There are three levels of time-to-arrival, and three distance-speed pairings within each of these levels (see Section 4.2.3). It is predicted that participants will cross more safely when time-to-arrival is greater, as they will have more time to cross the road to a safe position. Connelly et al (1996, 1998) found that children's distance thresholds for judging non-safe crossing remained constant regardless of vehicle speed. They argue that children base their road-crossing decisions solely on distance, failing to take vehicle speed into account. Participants in Connelly et al's studies were a maximum of 12 years of age, and it is not known whether adults also rely on distance information to make road-crossing judgements. If they do, then participants should cross more safely when the oncoming vehicle is closer as they will judge conditions to be less safe and cross the road more quickly to avoid collision.

4.2 Method

4.2.1 Participants

Five females and 14 males between the ages of 19 and 66 (mean 27.6, median 23, mode 21) took part in the experiment. The majority of participants were students from the University of Canterbury.

4.2.2 Materials and apparatus

4.2.2.1 The virtual environment

The virtual environment consisted of a straight, flat section of road, a tree, a street light, sky, roadside grass, and a vehicle. The road was marked with continuous white edge lines and dashed white centre stripes that divided the road into two lanes each 3 m in width. The dimensions and spacing of the markings were based on Land Transport Safety Authority regulations (1992). The vehicle was modelled on a simple van 1.54-m wide, 1.76-m high and 3.89-m long, and primarily white in colour. The participant's body did not have a visible presence in the virtual environment (i.e. participants could not see a representation of themselves). Figure 13 shows the layout of the central portion of the virtual environment from a bird's eye view. Figure 14 shows one frame of the participant's view of the virtual environment from the side of the road. The scene was updated 60 times per second, synchronized with the refresh rate of the display. The virtual environment was developed as a Windows application using the C programming language and OpenGL graphics libraries.

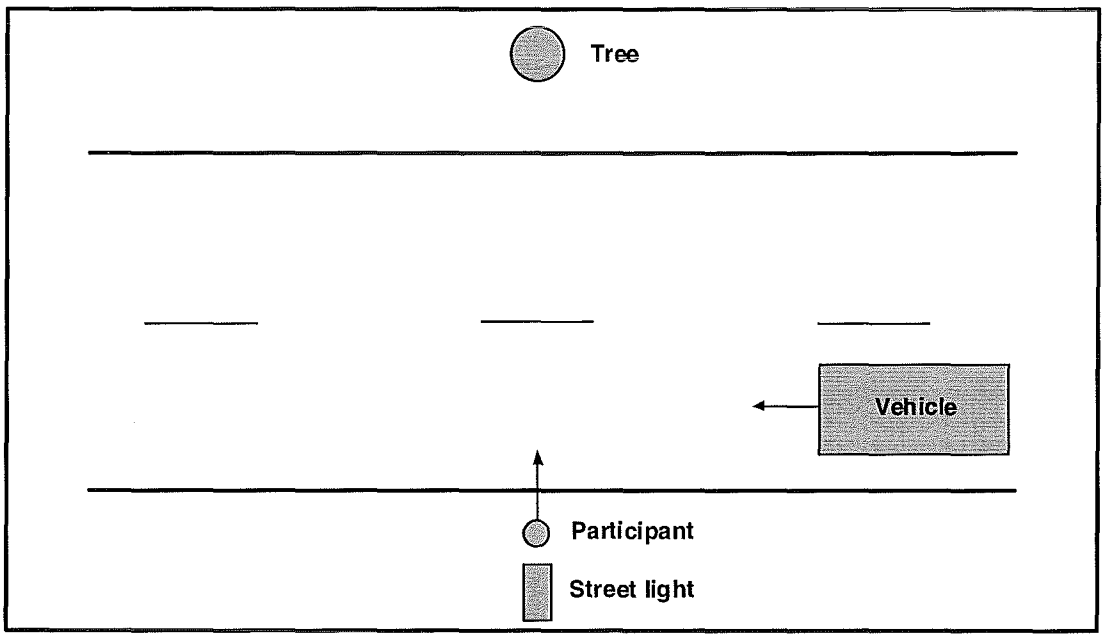

Figure 13. A bird's eye view of the central portion of the virtual environment. The participant is shown at the starting position at the side of the road with the vehicle travelling towards their intended crossing path.

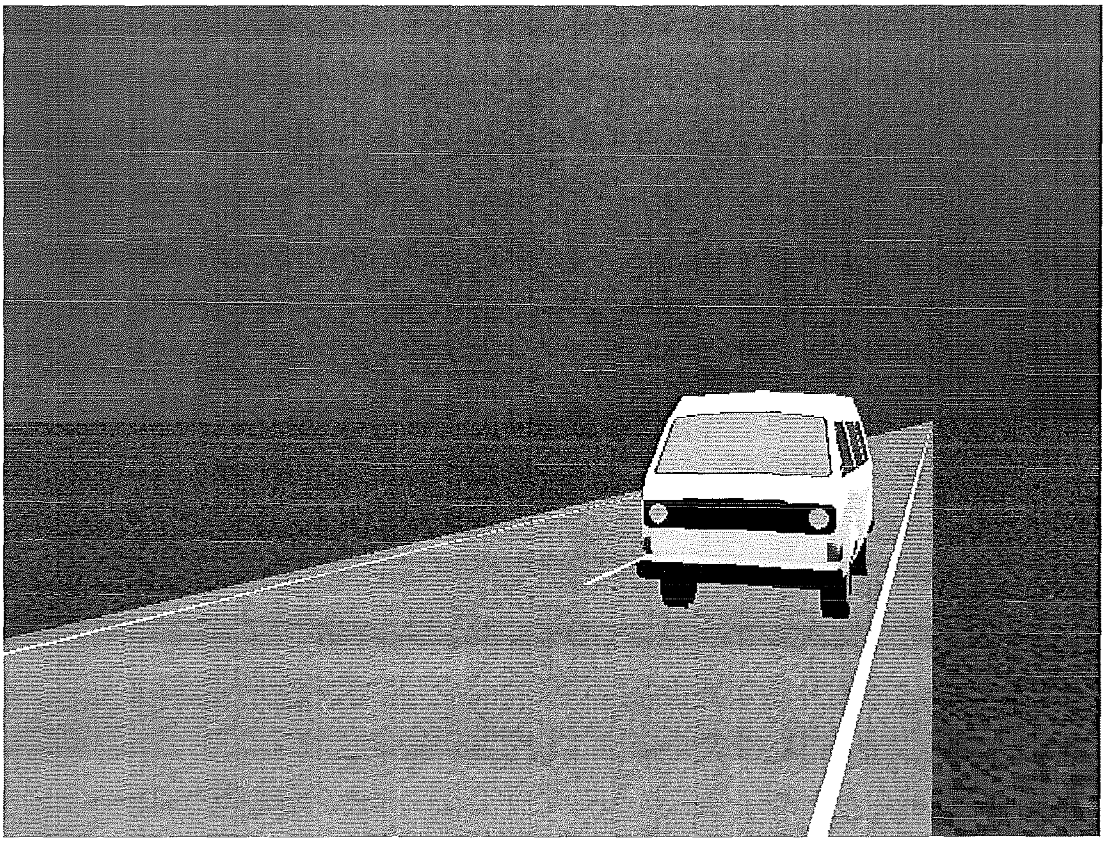

Figure 14. A screenshot of the participant's view from the side of the road as they look towards the oncoming van.

4.2.2.2 Hardware

The virtual environment was generated by an 800-Mhz Pentium III PC with 128-Mb of RAM and a 32-Mb Riva TNT2 3D graphics accelerator card. The virtual environment was viewed through a Virtual Research Systems V8 HMD containing two full-colour 3.3-cm x 640- x 480-pixel active matrix liquid crystal displays with a refresh rate of 60 frames per second, presenting a 48-degree horizontal and 60-degree diagonal field-of-view to each eye. Although the system has the potential to produce stereoscopic images, the same image was presented to each eye (synoptic images) due to technical difficulties. The system used a 6-degree-of-freedom head tracker (Ascension Technology Flock of Birds with extended range transmitter) to monitor the participant's head position and orientation at a sample rate of approximately 8 times per second.

4.2.3 Design

The experiment consisted of a total of 26 trials. The first two trials were performed in the real world with the HMD propped on the participant's head. The remaining 24 trials took place in the virtual environment with the first six of these being training trials. In particular:

- The participant was told to walk normally in the first (real-world) trial.
- The participant was told to walk as if in a rush in the second (real-world) trial.
- The participant was told to walk normally in the first five (virtual) training trials.
- The participant was told to walk as if in a rush in the last (virtual) training trial.
- The participant was told to walk as fast as required to safely cross in front of the van in the 18 (virtual) experimental trials.

There was no traffic in the six training trials and the participant simply practiced walking across the virtual road. The participant was instructed to turn around after reaching the centre of the road via a pre-recorded message played back through the HMD headphones. The purpose of the training trials was twofold: to familiarize participants with walking in the virtual environment, and to obtain measures of participant's normal and rushing walking speeds in the real and virtual environments. The experimental trials were then calibrated according to the walking speed data recorded in the training trials (see below).

In the experimental trials, the participant's task was to cross in front of an approaching van. Each trial began with the participant facing across the road towards the tree. The participant was instructed to turn their head to the right to bring an oncoming van into sight. They were told to cross in front of the van and that if they walked quickly enough then it would not collide with them. It was emphasized in both the training and experimental trials that they should not stop walking until they heard the instruction to turn around played through the HMD headphones (as they reached the centre of the road). This was because accurate measures of walking speed could not be recorded if the participant stopped walking part way through the lane crossing. Two repetitions of nine unique trials made up the 18 experimental trials. The order of the nine trials was randomised within each block. Table 6 details the independent variables.

Table 6. Independent variables for Experiment 2.

Variable	Description	Number of Levels	Levels	Unit
Block	The two repetitions of the nine unique trials	2	First, second	-
Initial Time-to-arrival	Initial time gap before the van would cross the participant's intended path	3	Short, medium, long	s
Van Velocity	Constant velocity of the van	3	30, 45, 60	km/h

The initial time-to-arrival was the time difference between when the participant brings the van into their field of view and the time at which the van would cross the participant's intended path. This was effectively the time available for the participant to cross to a safe position. The van did not start to move until *after* the participant had turned their head to bring it into their field of view, so that the time the participant had to cross in front of the van was not dependent on how long they took to turn their head. There were three levels of initial time-to-arrival (short, medium and long). Rather than using arbitrary absolute values, these times were individuated according to how long the participant took to cross the road in the training trials:

$$\text{initial time-to-arrival} = \text{training cross time} + 0.5, \qquad (8)$$

where training cross time is the time taken for the participant to cross from 0.5 m forward of the starting position to the centre of the road. The forward displacement of 0.5 m was used as a boundary to determine when the participant had actually started to cross the road, as opposed to a displacement resulting from body sway. A constant factor of 0.5 s was added primarily to ensure that the participant had enough time to cross safely in short time-to-arrival trials (provided they walked quickly). In the experimental trials, the total crossing time can be said to be composed of two components: the reaction time to turn after seeing the van and initiate crossing, and the time taken to actually walk across the road. The training cross times correspond to only the second component, so the 0.5 s was added to allow for participants' reaction times. The short time-to-arrival was calculated using the shortest training-cross-time (i.e. usually when the participant was told to rush). The long time-to-arrival was calculated using the mean of the first five training cross times (participant walking at normal speed). The medium time-to-arrival was the mean of the long and short times-to-arrival.

There were three levels of van velocity (30, 45 or 60 km/h) within each level of time-to-arrival. The initial distance of the van was calculated from van velocity and initial time-to-arrival:

$$\text{initial distance} = \text{van velocity} \times \text{initial time-to-arrival.} \tag{9}$$

The levels of initial distance were not absolute values as they depended on the levels of time-to-arrival, which in turn depended on each participant's crossing times in the training trials. Initial distance tends to be closer when either van velocity is low or initial time-to-arrival is short. Note that there is no guarantee that all the initial distances at the lowest van velocity (or shortest time-to-arrival) were in fact closer than all the initial distances at the two higher van velocities (or two longer time-to-arrivals). This is because the specific distribution of initial distances depended on the distribution of the participant's training cross times (i.e. how much less their shortest training cross time was than their mean training cross time). A sample of the actual levels of time-to-arrival and distance for one participant is shown in Appendix C to illustrate this point.

The three dependent variables used to measure performance are shown in Table 7.

Table 7. Dependent variables for Experiment 2.

Variable	Description	Unit
Walking Speed	The speed with which the participant crossed the lane	m/s
Tight Fits and Collisions	Crossings in which the participant was hit or was close to being hit	-
Safety Ratio	The ratio of available crossing time to time taken to cross	-

Walking speed was calculated as the average speed over the distance from 0.5-m forward of the starting position to the middle of the road. A tight fit was defined as a crossing in which the participant was within 0.5-s of being hit by the van (but was not hit). A collision was a crossing in which the participant was hit by the van. The participant was hit when their position (i.e. eye position / camera point of view) came within the width and length bounds of the van's position (height dimension was not considered). Tight fits and collisions were pooled into one category that represents unsafe crossing trials.

Safety ratio is the ratio of available crossing time to actual time taken to cross to safety:

$$\text{safety ratio} = \text{time-to-arrival} / \text{time-to-cross}, \qquad (10)$$

where time-to-arrival is the initial time-to-arrival of the van (i.e. the independent variable described above) and time-to-cross is the difference between when the participant brings the van into their field of view, and when they have crossed past the far edge of the van's extent in the lane (i.e. has reached a safe position). Safety ratio is a ratio of an environmental variable (time-to-arrival) to an individual variable (time-to-cross) and is a dimensionless measure. A safety ratio of 1.0 is the boundary case of collision/ non-collision and means that the participant reached a safe position on the road at exactly the same time as the van arrived at their crossing path. A safety ratio of less than 1.0 means that the participant took longer to cross to a safe position than it took for the van to arrive at their crossing path, therefore a collision between participant and van must have occurred. A safety ratio of greater than 1.0 means that the participant crossed to a safe position before the van arrived at their crossing path, therefore they crossed to a safe position without collision. For example, if the initial time-to-arrival of the van was 5 s, and the participant crossed to a safe position in 4 s, then the safety ratio would be 5/4 = 1.25 which is a 25% margin of safety. Margin of safety is intuitively easy to understand as it expresses relative safety as a percentage, and is related to safety ratio by the formula:

$$\text{margin of safety} = (\text{safety ratio} - 1) \times 100. \qquad (11)$$

4.2.4 Procedure

Participants were tested individually. They were given time to read the instruction sheet (Appendix D) and the opportunity to ask questions regarding the task. At the start of each trial, the participant was positioned by the experimenter to stand at the same place and face the same direction. The participant walked from one end of the rectangular testing area and returned to the starting place over the course of one trial. When crossing towards the centre of the road, the participant was instructed to walk towards the tree, and when returning to the starting position they were instructed to walk towards the street light (see Figure 13). These objects were positioned in the virtual environment such that if the participant stayed roughly on a walking path between them, they would also stay within the confines of the testing area. The experimenter walked beside the participant to ensure that if they strayed from the intended walking path, that they would not collide with objects on the perimeter of the testing area. At the end of each trial, a black inter-trial screen with white text instructed the participant to prepare for the next trial. Participants were advised that they could withdraw from the experiment at any stage if they felt unwell.

4.3 Results

Some of the performance data for the various dependent measures was invalid and was manually deleted. Even though instructed not to, participants sometimes stopped part way across the road (this tended to occur when participants thought they had been hit or were about to be hit by the van). In this case the walking speed and safety ratio data for the trial were deleted, as inclusion would have contaminated the results. When a participant did not attempt to cross in front of the van, all of the data for the walking speed, safety ratio, tight fits and collisions were deleted. Empty cells were replaced using the method of mean substitution of missing data. This method replaces all missing data for a variable by the mean of that variable (across all participants), and has the effect of reducing variation of scores and affects tests of significance. The advantage of the substitution method is that participants with missing data are not discarded entirely (an alternative method of treating empty cells), which given the relatively small number of participants would have been undesirable.

4.3.1 Walking speed

A comparison of the walking speeds in the various real and virtual world conditions is shown in Figure 15. Participants walked considerably faster when told to walk as if in a rush than when walking at their normal pace. In the real world, participants walked 63%

faster when rushing, compared with a 57% speed increase in the virtual world when rushing. Participants walked slightly faster in the real world than in the corresponding virtual world conditions. When walking at normal pace, participants were 23% faster in the real world, and when walking in a rush they were 28% faster in the real world.

The average maximum walking speed attained by participants in experimental trials was 27% faster than the average walking speed in the virtual environment when told to walk as if in a rush. This shows that participants walked faster when the situation *demanded* walking in a rush (crossing in front of the van to ensure virtual safety) than when *instructed* to walk in a rush (but not otherwise motivated to do so). A post hoc comparison using the Tukey honest significant difference test revealed that there were significant differences between all conditions except the real-world rushing condition and the average maximum walking speed attained in the virtual environment experimental trials.

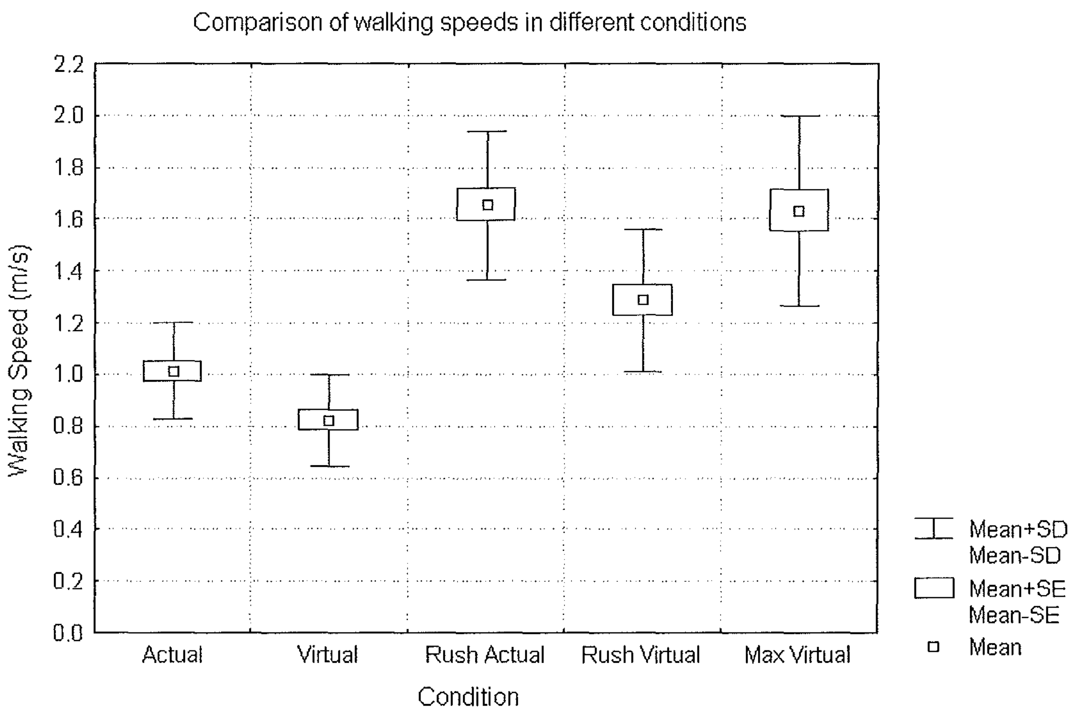

Figure 15. The graph shows the mean, standard error and standard deviation of the walking speeds of the 19 participants in the five different conditions. The Actual condition is the participant's normal walking speed in the real world (with the HMD on their head). The Rush Actual condition is walking speed in the real world when told to walk as if in a rush. The Virtual condition is the mean walking speed in the first five training trials, in which participants crossed the virtual road with no traffic. The Rush Virtual condition is the walking speed in the last training trial, in which participants were told to walk as if in a rush. The Maximum Virtual condition is the maximum walking speed attained in the experimental trials, in which participants had to cross in front of the approaching van.

4.3.2 Safety ratio

A 4-way (3 times-to-arrival × 3 velocities × 2 blocks × 2 genders) ANOVA with repeated measures on the first three factors was performed on the safety ratio data. Main effects of initial time-to-arrival, van velocity and block were significant, as well as a significant interaction of van velocity and time-to-arrival. The main effect of gender was marginally significant as was the interaction of block and van velocity.

Figure 16 shows the interaction of initial time-to-arrival and van velocity. The main effect of time-to-arrival, $F(2,34) = 87.21$, $p<.0000$, shows that that participants left a greater margin of safety when time-to-arrival was longer. This is an obvious result given that safety ratio is calculated by dividing available crossing time (initial time-to-arrival) by actual crossing time. In the shorter time-to-arrival conditions participants could only cross safely if they walked quickly, meaning they could not achieve high safety ratio values in these conditions. If there is less time available in which to cross the road, crossings will tend to be less safe. The main effect of van velocity, $F(2,34) = 25.77$, $p<.0000$, can be seen and shows that participants left a greater margin of safety when the van velocity was lower. The interaction shows that the effect of van velocity increases at the longer levels of initial time-to-arrival. The interaction is likely a result of the fact that high safety ratios are not as likely at the shorter level of time-to-arrival, as in this case the participant must walk relatively quickly just to avoid collision.

Figure 17 shows the marginally significant interaction of block and van velocity. The mean safety ratio in the first block of trials was 1.39 compared with 1.51 in the second block of trials with $F(1,17) = 13.49$, $p<.0019$. This learning effect shows that participants were crossing the road with a 12% greater margin of safety in the second set of trials. The interaction shows that the learning effect was greater at 30 km/h than at the higher two van velocities.

The marginally significant main effect of gender, $F(1,17)=2.74$, $p<.1164$, shows that females tended to cross the road with a higher margin of safety than males, with safety ratios of 1.51 for females and 1.40 for males.

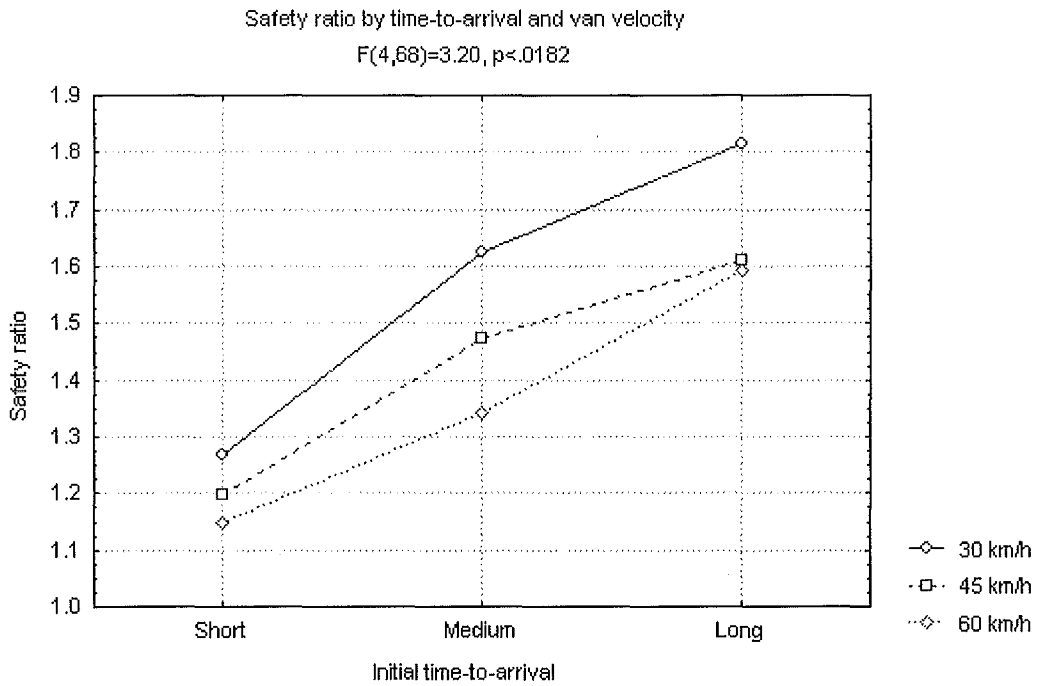

Figure 16. Interaction of initial time-to-arrival and van velocity as indexed by the safety ratio.

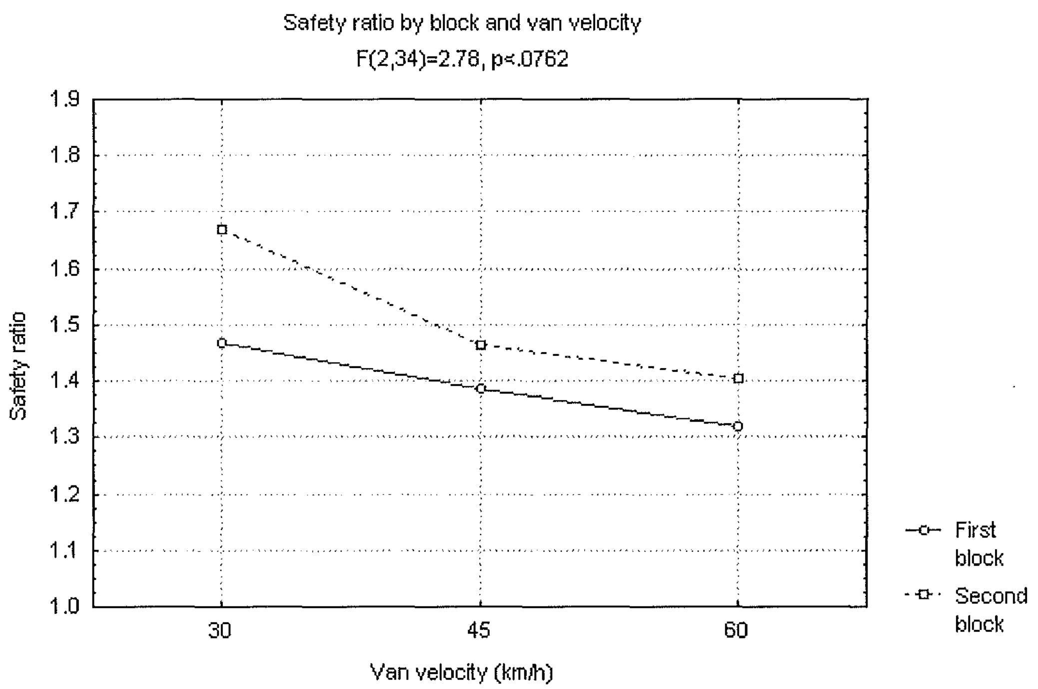

Figure 17. Interaction of block and van velocity as indexed by the safety ratio.

4.3.3 Tight fits and collisions

Tight fits and collisions index unsafe road-crossings. Unsafe crossings occur when the participant leaves an inadequate safety margin, hence tight fits and collisions correspond to crossings with low safety ratios (a safety ratio of less than 1 is a collision). A 4-way (3 times-to-arrival $\times$ 3 velocities $\times$ 2 blocks $\times$ 2 genders) ANOVA with repeated measures on the first three factors was performed on tight fits and collisions. The main effects of time-to-arrival, van velocity and block were all significant, as well as significant 2-way interactions of time-to-arrival with van velocity and block.

Figure 18 shows the interaction of time-to-arrival with van velocity for the proportion of unsafe crossings. As expected, there was a lower proportion of unsafe crossings when the participant had more time in which to cross, as indicated by the main effect of time-to-arrival $F(2,34) = 56.301$, $p<.0000$. The main effect of van velocity reveals that there were fewer tight fits and collisions when the van velocity was lower, $F(2,34) = 7.53$, $p<.0020$. The interaction of time-to-arrival with van velocity shows a floor effect where a long time-to-arrival leads to a near-zero proportion of unsafe crossings, regardless of velocity.

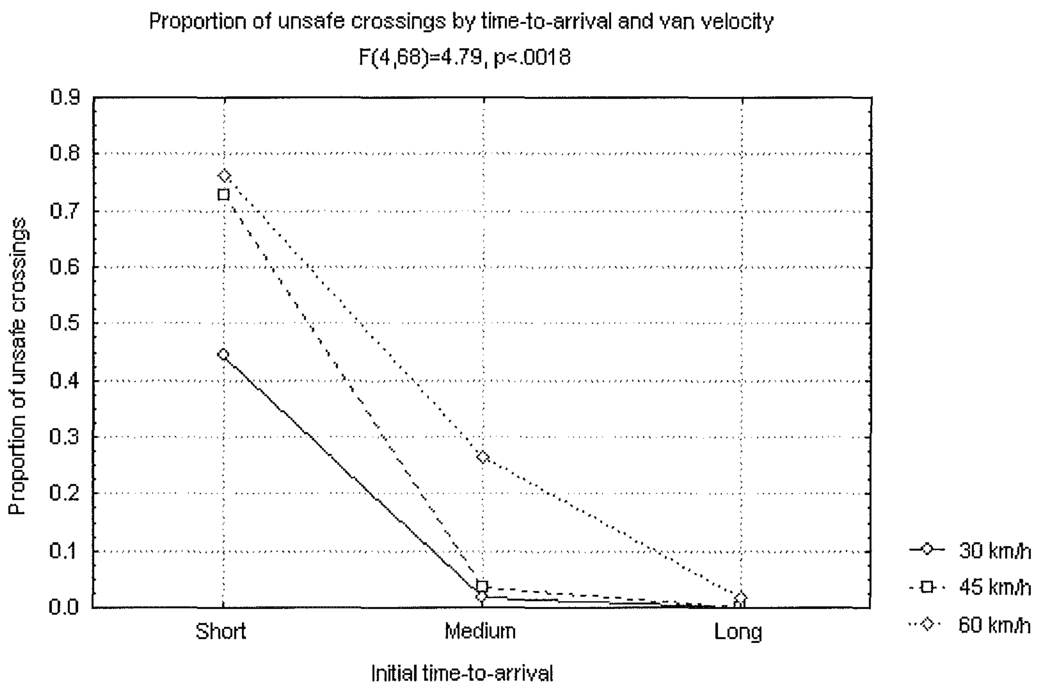

Figure 18. Interaction of initial time-to-arrival and van velocity as indexed by the proportion of unsafe crossings.

Figure 19 shows the interaction of initial time-to-arrival and block. The mean proportion of unsafe crossings in the first block of trials was 0.31 compared with 0.20 in the second block of trials, $F(1,17) = 6.70$, $p<0.0191$. This shows that participants learnt to cross safely more often with practice. The interaction shows another floor effect where a long time-to-arrival leads to a near-zero proportion of unsafe crossings, regardless of block.

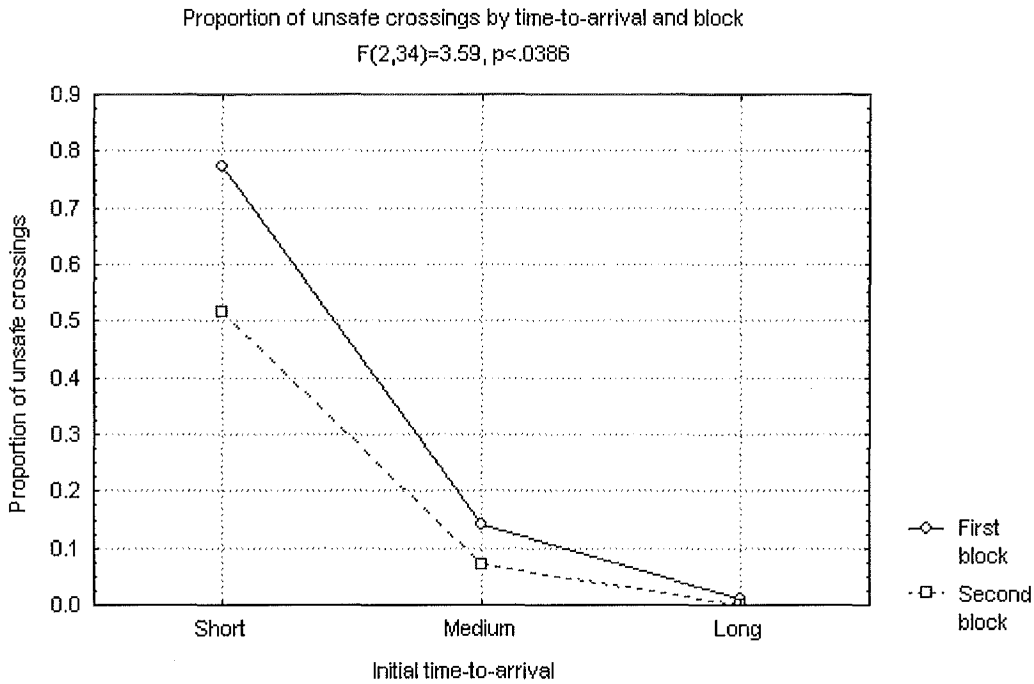

Figure 19. Interaction of initial time-to-arrival and block as indexed by the proportion of unsafe crossings.

4.3.4 Summary

Participants walked 25% faster in the real world than in the virtual environment, both when walking at normal speed and when told to rush. The maximum walking speed in experimental trials was not significantly different from their real-world rushing speed however. Main effects of time-to-arrival, van velocity and block were found for both the safety ratio and proportion of unsafe crossings. It was found that the safety ratio was higher and unsafe crossings fewer when the van velocity was lower, the time-to-arrival longer, and after participants had completed the first block of trials. The learning effect was found to be greatest at the lowest van velocity (30 km/h). The small effect of gender for safety ratio suggested that females crossed slightly more safely than males.

4.4 Discussion

Participants were shown to walk relatively faster in the real world than in the virtual environment. The degree to which participants walked faster in the real world is a measure of the fidelity of the simulation and participants' confidence in it. The experiment was by necessity conducted in a confined indoor environment where participants may well have had concern for the location of walls and furniture. If participants are concerned about their real-world position while in the virtual environment, then they will tend to behave cautiously and walk more slowly. The limitations of the VR system, such as display resolution, field of view and update rate of the tracker tend to reduce the fidelity of the simulation and consequently are likely to reduce the participant's abilities in the virtual environment (such as walking speed) when compared to those in the real world. Reduction of the relative importance of these factors would be possible by conducting further experiments in a less confined environment and by improving the fidelity of the simulation (see Section 4.4.2)

The results revealed that there was no difference between rushing walking speed in the real world and the maximum walking speed attained in the experimental trials. This shows that when given adequate motivation (avoiding virtual collision), participants were prepared to walk as fast in the virtual environment as in the real world. This indicates that participants found the simulation of the road-crossing task a compelling one. Comparison of real-world with virtual environment performance is important because it provides an objective criterion for immersion in a virtual situation.

Participants crossed the road with higher safety ratios and a lower rate of unsafe crossings when the van velocity was lower. A lower van velocity did not mean that the participant had more time available to cross, since in this case the van would have started at a closer initial distance (see Equation 9). It seems counter-intuitive that participants would tend to walk faster to achieve higher safety ratios because van velocity was lower, however this result can be explained by considering that initial distance tends to be closer when van velocity was lower. It appears then that participants used distance to determine how fast to cross the road (and what safety margin they left). In one sense this behaviour is again counter-intuitive – the important information as far as crossing the road safely is concerned is how much distance in *time* the participant has to cross, not how much distance in *space* they have (which does not take account of vehicle velocity). If the demand characteristics of the task are considered however, participants' behaviour can be interpreted more favourably. The task had participants presuppose that they were already committed to crossing the road, and all they had to determine was how fast to walk in order to cross safely. The longer participants took to observe the approaching van, the less time they had available to cross the road. This encouraged participants to look towards the van only briefly before crossing the road. Information about distance may be picked up in a glance, as it is not dependent on changes over time. Information about velocity (and time-to-arrival) is specified by transformations over time and so necessarily takes more time to perceive. Time-to-arrival, the functionally important variable for road crossing, is related to both distance and velocity as shown in Equation 9. This means that if distance is known but velocity (or time-to-arrival) is not known (or not known precisely), then using distance as a guide to walking speed is a sensible first approximation. In this light then, participants use of initial distance was appropriate given the task demands of the road-crossing situation. Also note that when crossing a road in the real world, people may use knowledge about speed limits or average speeds to determine crossing speed, thus making distance a reasonable approximation for relative crossing time. A generalization of this strategy to the virtual environment task is another possible explanation for participants' use of initial distance as a guide to crossing speed. The findings are also consistent with those of Connelly et al (1996, 1998), that children under the age of 12 base their road-crossing decisions on distance information. Further research is needed to determine which of the above interpretations provide the best explanation for the effect of initial distance (see Section 4.4.1).

Figure 18 shows that when time-to-arrival is medium, there are few unsafe crossings when van velocity is low or medium, but a high proportion (around 35%) of unsafe crossings at the high van velocity. This is the case when the participants should have adequate time to cross the road (medium time-to-arrival), but appear to misjudge the available time when the van is travelling rapidly (and tends to be far away). When time-to-arrival is short, there are fewer tight fits or collisions when velocity is low (and distance tends to be close). In this case participants appear to perceive the danger and make an extra effort to rush across in front of the van.

The use of the safety ratio as a performance measure has proved successful. It has been shown to be sensitive to both the functionally important variable of road crossing (initial time-to-arrival) and to a functionally irrelevant variable used by the participant (initial distance). Safety ratio is a unit-less measure that expresses the relative safety/ risk of a road-crossing event. It allows meaningful comparisons between events that are not possible if absolute measures such as walking speed are used (a given walking speed may be fast for one person and slow for another). The present study has shown that affordance analyses can be extended beyond the geometric domain to parse temporal event properties as well.

The marginally significant main effect of gender suggests that females crossed the road with less risk than males. A self-report study investigating risky behaviour found that males took significantly more risks in the areas of drug use, driving and gambling, but that there were no gender differences in the areas of smoking, drinking and sex (Zuckerman & Kuhlman, 2000). An observational study found that males were more likely to proceed through a traffic light changing from yellow to red than were females (Konecni, Ebbesen & Konecni, 1976). These risk related gender difference findings suggest that females are less likely to accept high risk than males in the road-crossing simulation. Future experiments should recruit a larger and balanced number of male and female participants to investigate possible gender effects.

4.4.1 Design extensions

The present experiment found that participants used initial distance to the van to decide how quickly to cross the road. As discussed above, this could (at least in part) be due to the forced-choice nature of the task demands. If the task were changed to one in which participants had a choice whether to cross in front of an approaching vehicle, or to wait until it passed, would the effect of initial distance still be found? In this case participants would not be pre-committed to crossing in front of the van and would not be disadvantaged by taking more time to assess how quickly they must walk to cross safely. Another important question is whether participants can be taught to disregard the irrelevant distance information (i.e. distance taken without reference to vehicle velocity is irrelevant, taken together they determine time-to-arrival which is the functionally important variable for road crossing). For example, participants could be told "distance to the van and speed of the van together determine how much time you have to cross the road – this means you do not necessarily have less time to cross when the van starts closer to you, or more time to cross when the van starts further away". Alternatively, participants could be trained to pay attention to time-to-arrival information by displaying an additional visual cue. For example, an approaching van could gradually change in colour from green to amber to red as it came closer in time.

In the present experiment, the initial distance to the van was varied in order to set the desired levels of van velocity and time-to-arrival (see Equation 9). When three variables are related in such an equation, it is always necessary to let one vary freely in order to set the desired levels of the other two variables. Because it was chosen to co-vary distance with velocity and time-to-arrival it is in theory not possible to determine whether a given effect is due to a variation in velocity/ time-to-arrival or a variation in distance. In the case of van velocity, the results were in fact best explained in terms of the variation in distance (see Section 4.4). The case of time-to-arrival is more complex. In terms of safety ratio or unsafe crossing effects, these effects are best explained by the variation in time-to-arrival, as this is the functionally important environmental variable for safety. However, if effects were found in terms of crossing time (walking speed), then these could be explained by *either* the variation in initial time-to-arrival or the variation in initial distance. If for example, participants crossed the road more quickly when time-to-arrival was short, then this could be because they perceived time-to-arrival to be short *or* because they perceived the initial distance to be short. For this reason, the results in terms of crossing time were not included in the present study. In a future study, Equation 9 should be rearranged so that the levels of time-to-arrival and distance are set, and velocity is free to vary. This design alteration will allow investigation of participants' sensitivity to time-to-arrival and distance independently.

It is not possible in this experiment to determine whether participants were using distance to the van or optical size of the van as informative, because the two variables were linked in the design. If different sizes of van were used, then the effects of optical size and distance could be investigated independently. Studies have shown that time-to-contact estimations are less accurate for smaller objects, specifically that time-to-contact estimations increase as object size decreases (Caird & Hancock, 1994). This finding suggests that the safety ratio will decrease with decreasing van size. Another study found that observers based their judgements of time-to-contact on optical variables, and that judgements were unaffected by perceived distance (Gray & Regan, 1999). This suggests that the initial distance of the van may not have an effect when varied independently of optical size. Note also that optical size as determined by both van size and distance had an effect in Experiment 1a (although the task and performance measures here were quite different).

Changing the design from a forced choice situation would also allow investigation of another important aspect of road crossing, that of risk acceptance. The experiment could be designed so that the levels of time-to-arrival are based on training cross times as in the present experiment. However, instead using the somewhat arbitrary addition of 0.5 s to model reaction time (see Equation 8), the initial times-to-arrival could be calculated as proportions of the (mean or fastest) training cross time. In this way, the participant would be exposed to conditions of varying risk, and the minimum safety ratio that they are prepared to accept (i.e. cross with) could be determined.

Some people may be more susceptible to pedestrian accidents than others. A study correlating personality traits with performance in a driving simulator found that people with high-risk or deviant personality subtypes displayed lower levels of driving skill (Deery & Fildes, 1999). It would be of interest to investigate whether a similar correlation between risk-taking tendencies and road-crossing performance might exist. Road crossing is an everyday activity that involves risk, and the margin of safety is designed to be an index of risk in road-crossing events. A correlation between risk taking in real-world activities, and the level of risk accepted in the road-crossing simulation is therefore expected. The search for such a result can be seen as a validation test of both the simulation and the use of the margin of safety as a measure of risk.

None of the 19 participants tested in the virtual environment reported feeling ill as a result of the experimental conditions. Simulator sickness is however a major concern in VR systems, especially since evidence suggests that some users may be maladjusted to real-world tasks for some time following immersion in a virtual environment (c.f., Stanney, Kennedy, Drexler, & Harm, 1998; Cobb, 1998). In order to investigate possible incidence of simulator sickness in more detail, future experiments should require participants to complete the simulator sickness questionnaire developed by Kennedy, Lane, Berbaum & Lilienthal (1993) both before and after the experiment. Steps should also be taken to minimize the likelihood of simulator sickness effects posing a safety concern. Participants should be made aware of the possible after-effects arising from their involvement in the simulation, and advised not to drive a vehicle for at least one-hour after completion of an experiment.

4.4.2 Technical extensions

The present research indicates that VR can successfully be used in the study of road-crossing behaviour. There are also, however, some limitations and drawbacks inherent in using VR equipment. Some of these limitations can be addressed with design improvements and further software development, while others will likely be lessened in the future with the continued evolution of VR technology.

The HMD itself may limit the effectiveness of the simulation of an actual road-crossing situation. The weight of the HMD and restrictive nature of the cables leads to greater difficulty in looking and moving around the virtual environment than is normally experienced in the real world. It is possible, therefore, that participants who make unsafe road-crossings in the virtual environment do so because they are basing their judgements on when it is safe to cross at their *typical* walking speed, not fully taking into account the hindrance of the HMD. However, the pedestrian should be able to adapt to a slower walking speed; wearing the HMD could be considered analogous to crossing the road when carrying large or heavy items or perhaps suffering from a restrictive injury. More importantly, the HMD has a horizontal field-of-view of 48-degrees whereas normal human vision has a horizontal field-of-view of 180-degrees. This reduction in horizontal field-of-view has the effect of limiting peripheral vision and the ability to walk in one direction while looking in another. In the virtual environment participants tended to look towards the tree in order to know which direction they were walking. It is likely that participants in real-world settings look back towards the traffic during road crossing, hence acquiring more information about approaching traffic than is possible in the virtual environment. As HMDs become more sophisticated and lighter such restrictions will likely be reduced and the simulation of real road crossing will become more realistic still. Although the restrictions imposed by the HMD offer an explanation for the high overall rate of unsafe crossings, they cannot explain why there were relatively more unsafe crossings when initial distance was large.

The VR system used in this research has the potential to produce stereoscopic images but in the reported research, due to technical difficulties, the same image was presented to each eye. This type of (synoptic) imagery has been shown to reduce the perceived depth in an observed scene (Koenderink, van Doorn & Kappers, 1994, 1995), hence reducing perceivers' ability to accurately determine the distance of approaching vehicles. Although the use of synoptic images might have reduced the accuracy of the simulation in the present study, there was still information about distance available to perceivers – perspective, relative size, height in the field of view and motion parallax. Future research should, however, employ stereoscopic images. The update rate of the tracking system should also be increased from the relatively low 8 samples per second. This will reduce the 'lag' time between when head position or orientation is changed and when the display is updated to reflect this change. Sound should also be added to future simulations since the sound of approaching vehicles may provide additional useful information to pedestrians regarding time-to-arrival. Inclusion of sound effects must use an accurate algorithm, including appropriate variations in pitch, volume and 3-D spatialization. If the sound generation method used is not accurate, then information available to the participant from the modalities of sight and hearing will be in conflict.

5 General discussion

5.1 Findings summary and future research

Experiment 1 was composed of two driving simulation experiments with the primary purpose of investigating the relative merits of fractional rate braking control compared to the traditional linear mode of control. Measures of vehicle following performance and workload were recorded over a single braking episode in Experiment 1a and over a cycle of braking, constant speed, and acceleration in Experiment 1b. In Experiment 1a, it was found that vehicle following performance was superior and workload less with the fractional rate control type. It was also found that gap maintenance performance was worse when following a vehicle that was modelled to be braking in a fractional fashion. However, it was conceded that the assumptions behind the braking modelling need to be tested. The most pressing further research is to determine what the braking profiles produced with a fractional type control system are typically like, and how they compare to those produced with a linear type control system. Differences between control type or braking type were not found in Experiment 1b, and it is suggested that this was likely due to a decreased sensitivity to these variables in the design.

A preliminary study into the feasibility of examining road-crossing behaviour in virtual reality was successfully carried out in Experiment 2. The safety ratio, an affordance based performance measure, was used to score the relative safety of road-crossing events. Not surprisingly, it was found that when participants had more time in which to cross the road, they tended to cross more safely. However, it was also found that participants use distance information to judge how quickly to cross the road in front of an oncoming vehicle when this information is irrelevant. This finding was consistent with previous road-crossing research, but might also be explained as a consequence of the forced-choice design. Further research is required in order to determine whether the use of distance information is dependent on crossing conditions and/ or task demands. It is not known whether pedestrians are sensitive to time-to-arrival information independent of initial distance, or whether they can be taught to pay attention to time-to-arrival (and not distance) so that they might make safer road-crossing decisions. Future experiments are suggested to investigate these questions.

The tasks studied in the present simulation experiments have high ecological validity as they both match the constraints of everyday traffic situations. However, all simulations have limits to their fidelity and their complexity of modelling, and hence may not capture all of the functionally important variables for performance of the required tasks. Simulation studies therefore need to be validated. There are two aspects to validity, absolute and relative (Tornros, 1998). Absolute validity refers to the numerical correspondence between behaviour in the real and simulated situations, whereas relative validity refers to the correspondence between the effects of different variations in the situation. A simulation must have high relative validity, i.e. the effects obtained in the real and simulated situations must be the same or similar. Absolute validity is not necessarily a requirement as research questions are usually directed toward the effects of independent variables. For example, in Experiment 1 we are concerned that the effect of control type is similar in the real world to that found in the simulation, rather than the exact correspondence of braking rates or distance error between the real-world and simulated situations. Absolute validity in Experiment 2 is unlikely to be high as the collision rate was much higher than in reality. Estimates from Sweden, for example, suggest that a pedestrian will cross a road 500,000 times before they are involved in a collision (Vägverket, 1997). In Experiment 2, a collision occurred once every 14 road-crossings (although these figures are not directly comparable as the simulation involved a forced road-crossing). In fact, the higher rate of collision is advantageous for the purposes of analysis and participant training, as there are more opportunities to study the conditions that lead to collisions and for participants to learn from their mistakes. The relative validity of the simulations is yet to be established. For Experiment 1, this would involve testing the relative vehicle following performance of a fractional rate control system in an actual car. For Experiment 2, this would involve testing the effects of initial distance and initial time-to-arrival using observational testing of pedestrians in the real world.

5.2 End goal: An interactive simulation system

A car following situation like that simulated in Experiment 1 involves both a lead vehicle driver and a following driver. The road-crossing situation simulated in Experiment 2 involves a vehicle driver and a pedestrian. In both simulations, the former was computer controlled and the latter represented by the experimental participant. Many interesting traffic situations involve two or more participants, and ideally these inherently social situations should be investigated where one or more parties can simultaneously participate. This can be achieved through the development of an interactive simulation system designed to study applied problems in traffic-related situations. The system should be flexible enough to allow for differing numbers of participants and to be configured to study a number of traffic-related situations involving traffic lights, controlled and uncontrolled intersections, roundabouts, lane changing, overtaking, and cornering etc. In the present study, both experiments used computer simulation to model the behaviour of one of the participants. The advantage of computer modelling is that precise control over variables is possible, but this may be at the expense of realism (e.g. the modelling of fractional braking in Experiment 1 may not be realistic). A flexible simulation system will allow for series of complimentary single- and multiple-participant experiments to be conducted. Findings from more controlled single-participant experiments can be validated in more complex multiple-participant environments, and data from multiple-participant experiments can be used as the basis for modelling in single-participant experiments. Due to ongoing advances in computer processing power, the main constraint on the development of such a system is now programming time and resources rather than the expense of the required hardware. The system will have great potential to study the social psychology of traffic situations, to be used as both a test bed for new ideas and as a training tool, with an end goal of understanding and increasing traffic-related safety.

6 References

Bannatyne, R. T. (1999). Electronic braking control developments. *Automotive Engineering, 2*, 125-127.

Caird, J. K., & Hancock, P. A. (1994). The perception of arrival time for different oncoming vehicles at an intersection. *Ecological Psychology, 6*, 83-109.

Cobb, S. V. G. (1998). Measurement of postural stability before and after immersion in a virtual environment. *Applied Ergonomics, 30*, 47-57.

Connelly, M.J., Conaglan, H.M., Parsonson, B.S., & Isler, R.B. (1998). Child pedestrians' crossing gap thresholds. *Accident Analysis and Prevention, 30,* 443-453.

Connelly, M.J., Isler, R., & Parsonson, B.S. (1996). Child pedestrian's judgements of safe crossing gaps at three different vehicle approach speeds: A preliminary study. *Education and Treatment of Children, 19*, 19-29.

Deery, H. A., & Fildes, B. N. (1999). Young novice driver subtypes: Relationship to high-risk behaviour, traffic accident record, and simulator driving performance. *Human Factors, 41*, 628-643.

Demetre, J. D., & Gaffin, S. (1994). The salience of occluding vehicles to child pedestrians. *British Journal of Educational Psychology, 64*, 243-251.

Demetre, J.D., Lee, D. N., Grieve, R., & Pitcairn, T. K., Ampofo-Boateng, K., Thomson, J. A. (1993). Young children's learning on road-crossing simulations. *British Journal of Educational Psychology, 63*, 349-359.

Demetre, J.D., Lee, D. N., Pitcairn, T. K., & Grieve, R., Thomson, J. A., Ampofo-Boateng, K. (1992). Errors in young children's decisions about traffic gaps: Experiments with roadside simulations. *British Journal of Psychology, 83*, 189-202.

Fechner, G. (1966). *Elements of psychophysics* (Vol. 1). (Translated by H.E. Adler, edited by D. H. Howes & E. G. Boring). New York: Holt, Rinehart & Winston. (Original work published 1860)

Gibson, J.J. (1961). The contribution of experimental psychology to the formulation of the problem of safety: A brief for basic research. *Behavioral approaches to accident research* (pp. 77-89). New York: Association for the Aid of Crippled Children.

Gibson, J. J. (1977). The theory of affordances. In R. E. Shaw & J. Bransford (Eds.), *Perceiving, acting and knowing: Toward an ecological psychology*. Hillsdale, NJ: Erlbaum.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.

Gray, R., & Regan, D. (1999). Do monocular time-to-collision estimates necessarily involve perceived distance? *Perception, 28*, 1257-1264.

Hallford, E. W. (1984). *Sizing up the world: The body as referent in a size-judgement task.* Unpublished doctoral thesis. The Ohio State University, Columbus, OH.

Jarvis, J. R. (undated). *The braking behaviour of heavy vehicle drivers*. Australian Road Research Board.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*, 203-220.

Konecni, V. J., Ebbesen, E. B., & Konecni, D. K. (1976). Decision processes and risk taking in traffic: Driver response to the onset of yellow light. *Journal of Applied Psychology, 61*, 359-367.

Koenderink, J.J., van Doorn, A.L., & Kappers, M.L. (1994). On so-called paradoxical monocular stereoscopy. *Perception, 23,* 583-594.

Land Transport Safety Authority (1999). *The official New Zealand road code and licence guide for car drivers (1st ed.).* Wellington, New Zealand: DLM Campaign Ltd.

Land Transport Safety Authority, WORKS Consultancy Services. (1992). *Manual of traffic signs and markings (3rd Ed.).* Wellington, New Zealand: Transit New Zealand; Land Transport Division, Ministry of Transport.

Land Transport Safety Authority (1998). *Motor accidents in New Zealand: Statistical statement: Calendar year 1998.* Wellington, New Zealand.

Lee, D.N., Young, D.S., & McLaughlin, C. M. (1984). A roadside simulation of road-crossing for children. *Ergonomics, 27*, 1271-1281.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of time-to-contact. *Ecological Psychology, 8*, 71-99.

Oudejans, R. R. D., Michaels, C. F., van Dort, B., & Frissen, E. J. P. (1996). To cross or not to cross: The effect of locomotion on street-crossing behaviour. *Ecological Psychology, 8*, 259-267.

Owen, D. H. (1984). Optical flow and texture variables useful in detecting decelerating and accelerating self-motion. *Interim Paper AFHRL-TP-84-4.* Ohio State University Research Foundation and Air Force Human Resources Laboratory, Brooks Air Force Base, Texas.

Owen, D. H. (1990). Perception and control of changes in self-motion: A functional approach to the study of information and skill. In R. Warren & H. Wertheim (Eds.), *Perception and control of self-motion* (pp. 289-326). Hillsdale, NJ: Erlbaum.

Owen, D. H. (1993). Alternative modes of control and visual information for rotorcraft flight: Control of path speed during approach to landing. *Interim Technical Report, Project RG 1689617.* University of Canterbury and NASA Ames Research Centre.

Spurr, R. T. (1965). Subjective assessment of brake performance. *Automobile Engineer, 55*, 393-395.

Spurr, R. T. (1969). Subjective aspects of braking. *Automobile Engineer, 59*, 58-61.

Stanney, K. M., Kennedy, R. S., Drexler, J. M., & Harm, D. L. (1998). Motion sickness and proprioceptive aftereffects following virtual environment exposure. *Applied Ergonomics, 30*, 27-38.

Tignor, S. C. (1966). Braking performance of motor vehicles. *Public Roads, 34,* 69-83.

Tornros, J. (1998). Driving behaviour in a real and a simulated road tunnel – a validation study. *Accident Analysis and Prevention, 30,* 497-503.

Vägverket (March, 1997). Swedish National Road Association.

Warren, W. H, (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 683-703.

Weiler, J. M., Bloomfield, J. R., Woodworth, G. G., Grant, A. R., Layton, T. A., Brown, T. L., McKenzie, D. R., Baker, T. W., & Watson, G. S. (2000). Effects of fexofenadine, diphenhydramine, and alcohol on driving performance. *Annals of Internal Medicine, 132*, 354-363.

Zuckerman, M., & Kuhlman, D. M. (2000). Personality and risk-taking: Common biosocial factors. *Journal of Personality, 68*, 999-1029.

7 Appendices

7.1 Appendix A: Experiment 1a instruction sheet

If you are left-handed please use one of the two computers on the bench below the windows, as the joystick can be positioned accordingly.

You are about to take part in a driving simulation experiment. Each trial of the simulation begins with you driving behind a bus at a certain distance and speed. After a few seconds, the bus will begin to decelerate (brake). Also at this time you gain control over your speed by using the small black joystick mounted on the counter top in front of you. The joystick acts as both an accelerator and brake. To speed up, push forward on the joystick. The further you push forward the faster you will accelerate. To slow down, pull back on the joystick. The further you pull back, the faster you will brake. Note that you cannot control your speed **until after** the bus has started to decelerate. The bus will not initiate braking until the joystick has been centred for a few seconds, so try to remember to centre the joystick before starting each trial - that is, open your hand so that it is not touching the knob.

Your task is to maintain the initial distance between yourself and the bus in front of you for the duration of the trial – that is, keep the separation the same as it was when the trial began. A numerical measure of your performance is shown at the conclusion of each trial. This number represents your error in distance throughout the duration of the trial (technically your RMS or Root Mean Squared error). Good performance corresponds to a small error value, poor performance a large value. Perfect performance would result in zero error, and would be achieved by exactly maintaining the initial distance between the bus and yourself throughout the duration of the trial (although this is probably not possible in practice).

There are two parts to the experiment. Each part is the same except that the properties of your controller differ. Each part consists of 42 trials of around 10-seconds duration. The first few trials are training trials provided to acquaint you with the task. Data will not be recorded from these trials. Once you have finished the first part of the experiment, raise your hand and the supervisor will show you how to begin the second part. If you find that you are losing concentration then take a short break before starting the next trial, or second part. If you feel ill, do not continue with the lab and inform the supervisor of your condition.

7.2 Appendix B: Experiment 1b instruction sheet

Note: If you are **left-handed** please use one of the two computers on the bench below the windows, as the joystick can be positioned accordingly.

You are about to take part in a driving simulation experiment. Each trial of the simulation begins with you driving behind a bus at an initial constant speed. The bus will speed up, slow down, and travel at constant speeds for varying periods of time. Your task is to maintain the **initial** distance between yourself and the bus in front of you for the duration of the trial – that is, keep the separation the same as it was when the trial began.

Your task is to maintain the initial constant distance between yourself and the bus in front of you.

You can control your speed by using the small black joystick mounted on the counter top in front of you. The joystick acts as both an accelerator and brake pedal. Pushing the joystick forward is like pushing your foot down on the accelerator of a car. If you hold the joystick forward by a constant amount, you will accelerate until you reach a certain speed and then maintain this speed. If you then pull the joystick back a little (so it is still forward, but by a lesser amount), then you will gradually slow down, just as you slow down due to engine braking and friction in a real car when you raise your foot a little from the accelerator. Pulling the joystick backwards is like pushing your foot down on the brake pedal of a car. The further you pull the joystick back the faster you will brake, just as pushing further on the brake pedal of a car will give rise to faster braking.

It is possible (though obviously undesirable) to collide with the bus. Implicit in the task of maintaining a constant separation distance between yourself and the bus is avoiding collision. If you do collide with the bus, you should simply slow down and continue the driving task – the trial does **not** end when collision occurs.

The experiment consists of two sessions with 21 trials of 60-seconds duration in each session. The first three trials of each session are training trials provided to acquaint you with the task. Data will not be recorded from these trials. Once you have finished the first session, raise your hand and the supervisor will show you how to begin the second session. If you find that you are losing concentration then take a short break before starting the next trial, or second session. If you feel ill, do not continue with the lab and inform the supervisor of your condition.

7.3 Appendix C: A sample of the levels of independent variables in Experiment 2

Table 8 shows the levels of van velocity, initial distance and initial time-to-arrival for a participant from Experiment 2. There were three levels of van velocity (30, 45 and 60 km/h) and these levels were the same for each participant. There were also three levels of time-to-arrival but the actual values varied between participants as they were determined by their training cross times (see Equation 8). There were nine levels of initial distance. Note how initial distance tends to be smaller when van velocity is low and when time-to-arrival is short. The levels of van velocity and time-to-arrival together determine the value of initial distance (see Equation 9).

Table 8. A sample of the actual values and categories of independent variables in Experiment 2.

Block	Van velocity (m/s)	Initial distance (m)	Time-to-arrival (s)	Time-to-arrival (category)
First	8.3333	19.3407	2.3209	Short
First	8.3333	24.6772	2.9613	Medium
First	8.3333	30.0137	3.6016	Long
First	12.5	29.0111	2.3209	Short
First	12.5	37.0158	2.9613	Medium
First	12.5	45.0206	3.6016	Long
First	16.6667	38.6815	2.3209	Short
First	16.6667	49.3545	2.9613	Medium
First	16.6667	60.0275	3.6016	Long
Second	8.3333	19.3407	2.3209	Short
Second	8.3333	24.6772	2.9613	Medium
Second	8.3333	30.0137	3.6016	Long
Second	12.5	29.0111	2.3209	Short
Second	12.5	37.0158	2.9613	Medium
Second	12.5	45.0206	3.6016	Long
Second	16.6667	38.6815	2.3209	Short
Second	16.6667	49.3545	2.9613	Medium
Second	16.6667	60.0275	3.6016	Long

7.4 Appendix D: Experiment 2 instruction sheet

You are about to take part in a road crossing simulation. You will wear a virtual reality helmet that displays a straight, flat stretch of road. You can look around by turning your head and move around by walking.

Before the experimental trials, there will be a block of 6 trials to familiarise you with walking around in the virtual environment. There will be no traffic in these trials. When you have crossed the first lane, you will hear a verbal instruction to turn around and return to your starting position. It is important that once you have begun walking towards the tree, that you **keep walking until you hear the instruction to turn around**. Do not stop walking until you hear the instruction. At this point you should turn to your right and walk back across the road towards the street light that you will see in front of you.

In the experimental trials, assume that you have committed yourself to crossing the road every time. What you have to determine is how **fast** you need to walk to avoid being hit by an oncoming vehicle. Begin each trial by facing the tree, then turn your head to look towards the right before crossing the road. When you look to your right you will see a van travelling down the road towards you. **You must cross the road in front of this van**. Do not wait for the van to pass before crossing. If you cross quickly enough you will be able to avoid being hit by the van. Again, it is important that you keep walking until you hear the instruction to turn around. There will not be any traffic as you return to the start position and you may walk back at any speed.

The experimenter will walk beside you to make sure that you do not walk into anything.