HOW MUCH VISUAL ATTENTION DOES BRAKING REQUIRE? A STUDY OF THE EFFECT OF MEMORY OF THE SCENE ON DRIVER'S BRAKING BEHAVIOUR

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Abstract – Braking is a common activity of driving. An important question as yet remains unanswered: how much attention, both visual and mental, is required to execute a correct braking response? We measured drivers' abilities to stop accurately at visually pre-designated positions. We compared performances in two conditions: with and without continued visual input during the braking action.

We found that drivers' responses differ as a function of temporal demand. When the temporal demand is high, drivers use visual information after the brake onset to adjust the braking effort. When the visual information is available, drivers brake faster, shorter and harder. Drivers' brake timing was least effective to control the distance when the temporal demand was low and visual was occluded during braking.

Key words: driver behaviour, braking control, occlusion technique, visual information, attention, distance perception.

1. Introduction

Roads present a myriad of opportunities for collision. Cars can run into each other; they can go off the road; they can hit other objects on the road. Braking is possibly the most common activity that drivers use to avoid collision [Mal1, Gik1]. By braking, drivers can control the speed and maintain an appropriate distance from the other objects on the road; hence braking reduces the probability of collision. While proper braking can save lives and limbs, improper braking can escalate the risk of collision: for example, if a driver brakes too hard in a highway lane, he increases the risk of rear-end collision by increasing the speed difference between his car and the following vehicle. In contrast, if a driver does not brake hard enough or early enough at a signalled intersection, he can block the intersection and increase the risk of collision.

Despite its fundamental role in driving safety, drivers' braking behavior is not well understood. Like other locomotion tasks, brake theories are based on the principle that a driver uses visual information of the motion of other vehicles to regulate his own motion. Current theories of braking assume drivers perceive possible collisions and, based on this information, change or maintain the course of motion to avoid a collision [see Lee1, Yil1, And1]. These theories propose that a driver's action is an almost automatic response of human motor system when the magnitude of certain visual parameters passes a threshold. The driver's role is to close the control loop and compensate the deviation from this threshold. These theories assume that during braking, drivers can perceive and use the parameters such as speed differential, distance or rate of visual expansion to control their braking response.

Although these theories describe how drivers can use the perceived information, they are less clear on how drivers actually behave [Gre1]. It is assumed that driver's decision to brake and the resulting braking pattern depends on driver's perception of changes in the driving scene, and on whether these changes require braking. Lack of attention and lack of skill are proposed as the main human causes of motor vehicle accidents. In case of braking, it is not known how these two factors interact with each other and shape the driver's response. Is braking a tacit skill that drivers execute with minimum dependency on feedback during its execution, or do drivers depend on the visual information to brake properly during the course of braking?

Driving is considered mainly as a visual task. Some research claims that the visual channel accounts for 90% of the information acquired and used in driving [Siv1]. Most of the previous research on driving behaviour in general, and braking behaviour in particular, has been focused on predicting the behaviour based on the state of the traffic percieved in the front road. Drivers can use vision to estimate position and velocity, and to a lesser degree to estimate their acceleration and deceleration, particularly at lower levels of deceleration. However, previous research in human perception suggests that the perceptual world of human is different from the physical world. The visual space perception law of distance (and size) proposes the relation between the physical and the percieved world [Gli1]. Gilinsky's empirical theory formulates the perceived distance (d) as a function of real distance (D):

$$\frac{d}{D} = \frac{A}{A+D} \tag{1}$$

This relation can have a serious safety implication for driving and for our understanding of how drivers use visual information to control speed and distance with brake systems. It suggests that drivers perceive a world with more compressed distances relative to the reality. It also states that the greater distance, the greater the shortening. The maximum limit of the perceived distance is captured by A, which is an idiosyncratic parameter. If it holds in driving, Glisnky's hypothesis suggests that a drivers' visual system is equipped with a safety mechanism that magnifies the collision hazard and actually reduces the collision risk.

In this work, we have investigated whether Glisnky's hypothesis can explain drivers' braking behaviour in a simulated driving situation. In an experiment, we asked drivers to execute a series of braking maneuvers requiring a stop at a predefined spot on the road. The tasks were executed in a driving simulator where there were no driving hazards. It was expected that in scenarios with no visual input during the brake, drivers brake harder and quicker since they must rely on the shortened perceived distance at the start of the braking task.

Former experiments have shown the capabilities of drivers to perform some driving tasks in the absence of vision using preview or anticipation information [God1]. The vision channel may not be available for a short period of time during driving tasks, as drivers may not pay attention to the road scene or the visual scene maybe blocked by conditions such as rain, fog or smoke.

The need for vision in performing these tasks arises from the unpredictability and the consequent uncertainty that exists in driving environments. The time available to execute a maneuver can have a significant impact on the driving performance. The modified Fitt's speed-accuracy tradeoff predicts that the accuracy of a response is proportional to the magnitude and inversely proportional to the speed of that response. Braking tasks can occur at different driving speeds and at different amount of time available to respond. As the final question of this work, we wanted to know how driver braking pattern changes for different available braking time. Driver motor acuity in performing a braking task without seeing the driving scene during the brake is investigated. The hypothesis is that the lack of visual feedback degrades the braking performance more as the temporal demand of a braking event decreased. The basis for this hypothesis is that in braking events with low temporal demand, drivers have sufficient time to regulate the brake and use visual information to control the braking force. In sudden braking drivers highly dependent on their motor skill and may not use visual information to adjust their braking response. In the other word, when it comes to sudden braking, braking blindly may suffice.

2. Method

Driver perception input and control output were measured during braking events with different urgencies. It was assumed that drivers would devote their full attention (as required in a typical driving task) during the experiment: the attention level was not manipulated, nor was the effect of surprise tested.

2.1. Driving simulator

The experiment was carried out in a fixed-based NADS minisim driving simulator; the simulator provides a 130 degrees horizontal by a 24 degree vertical field of view at 48'' viewing distance. It mimics the sound of the vehicle and the surroundings using two speakers at the front. The roadway vibration is simulated using a speaker located below the driver's seat. The brake and gas pedals, the steering wheel, the automatic gearshift, and the seat are the same as those in an actual vehicle. The simulator measures both driver inputs and telematic data of the vehicle and surroundings at a rate of 60 Hz.

2.2. Participants

For this experiment, 24 participants (19 men and 5 women) with a valid Ontario Class G driving license were recruited from the University of Toronto community. All the participants provided written informed consent and were compensated with a payment of CDN $25. On average, the participants were 27 year old (SD=5years) and had obtained their (first) driving license 9 years previously (SD=5.1years). Four participants had used a driving simulator in the past. Based on the frequency and amount of driving, it was inferred that the majority of the participants (17 out of 24) drove at least once per week for more than 10 km, and 21 participants drove more than 1000 km per year; only one participant drove less than 100 km on an annual basis. During the experiment, the participants drove in cruise control mode before carrying out the braking tasks, and thus previous experience in using cruise control could have an effect on performance. Thirteen participants had used cruise control more than 1-2 times per year.

2.3. Experimental setup

Each participant completed a series of questionnaires, driving simulator tests and work load assessments (Fig. 1). In a simulator setting, the performance of the participants during a series of braking events was compared between the conditions that the information of the driving scene is present or absent. The time available for braking was changed by manipulating the trigger time of the braking event. The participants were instructed to 1) stop the vehicle by braking at a certain position on the road indicated by a circular patch with a drum at either side of the road (Fig. 2); and 2) maintain the vehicle in the centre of the road.

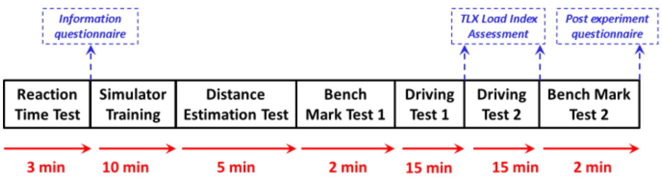

Fig. 1. Timeline of different stages of the experiment

Drivers were asked to respond "at" or "after" a fixed time before reaching to the stop target. The speed and path of the driving is kept constant; drivers drove at 60 mph and on a straight road. Half the participants were instructed to start braking right after hearing the beep or seeing the occluded scene; the other half were free to start braking at any time after the occlusion or beep sound. The participants were instructed not to pump their brakes.

Fig. 2. View of the stopping target

2.4. Reaction Time Tests

The visual and auditory reaction times of the participants were measured using two separate tests [Att1]. Each test consisted of 10 trials, among which the first five trials were used as practice runs. In the visual reaction time test, the participants had to click on the screen as soon as they saw a green balloon appeared. The balloon is always the same size and appears at the same location. In the auditory reaction time test, the participants had to click on the screen as soon as they heard a beep. For both tests, the interval between the start time of the trial and the projection of either the beep sound or the balloon were changed among trials.

2.5. Dependent Variables

For the driving tests, the descriptive statistics (means and standard deviations of the participant responses) of the following variables were calculated:

2.5.1. Vehicle control activity

Brake response time (T_{RT}; *s*): The time between the start of occlusion or beep sound and the initial brake input of the participant. T_{RT} is a measure of reaction time of the participants to the brake events of this experiment.

Maximum brake force (F_{max}; *lb*): The maximum brake force that the participant applies on the brake pedal in a braking event. Low F_{max} values correspond to normal, modulated braking behaviour, whereas higher F_{max} values show the shift of braking behaviour towards slam on the brake.

Maximum brake force Time ($T_{\max}$; s): The time between the start of occlusion or beep sound and the moment that the maximum brake force was applied by the participant.

Average brake force (F_{avg} ; lb): The average of the brake force that the participant applies on the brake pedal during a braking event.

2.5.2. Driving performance

Distance gap (D ; ft): The difference between the final stopping position of the vehicle and the position of the stopping target on the road. The distance gap is an indicator of the driver's performance in stopping at the pre-determined position.

2.5.3. Non-driving perception and reaction time performance

Distance estimation error (E ; %): The distance estimation error is the ratio of the difference between the estimated and the projected distances to the projected distance. The average and standard deviation of E indicate the accuracy and the reliability of the distance perception by the participants in the simulator environment, respectively.

Auditory and visual reaction time (RT^a, RT^v ; seconds): RT^a and RT^v measure the reaction time of the participants to an standard auditory and visual stimuli (see Section 2.4).

2.5.4. Data analyses

The dependent variables were measured during each braking event: after the occlusion or beep tone trigger until the moment that participant stopped the simulated car. The differences between conditions were compared using a mixed between-within analysis of variance (ANOVA) test. There were two within and one between subject factors. The within subject factors were Time to Arrival (T) with four levels of 2, 4, 6 and 8 seconds, and the existence of visual information after the initiation of braking (V) with two levels: with and without occlusion. The between subject factor was the two driver's group (G): group 1 (G1), who were told to start braking any time after the braking event triggered and group 2 (G2), who were asked to start braking right after the event trigger.

3. Results

3.1. Reaction time and distance perception in the simulator

Descriptive statistics of reaction time, distance error estimate and the distance limit parameter of the Glinsky's model (see Equation 1) are reported in Table 1. Results of independent t-tests found no significant differences between the estimated parameters of G1 and G2 participants.

Table 1. Mean (and standard deviation) of reaction time and perception parameters of participants

RT^a	RT^v	E	A
212.6 (48.2)	304.5 (54.5)	70 (16)	45.08 (32.43)
t(118)=0.23 p=0.59	t(118)=0.73 p=0.77	t(477)=3.13 p=1	t(10)=5.45 p=1

3.2. Vehicle control performance

Fig. 3 results show that the response time of the participants increase as the TTA of the braking event increases, F (3,66) =26.24, p<.000. There is also a significant main visual information effect: F (1,22)=6.12, p<.05. Over all, the brake reaction time is faster in the scenarios with occlusion than that of the scenarios without occlusion.

Considering the standard deviation of the response time, there are two main effects of G: F(1,22)=7.94, p<.01, and TTA: F(3,66)=17.32, p<.000. All participants show less consistent reaction time at longer levels of TTA. Overall, G2 participants possess more consistent reaction time. There is also a significant G × T interaction effect: F(3,66)=4.29, p<.01. This shows that as the TTA increases, G1 participants adapt a wider range of reaction time compared to the G2 group, whose reaction time is tied to the start of the braking event.

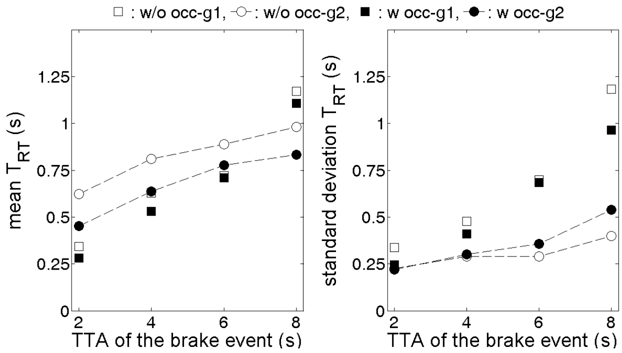

Fig. 3. Mean (left) and standard deviation (right) of the brake response time

The results of the maximum brake force (Fig.4) indicate significant effect for both main factors of visibility: F (3,66) =16.91, p<.001, and time to arrival: F (3,66) =68.36, p<.000. The maximum brake force decreases as the TTA increases. The maximum brake force is also larger when there is no occlusion. There is also a significant V × T interaction effect, F (3,66)

=11.41, p<.000. This means that the maximum brake force decreases faster for the scenarios without occlusion than that it does for with occlusion scenarios.

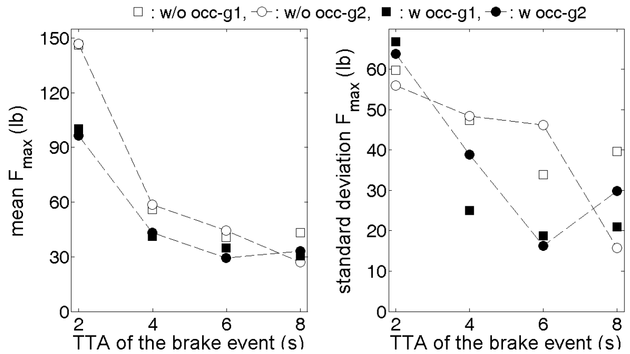

Fig. 4. Mean (left) and standard deviation (right) of the maximum brake force

The maximum brake force time (Fig. 5) reveals significant main effect of TTA: F (3,66) =56.42, p<.000, and interaction effect of V × T: F (3,66) =90.29, p<.000. This suggests that as the TTA of a braking event increases, the maximum brake force occurs later during the brake execution. However, for the scenarios with occlusion the pace of the peak braking force delay increase slows down at longer TTAs. For without occlusion scenarios, the maximum brake force delay increases for longer TTAs. Considering the standard deviation of the maximum brake force, V × T interaction is the only significant effect: F (3,66) =5.04, p<.005. The standard deviation results of the maximum brake force time show only one significant effect of TTA: F (3,66) =14.19, p<.000. As the TTA increases, the time of the maximum brake force varies more.

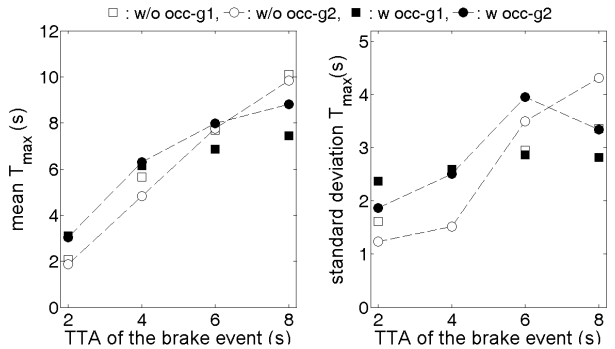

Fig. 5. Mean (left) and standard deviation (right) of the maximum brake force time

For the average brake force (Fig. 6) there are significant effects of visibility: F (1,22) =8.57, p<.01, TTA: F (3,66) =79.86, p<.000 and V × T interaction: F (3,66) =15.06, p<.000. The average is calculated for the moments that the brake pedal is pressed. The results show that the average brake force decreases with the increase in the TTA levels. On average, participants also exert lower force levels on their brake pedals during the scenarios with occlusion than they do in the scenarios without occlusion. The difference between the average braking forces exerted in these two scenarios decreases as the TTA increases.

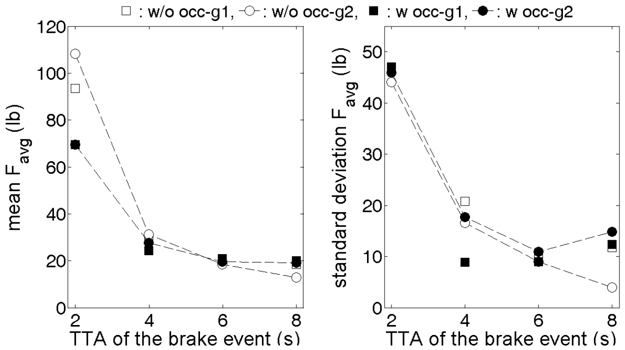

Fig. 6. Mean (left) and standard deviation (right) of the average brake force

The standard deviation results for the average braking force show two main T and V significant effects. Participants average brake force is more consistent with the presence of visual information: F (1,22) =4.96, p<.05 and with the increase in TTA: F (3,66) =28.59, p<.000. There is also a significant V × T interaction effect: F (3,66) =2.81, p<.05. For the scenarios without occlusion, the standard deviation of the average braking force of the participants as the TTA increases. For the occluded scenarios however, the standard deviation of the braking force increases at TTA=6s and 8s.

3.3. Driving performance

Fig. 7 shows the results of the distance gap achieved when the participants stop at the target. TTA is found as the only main factor with significant effect: F(3,66)= 67.14, p<.000. Participants stop after the target at shorter TTAs and before the target at longer TTAs. The V × T interaction effect is also significant: F(3,66)= 30.90, p<.000. The distance gap increases at a significantly higher rate for the with occlusion scenarios than it does for the without occlusion scenarios.

The standard deviation results reveals two main significant effects of TTA: F(3,66)=25.59, p<.000 and V: F(1,22)=12.49, p<.005. As the TTA increases, participant distance gap response varies more. The distance gaps for the occluded scenarios are also less consistent than they are for the scenarios without occlusion. There are also two significant interaction effects of G × T: F(3,66)=3.35, p<.05 and V × T: F(3,66)=7.24, p<.000. G1 participants show more consistent responses than G2 at the TTA=2s. This trend reverses at longer TTAs. The inconsistency of the responses at higher distances increases at higher rate for the scneraios with occlusion compare to the ones without occlusion.

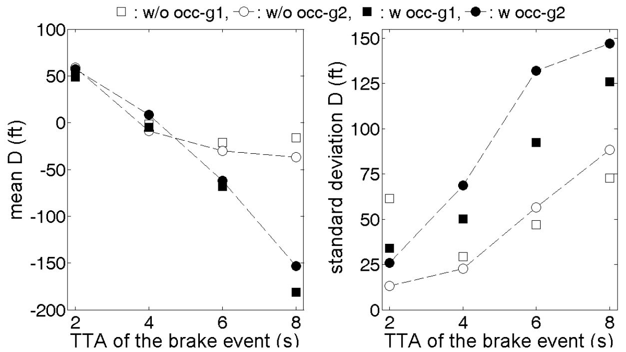

Fig. 7. Mean (left) and standard deviation (right) of the distance gap

3.4. Analysis of braking duration

The results of the brake duration (Fig. 8) reveal only one main factor with significant effect: F(3,66)= 101.72, p<.000. The brake duration increases as the TTA increases. The V × T interaction effect is also significant: F(3,66)= 15.57, p<.000. The braking duration increases at faster rate for scenarios without occlusion than it does for the occluded scenarios. There is also a significant G × T interaction effect: F(3,66)= 7.69, p<.000. The braking duration is similar for both G1 and G2 at shorter TTAs of 2s and 4s. However, at higher TTAs the duration differs between the two groups, with the G1 duration being higher. The standard deviation trend shows that as the TTA increases, the consistency in response decreases for both groups of participants and in both scenarios. However, this trend found not to be significant.

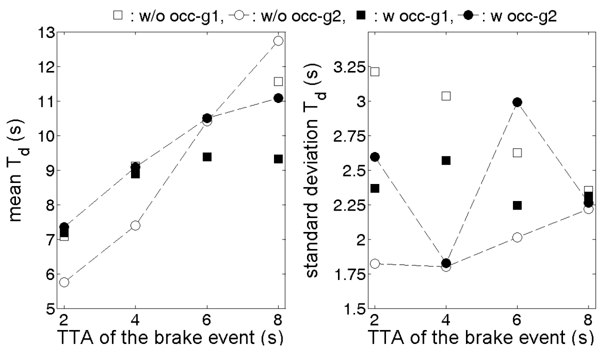

Fig. 8. Mean (left) and standard deviation (right) of the braking duration

The force characteristic of the brake pedal is divided into five different ranges. The relative duration of the braking force ranges exerted by each participant is calculated to quantify the braking patterns of the drivers under with and without occlusion conditions. Table 2 lists the ranges and the corresponding duration parameters. Each duration is calculated as a percentage of the total braking time (Figures 9 and 10).

Table 2. Brake force ranges

<20lb	20–40 lb	40–60 lb	60–80 lb	>80 lb
$T^d_{<20}$	T^d_{20-40}	T^d_{40-60}	T^d_{60-80}	$T^d_{>80}$

An ANOVA analysis revealed that there is a significant TTA effect for all ranges of the brake force (p<.000). Specifically, it was found that the shorter the TTA, the greater the proportion of more severe braking.

Visual information found to be significant for $T^d_{>80}$: F(1,22)= 11.75, p<.005. The amount of severe braking is significantly higher for the scenarios without occlusion.

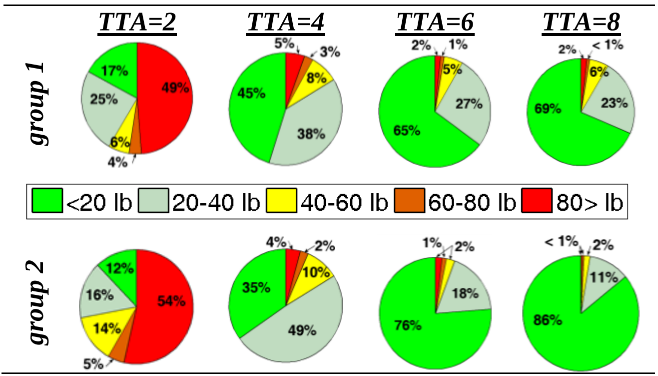

Fig. 9. Time ratios of brake force ranges for without occlusion scenarios

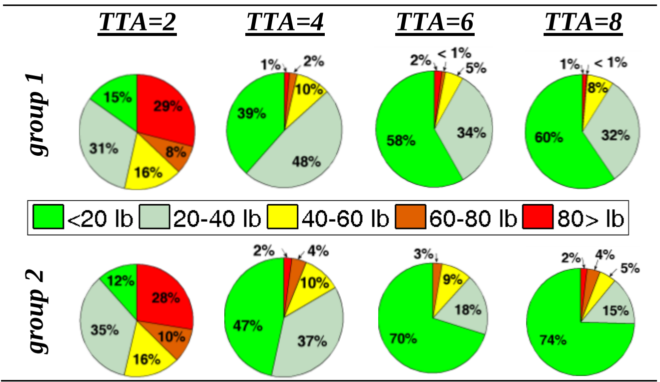

Fig. 10. Time ratios of brake force ranges for with occlusion scenarios

For $T^d_{80>}$, there is a significant V × T interaction effect: F(3,66)= 11.98, p<.000; For shorter TTAs (TTA=2s and 4s) $T^d_{80>}$, the ratio of the most severe braking range, is higher for scenarios without occlusion. There is a significant V × T interaction effect for T^d_{60-80}: F(3,66)= 2.76, p<.05; The share of T^d_{60-80} for the occluded scenarios is larger than it is for the non-occluded scenarios. Finally, there is a significant interaction effect of G × T: F(3,66)= 3.95, p<.05 for $T^{d}_{<20}$. Most notably, the share of $T^{d}_{<20}$ increases faster for G2.

4. Discussion and Conclusion

As the urgency of a braking event increases, drivers are expected to press the brake pedal more rapidly and more forcefully. The result of this experiment shows that occlusion does not significantly change the reaction time of participants regardless of the urgency of braking events. However, the results suggest that compared to the occluded scenarios, participants press the brake pedal harder during the scenarios without occlusion. This effect is evident for both the average and the maximum brake forces of the events with TTA=2s. Occlusion also moderates the rate at which the braking force increases when the available braking time is short. The maximum braking force in the occluded scenarios occurs later during the braking events with shorter TTAs than it does in the scenarios without occlusion. Over all when the time to brake is short, participants brake with less maximum force and for longer period during the scenarios with occlusion than they do during the without occlusion scenarios. The results of the distance gap indicate that the performance degrades at events with longer TTAs. For those events, drivers are less capable to stop at the target during the occluded scenarios than they are in the non-occluded scenarios. This result indicates that participants use visual information to control the distance when they have more time available to execute the brake and are far from the stopping target.

These findings reveal some important aspects of drivers braking behaviour. First, they show that occlusion degrades the flexibility of drivers in using the full range of the braking force when the temporal demand is high. Affordance control of brake proposes that actors keep a safe region between ideal acceleration and maximum acceleration to ensure safe braking is possible [Faj1]. Second, the result of this experiment suggests that the lack of visual information after the brake onset reduces the maximum brake force threshold used by drivers, especially in braking events with high temporal demand. The results also show that as the urgency increase, participants brake longer when the visual information is not available. In the occluded scenarios, drivers brake less severely and adapt larger distance gaps than they do in without occlusion scenarios. This can be explained by the perceived visual distance of the stopping target during the distance estimation test (Fig. 11).

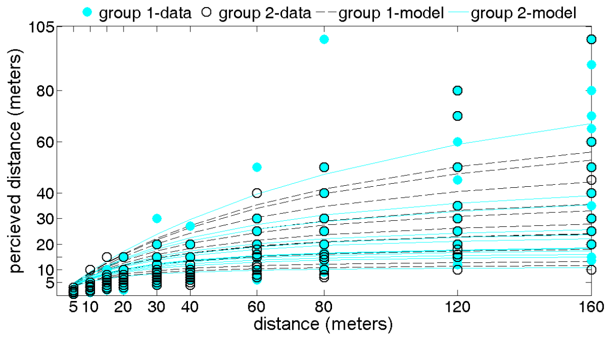

Fig. 11. Perceived vs. projected distances in the NADS minisim simulator, Dot lines are the Glinsky distance estimation model for each participant

For longer TTAs, drivers are far from the stopping target at the initiation of braking. Under these conditions, the distances at the start and in the early stages of the brake fall within the perception limits predicted by Glinsky's Equation (1). If the participants do not pump the brakes, they build up the maximum braking force early in the brake execution. Perceiving the target at a far distance significantly decreases the duration of the brake and slows down the rate that participants exert the braking force. In the non-occluded scenario, participants can regulate the force to stop at the stopping target as they approach the target.

These findings imply the potential benefit for driving information systems that assist drivers to look at the scene shortly before and during the brake. We also showed that the driver's perception of space may limit their performance. Based on the integrated relationship between time and space in driving, any driving assistance systems that provides timing advice should examine the usability of such advice at the given location.

5. References

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