Active stabilisation and perceptual sensitivity in safe driving

Paul Treffner[1], Rod Barrett[2], Andrew Petersen[1], & Russell White[3]

[1]School of Information Technology, Griffith University, QLD
[2]School of Physiotherapy and Exercise Science, Griffith University, QLD
[3]Holden Performance Driving Centre, Ormeau, QLD

Winner: "Best Refereed Paper" Award

Full reference:
Treffner, P. J., Barrett, R. S., Petersen, A. J., & White, R. (2002). Active stabilisation and perceptual sensitivity in safe driving. In *Developing safer drivers and riders* (Proceedings of Travelsafe- Australian College of Road Safety conference), *91-104*, Mawson, ACT: ACRS.

Summary

We examined the relation existing between postural stability, perceptual sensitivity, and stability of driving performance. Using a specially instrumented vehicle, we quantified differences in driving behaviour between untrained experienced drivers and trained instructors from the Holden Performance Driving Centre (PDC). Using a variety of everyday manoeuvres, results indicated that PDC instructors found a different cornering trajectory, a different emergency braking strategy, and were able to perform a high-speed swerve and recovery task more effectively than experienced drivers. Importantly, instructors applied greater bracing forces using the door and console compared with experienced drivers. They also applied greater footrest forces during emergency braking than did experienced drivers. The greater use of bracing by instructors to resist g-forces represents a strategy of active stabilisation and may enhance both postural stability and overall stability and consistency of driving performance. Results are discussed with regard to recent developments in the theory of dynamical systems and human motor control, especially the dynamics of perceptual-motor coordination and how increased stability can improve sensitivity to relevant perceptual information. Theoretically motivated driver-training programmes such as that of PDC should be encouraged. Because they focus on the fundamental technique of increasing dynamic stability as a means of surreptitiously increasing perceptual awareness during driving, principled driver-training programmes have the potential to dramatically improve road safety in general.

1. Introduction

Our research investigates the relation between biomechanics, the dynamics of perceptual-motor coordination, and the effects of cognitive demands on the control of a vehicle. In particular, we are examining a theoretically well-founded principle of driver-training as currently taught at the Holden Performance Driving Centre (PDC)[4]. While many driver-training programmes purportedly emphasise the need to develop good driving skill (i.e., through controlled environments and repetition of critical driving situations)[2,14], the PDC approach offers a particular technique with a strong theoretical foundation that has as its ultimate goal the improvement of attention during driving. To achieve this outcome the strategy involves *active stabilisation* through the application of appropriate bracing forces by the body against the foot-well of the vehicle[6,24]. This is in order to improve overall postural stability and thus provide the necessary physiological and dynamical basis upon which improved attention and perceptual awareness can be built[7,8-11,17,18,21,22]. Without a prerequisite level of postural stability and corresponding control, perceptual and attentional training is likely to be of questionable worth[1,4,7,19]. In accordance with recent theoretical advances in the study of perceptual-motor coordination, increased postural stability during driving can have a profound influence on control and can increase sensitivity and receptivity to relevant perceptual information about the body, vehicle dynamics, the driving environment, and the tripartite relations holding between them[12].

Through an ARC-funded collaboration with PDC, we have instrumented a vehicle with biomechanical sensors in order to conduct field tests of both the PDC driving technique and driving performance in general[4,23]. The purpose of the current study was to achieve an initial quantification of the purported differences in driving behaviour between untrained experienced drivers and driving instructors from PDC by using everyday manoeuvres such as cornering, emergency braking and swerve and recovery.

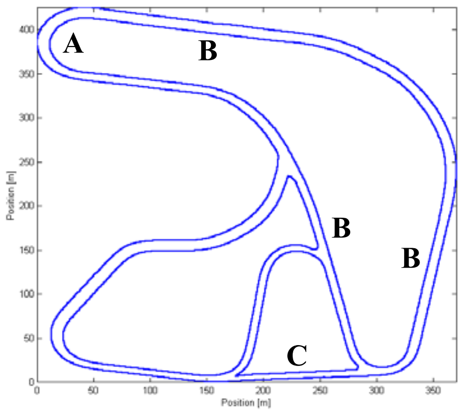

Figure 1. The Holden Performance Driving Centre track (using GPS). (A) Hairpin corner where the cornering task was performed, (B) Straight sections of the track where the emergency braking task were performed, (C) Section of track where the swerve and recovery task was performed. The outer perimeter of the track is 1.9 km and the average width is 10 m.

2. Methods

The Experienced Driver (ED) group consisted of four individuals (< 25 yrs) each having held a drivers license for more than five years and had not undertaken any formal driver training. The Instructor Drivers (ID) group consisted of four PDC instructors. The experiment was conducted at the PDC driving track using a specially instrumented vehicle. For ethical reasons, a PDC instructor sat in the passenger's seat at all times during testing. The experimenter sat in the back seat and monitored data-collection equipment.

All testing was performed in a 6-cylinder Holden Commodore Executive supercharged VX series sedan (2000 model) with automatic transmission and power steering. Anti-lock braking (ABS) was engaged. The in-vehicle data acquisition system consisted of a differential global positioning system (GPS) receiver (Trimble DSM 212H; 10 Hz sample rate, sub-metre accuracy) for measuring car position and speed, force sensors for measuring bracing forces against the footrest (Applied Measurements, S-beam load cell, ±1 kN), console and door (LPS single point load cell), linear potentiometers for measuring brake and accelerator depression (Honeywell, 3" stroke), and a triaxial accelerometer (Crossbow CXL02LF3, ± 2g) for measuring 3D accelerations (vertical, side-side, and front-back) of the vehicle. The GPS receiver was connected directly to a laptop computer via the serial port. A pair of strain gauge modules (DBK43A) connected to a DAQ Book (IOTECH DAQBook 200) were used to acquire data from the remaining analog sensors at 100 Hz. All data were synchronised with GPS data and stored on a laptop computer (Dell Latitude) using custom LabVIEW software. Custom written Matlab programs were used for subsequent data processing.

The three tasks chosen were designed to quantify performance during potentially critical events typically encountered during everyday driving. The cornering task was implicitly performed during circuit driving. This was conducted in an anti-clockwise direction whereby one of the corners was selected for further analysis (Fig. 1). Entry speed into and during the corner was specified as either 30, 35, or 40 km/h. The emergency braking task was performed at a speed of either 60, 70, or 80 km/h at randomly selected straight sections of the track (Fig. 1). The signal to stop was given as a loud "Stop!" command by the experimenter sitting in the back seat of the vehicle. The swerve and recovery task involved negotiating a set of traffic cones placed on a straight section of the track (Fig. 1). The driver was required to maintain an approach to the right of the central marker at a speed of either 40, 45, or 50 km/h and then to swerve to the left (simulating an obstacle in the path of the vehicle) and then swerve to the right and back onto the original (right) side of the road. Three trials of each task were performed. The drivers were informed that they could use the full width of the track and thus treat it as a single lane road.

Analysis of variance (ANOVA) was used to assess the effect of one between-subjects factor (ID vs. ED) and one within-subjects factor (speed) on the dependent measures for each task. The dependent measures assessed included the relative timing and magnitude of the bracing forces applied, the relative timing and magnitude of accelerator and brake depression, as well as the GPS trajectory and acceleration of the vehicle in the antero-posterior (AP) and medio-lateral (ML) directions.

3. Results and Discussion

3.1 Cornering

Representative data for an instructor driver and an experienced driver performing the cornering task in the anti-clockwise direction (i.e., left hand corner) at 40 km/h are displayed in Figures 2 and 3. GPS trajectories revealed differences in the vehicle trajectory produced by ID and ED through the corner. The apex is the closest point of the trajectory to the inside edge of track. In Figure 3, the ED can be seen to begin turning prior to the middle of the corner resulting in an apex too close to the beginning of the corner. In contrast, the ID tended to find an apex further into the corner and also made greater use of the full width of the lane when exiting the corner (Fig. 2). Results indicated a marginally significant effect of position of the apex within the corner (as a percentage along the corner) such that an apex was reached significantly earlier in the corner for ED (76.97%) compared to ID (88.47 %), $F(1, 6) = 5.43$, $p = .06$.

When performing the left-hand corner, the ID actively stabilised the upper body against leaning by bracing the right knee against the door in order to counteract the centrifugal force that would tend to tilt the head and body towards the door (Fig. 2f). It can also be seen that the onset of the active stabilising force applied to the door for ID coincided with the onset of ML accelerations (Fig 2c, f). Further, although lesser than the magnitude of door bracing, there was a definite force applied by the left knee to the console. Together, this bilateral bracing technique of the PDC instructors results in a stabilisation of the head and torso against postural tilt and instability. Further, the footrest force applied by the ID was steady but not excessive (Fig. 2e). Likewise, the application of a uniform and definite increase in accelerator pedal usage resulted in a smooth acceleration out of the corner (Fig 2d, b).

In contrast, Figure 3 depicts an ED who did not actively stabilise using the door but who instead attempted to counteract the centrifugal force by "leaning into" the corner. This is confirmed by large console forces and minimal door forces (Fig. 3f). This strategy effectively aligns the body with the direction of balance (DOB) and is one method, albeit non-optimal, for preventing the loss of postural stability under dynamic inertial frames of reference[17,18,20,29]. However, the negative consequence of body-lean is a tilt (and thus alteration) of the visual frame of reference and can lead to misjudgement of direction of heading[5,27,28]. In addition, because of leaning to the left, this driver inadvertently increased the asymmetric pressure applied by his left lower limbs resulting in a large but inappropriate footrest force. Such a left-directed footrest force would push the body further towards the right and would therefore amplify the already considerable centrifugal forces that are pushing his body rightwards. Such asymmetric biases, although inherent to the motor control system, are to be minimised rather than accentuated[25,26]. The ED also exhibited greater fluctuations in accelerator pedal depression (Fig. 3d) and together with the asymmetric application of forces due to bracing, it is clear that this driver is dynamically unstable and results in inappropriate (and potentially dangerous) coordination and control of the vehicle[6].

The average door forces were significantly greater for ID (15.03 N) than for ED (1.83 N), $F(1, 6) = 18.24$, $p < .01$. Similarly, peak door forces were greater for ID (22.41 N) than for ED (3.49 N), $F(1, 6) = 25.84$, $p < .01$. The effect of speed was also significant for both average door force (7.26 N, 8.38 N, and 9.66 N, for 30 km/h, 35 km/h, and 40 km/h, respectively), $F(2, 12) = 12.07$, $p < .05$, and peak door force (11.21 N, 13.02 N, and 14.62 N, for 30 km/h, 35 km/h, and 40 km/h, respectively), $F(2, 12) = 8.11$, $p < .05$. Further, there was a significant interaction between Group and Speed on both average door force $F(2, 6) = 5.42$, $p < .05$, and on peak door force $F(2, 6) = 3.93$, $p = .05$, both indicating a greater effect of speed for ID than for ED.

In contrast to the preceding significant effects for the door force, there was no difference between ED and ID on either average or peak console force indicating that the important difference between groups involved a bracing force applied in a direction to counteract the destabilising centrifugal force (i.e., towards the door). This was confirmed by the finding that there was a significant effect of speed on both average lateral acceleration (0.11g, 0.11g, and 0.19g, for 30 km/h, 35 km/h, and 40 km/h, respectively), $F(2, 12) = 121.32$, $p < .001$, and peak lateral acceleration (0.20g, 0.27g, and 0.31g, for 30 km/h, 35 km/h, and 40 km/h, respectively), $F(2, 12) = 210.99$, $p < .001$.

Interestingly, there was a marginally larger average footrest force applied by the ED (53.80 N) than by the ID (38.54 N), $F(1, 6) = 21.47$, $p = .09$. This would seem to indicate that the ED were using the footrest inappropriately, especially since it was a left-hand corner and such a force would be counter-productive to the goal of increasing postural stability.

The results indicate that ID maintain postural stability during cornering by bracing and applying active lateral forces to counteract destabilising centrifugal forces. The postural stabilisation strategy used by instructor drivers is consistent with the discovery that active stabilisation and postural stability increases sensitivity to visual and vestibular information[5,8-11,17,18,24]. In contrast to ID, the ED did not use the knees to sufficiently brace against lateral accelerations and therefore exhibited either less postural stability, gained their postural stability by leaning and aligning with the DOB, or used other means such as increasing grip and "hanging off" the steering wheel in order to use it as a postural anchor-point. However, the use of the steering wheel to enhance postural stability should be strongly discouraged. Excessive grip force can lead to oversteering in emergency situations, as well as being completely inappropriate given its prime function which is to steer a steady and unbiased course[6,7].

3.2 Emergency braking

Representative data for an ID and an ED performing the emergency braking task from 80 km/h are displayed in Figures 4 and 5. Although group differences did not reach significance, the mean stopping distances were uniformly less for ID (40.42 m) compared to ED (42.70 m). Speed was a significant factor (32.39 m, 41.81m, and 50.48 m, for 60 km/h, 70 km/h, and 80 km/h, respectively), $F(2, 12) = 23.54$, $p < .001$. Thus, at 80 km/h the difference between ED (52.7 m) and ID (48.3) was 4.4 m—equivalent to one car length. Such a difference would be sufficient to influence the probability and severity of a collision, and is therefore of practical significance. Although there was an effect of speed on braking time (3.03 s, 3.47 s, and 3.81s, for 60 km/h, 70 km/h, and 80 km/h, respectively), $F(2, 12) = 21.23$, $p < .001$, there was no group effect.

The effect of speed on the average magnitude of deceleration was significant (-0.54g, -0.56g, and –0.58, for 60 km/h, 70 km/h, and 80 km/h, respectively), $F(2, 12) = 4.79$, $p < .05$. Consequently, there was a marginal effect of speed on the time taken to reach peak deceleration (2.04 s, 2.34 s, and 2.60 s, for 60 km/h, 70 km/h, and 80 km/h, respectively), $F(2, 12) = 3.28$, $p = .07$.

Interestingly, when the time at which peak deceleration was reached is expressed as a percentage of the total braking time, then speed did not have any effect (67%, 68%, and 67%, for 60 km/h, 70 km/h, and 80 km/h, respectively), $F < 1$. Thus, drivers invoke an *invariant* control strategy in their production of deceleration, regardless of speed. This is supportive of the hypothesis that the controlled braking[23] (even emergency braking) and locomotion in general is primarily constrained by higher-order invariants of optical structure that constitute the relevant information for coordinated perception-action (e.g., "tau" or time-to-contact information)[7,12,22,27,28]. However, the groups differed in that peak deceleration was postponed by the ID (80%) in comparison to the ED (55%), *F* (1, 6) = 43.35, *p* < .01. These results were consistent with the finding that the relevant control action, the time to peak brake depression, was also later for ID (81%) compared to ED (41%), *F* (1, 6) = 15.44, *p* < .01. There was also a marginal effect of speed on the time to peak brake depression (66%, 55%, and 61%, for 60 km/h, 70 km/h, and 80 km/h, respectively), *F* (2, 12) = 3.55, *p* = .06. The preceding differences in braking style can be seen in the acceleration and braking profiles displayed in Figures 4 and 5.

It may be concluded from these results that instructor drivers and experienced drivers use different emergency braking strategies. Whereas experienced drivers tend to reach peak brake depression and hence peak vehicle deceleration rapidly (i.e., a "slam-on-the-brakes" strategy), the instructor drivers tended to apply force to the brake pedal in two distinct phases. In the first phase the brake was depressed to about 80% of maximum, which was followed by a second phase whereby increasing pressure was gradually applied to the brake so that maximum depression occurred as the car came to a stop. The graduated application of the brake in the manner used by the instructor drivers minimises sudden weight transfer to the front wheels associated with sudden braking. Maintaining a relatively equal weight distribution between the front and rear tyres through gradual application of the brakes enhances braking performance since the rear brakes can contribute to a much greater extent compared to when they are unweighted during sudden braking[6].

Importantly, there were group differences with respect to bracing forces required to resist the AP g-forces tending to push the body forward during braking. The average footrest force was greater for ID (175.92 N) than for ED (85.25 N), *F* (1, 6) = 8.55, *p* < .05, as was peak footrest force (ID = 247.29 N; ED = 105.27 N), *F* (1, 6) = 10.66, *p* < .05. From Figure 4c and 4e it may also be seen that the onset of the application of the footrest force for the driving instructor tended to coincide with the onset of the deceleration of the vehicle. In contrast, the experienced driver represented in Figure 5e did not increase the footrest force during braking. Instead this driver probably relied on the passive restraint provided by the seatbelt or pushed harder against the steering wheel in order to provide postural stability in the AP direction. Since standard 3-point diagonal set belt design reflects a compromise between providing stability and allowing mobility, the seatbelt does not fully stabilise the upper body in critical manoeuvres such as emergency braking. Active stabilisation via the footrest is the preferred means of providing postural stability during braking since the use of the steering wheel to stabilise the body (through increased grip pressure) would significantly compromise the sensitivity to and control of steering.

3.3 Swerve and recovery

Representative data for an ID and an ED performing the swerve and recovery task at 50 km/h are displayed in Figures 6 and 7. Each driver was required to approach the marker grid at the required speed, pass between two entry markers on the right hand side of the lane, swerve to the left and around the centre marker, move quickly back onto the right side of the road and exit between two exit markers. The ED were able to reduce the destabilising lateral accelerations acting on the body and the vehicle by applying the brake (Fig. 7d) and consequently decreasing speed and magnitude of the g-forces during the swerve. In contrast, the ID avoided braking suddenly, and could tolerate significantly greater lateral accelerations than the ED because the ID invoked active bracing using the footrest, door, and console (Fig. 6c, f).

Actual entry speed was significant (39.84 km/h, 44.31 km/h, and 48.25 km/h for 40 km/h, 45 km/h, and 50 km/h, respectively), *F* (2, 12) = 81.82, *p* < .001, and was higher for ID (45.53 km/h) compared to ED (42.74 km/h), *F* (1, 6) = 5.69, *p* = .05, thus indicating a more cautionary approach by the ED to the potential hazard. Actual exit speed was significant (38.72 km/h, 41.88 km/h, and 45.39 km/h for 40 km/h, 45 km/h, and 50 km/h, respectively), *F* (2, 12) = 34.20, *p* < .001, and was in general higher for ID (43.44 km/h) compared to ED (40.55 km/h), *F* (1, 6) = 10.24, *p* < .05. Because ID were able to complete the task without using the brake, this meant that the velocity of the car at exit was maintained closer to both the required and actual entry speed compared to ED.

For peak rightward lateral acceleration at entry, there was a marginally significant interaction between Group and Speed (ID = 0.29g, 0.35g, 0.36g; ED = 0.17g, 0.18g, 0.21g, for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 18.27, $p = .07$. This suggested that the peak lateral acceleration at entry was less affected by speed in ED than in ID. Overall, there was a significantly larger lateral acceleration for ID (.34g) than for ED (.19g), F (1, 6) = 21.62, $p < .01$. Peak lateral acceleration at entry also increased across speeds (.23g, .27g, and .29g for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 18.27, $p < .001$.

For the corresponding door force at entry (at the time of peak lateral acceleration), there was a marginally significant interaction between Group and Speed (ID = 39.13 N, 52.26 N, 46.45 N; ED = 2.21 N, 2.23 N, 2.54 N, for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 4.20, $p < .05$. This suggested that the bracing forces against the door for the ED were unaffected by speed in comparison to the ID. The door force was greater for ID (45.95 N) than for ED (2.33 N), $F = 40.04$, $p < .001$, but the effect of speed was only marginally significant, F (2, 12) = 4.27, $p = .08$.

Around the central marker, the peak leftward lateral acceleration for ID (0.54g) was marginally greater than for ED (0.41g), F (1, 6)= 4.73, $p = .07$. However, as speed increased, so did peak leftward lateral acceleration (0.42g, 0.49g, and 0.52g for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 16.70, $p < .001$. The corresponding console force around the central marker was greater for ID (95.60 N) than for ED (28.34 N), F (1, 6) = 33.80, $p < .001$, and as speed increased, so did console force (49.22 N, 65.37 N, and 71.32 N for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 6.84, $p < .05$.

The peak lateral acceleration around the exit marker for ID (.28g) was not significantly different from that for ED (.20g), although the corresponding door force at that time was greater for ID (43.30 N) than for ED (1.92 N), F (1, 6) = 32.49, $p < .001$, again indicating that active bracing was invoked as a stabilisation strategy. Speed had a significant effect on peak lateral acceleration at exit (.21g, .24g, and .28g for 40 km/h, 45 km/h, and 50 km/h, respectively), F (2, 12) = 8.08, $p < .05$, but had no effect on door force at exit.

Taken together, the results on the swerve and recovery task suggest that the lack of appropriately timed door and console bracing forces amongst normal experienced drivers may be a limiting factor in resisting lateral accelerations associated with a critical avoidance manoeuvre. Although braking helps to decrease lateral accelerations during swerve and recovery, this would be dangerous at high speeds, especially if braking was sudden, resulting in loss of control of the vehicle, or even a rear-end collision with another vehicle. In contrast, the coordinated bilateral bracing technique of the PDC instructors, together with the appropriate scaling of force with speed and associated g-forces, provides an effective countermeasure against the destabilising forces and ensuing skidding that potentially accompanies the majority of single-vehicle collisions.

4. General discussion

It can be concluded that PDC instructors use dramatically different driving strategies to untrained but well-experienced drivers when performing cornering, emergency braking and swerve and recovery manoeuvres. Differences were observed in the path taken by the vehicle as well as in the manner in which the body was stabilised via the use of bracing forces. Instructor drivers found a later apex and made greater use of the width of the road during cornering and so were able to "straighten out the corner". In the emergency braking task, instructors in general stopped in a shorter distance than the experiencing drivers by using a gradual rather than sudden braking strategy (i.e., the "brush-and-bury" braking technique)[6].

It must be recognised that a potentially confounding factor remains in the current study. Because the instructors were highly familiar with the driving track and use it on a daily basis, their trajectories and the high degree of trajectory consistency might be attributed to such familiarity. However, it remains a theoretically non-trivial question as to how the instructors could have achieved such high levels of consistency. To simply assume that the instructors were using "memory" of the track (based on "experience"), or landmarks as "cues" to guide performance is insufficient explanation of a highly skilled and remarkable feat. Extensive research into the coordination of perception and action confirms that organisms do not in any obvious sense use "simple cues" to guide performance. Instead, activities such as locomotion are controlled on-line through the pick-up of relevant perceptual information existing across multiple sensory systems[5,22,28]. The evidence in the literature confirms that if postural stability is increased, then perceptual sensitivity follows, and consistency of performance is possible. However, the potential confound remains and future research will target specifically this criticism through testing both on the PDC track and at a location unfamiliar to both trained and untrained drivers.

Importantly, the driving technique used by the ID can be characterised as one of dynamic balance through active stabilisation[12,24]. During tasks where the destabilising g-force was sideways to the vehicle (e.g., in cornering and in swerve and recovery), the ID applied greater bracing forces against the door and console than ED. Although postural stability was not explicitly measured in this study, results indicate that the use of lateral bracing forces by ID represents an attempt to achieve postural stability. A similar strategy was used by ID during emergency braking that involved resisting the g-forces associated with vehicle deceleration by pushing with the left foot against the footrest. Importantly, since applying pressure with the foot and lower leg would also create co-contraction of the upper body musculature (e.g., the core stabilising muscles of the abdomen and pelvis) this technique not only improves postural stability by preventing forward movement of the body but also improves lateral stability of the trunk. In addition, the lower body is more symmetrically braced by using both feet instead of only a single foot on the brake pedal. This would result in a greater base of support and permit the driver to rely less upon the steering wheel as a postural anchorpoint.

The manner by which experienced drivers achieved postural stability is not completely clear from this study. Frank Gardner, who is largely responsible for developing the technique, suggests that untrained drivers may use the steering wheel to provide postural stability during critical manoeuvres to the detriment of their steering performance[6]. The specific means by which drivers achieve postural stability during driving is the subject of ongoing research by our group and involving simultaneous measurement of head movement, steering wheel grip force and seat belt tension[3,4].

In summary, the results indicated that the PDC instructors used a consistent cornering trajectory, a consistent braking strategy and were able to perform the swerve and recovery task more effectively than the experienced drivers. During the cornering and swerve and recovery tasks instructor drivers applied greater bracing forces against the door/console than experienced drivers. Instructor drivers also applied greater forces to the footrest during emergency braking than experienced drivers. The greater use of leg bracing by instructor drivers to resist g-forces represents an attempt to enhance postural stability and maintain a balanced base of support. Bracing with the legs also reduces the need to stabilise the upper body via steering wheel grip force and may therefore help reduce the risk of oversteering in emergency situations. Recent evidence from perceptual-motor control research supports the good-sense of the PDC technique since improved postural stability can heighten sensitivity to perceptual information (and vice-versa)[5,8-11,17,18]. Importantly, the PDC training programme is not an opportunity for the individual to "have fun and throw the car around" in a controlled environment. Rather, the sole purpose of the PDC technique is improved driver attention to car and road conditions, better vehicle control and coordination skills, and therefore potentially increased safety in driving. It is crucial to recognise that not all advanced driving courses are the same[14]. Recent critiques have prematurely concluded that driver-training is counter-productive and a waste of resources. A popular reason given for such purported counterproductivity is that advanced driver-training engenders "over-confidence" in the driver[2]. There is, however, little evidence in refereed journals to support such a contention[14]. Therefore, any well-founded attempt to improve driving skill should be viewed with considerable interest (not disinterest), and those that claim to actually *have* a technique to teach, should welcome careful examination and evaluation through scientific means. Because our research is relatively recent and the PDC technique has thus far not been explicitly scientifically studied, no evidence yet exists in terms of the reduced crash statistics following stability-based driver training. However, this should in no way be taken as reason for dismissal, lest the worthiness of such theoretically well-founded and systematic techniques as employed by PDC are ignored. Our investigations of the PDC technique thus far confirm that it is deserving of close scrutiny in its emphasis on dynamic stability as a prerequisite for improved attention and control[3,4,23].

In collaboration with PDC, our most recent experiments (as of May 2002) are determining precisely how cognitive interference such as conversational complexity using a hands-free mobile phone affects young persons' driving performance[16] (e.g., the ability to perform a controlled braking manoeuvre safely[23]). We are also beginning a major experiment examining the PDC technique through measuring the influence of driver-training on driving performance prior to, following, and at extended intervals after initial 2-day training. Further, through a joint collaboration with PDC and Vigil Systems (Brisbane, QLD), we are determining the efficacy of closed-circuit driver-training at PDC by comparing driving performance with long-term data gained from extended driving episodes on the open road (e.g., for a week of typical driving). Because Vigil Systems can provide in-car data-loggers for the collection of long-term driving data not unlike from the data herein presented, and since they can be installed at relatively low cost in numerous vehicles, it will for the first time be possible to obtain precise behavioural data on the efficacy of, correlation between, and long-term effects of stability-based driver-training and driver performance. When available, such results are expected to confirm the wisdom behind designing training strategies that, first and foremost, target the improvement of the foundational basis of successful locomotion (postural stability) before even attempting to modify higher-order aspects of driving such as visual attention, perceptual awareness, and cognition[7,21].

Project funded by Australian Research Council (ARC) SPIRT grant C00002600.

5. References.

1. Amazeen, E., Amazeen, P., Treffner, P. J., & Turvey, M. T. (1997). Attention and handedness in bimanual coordination dynamics. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1552-1560.
2. Christie, R. (2001). The effectiveness of driver training as a road safety measure: An international review of the literature. In *Proceedings of Road Safety Research, Policing & Education Conference 2001*. Melbourne, Australia.
3. Doyle, T. L. A., Barrett, R. S., Treffner, P. J., & White, R. (2001). A field investigation of advanced driver training using an instrumented vehicle. In *Proceedings of Vision in Vehicles 9*. Brisbane, QLD, Australia.
4. Doyle, T. L. A., Treffner, P. J., Barrett, R. S., & White, R. (2000). Perceptual and biomechanical constraints on safe driving: Theoretical issues and experimental approach. In *Proceedings of Road Safety Research, Policing & Education Conference 2000* (pp. 17-22). Brisbane, QLD, Australia.
5. Foque, F., Bardy, B. G., Stoffregen, T. A., & Boutsma, R. J. (1999). Action and intermodal information influence the perception of orientation. *Ecological Psychology, 11,* 1-44.
6. Gardner, F. (1998). *Drive to survive*. Drive Publishing, Australia.
7. Gibson, J. J. (1979). *The ecological approach to visual perception*. Mahwah, NJ: Erlbaum.
8. Jeka, J.J. (1998). Touching surfaces for control not support. In D. Rosenbaum & C. Collyer (Eds.), *Timing of Behavior: Neural, Computational, and Psychological Perspectives*. Cambridge: MIT press.

9. Jeka, J.J., Easton, R.D., Bentzen, B.L., & Lackner, J.R. (1996). Haptic cues for postural control in sighted and blind individuals. *Perception & Psychophysics, 58*, 409-423.
10. Jeka, J.J., Ribeiro, P., Oie, K.S. & Lackner, J.R. (1998). The structure of somatosensory information for human postural control. *Motor Control, 2*, 13-33.
11. Jeka, J.J., Schöner, G.S., Dijkstra, T.M.H., Ribeiro, P. & Lackner, J.R. (1997). Coupling of fingertip somatosensory information to head and body sway. *Experimental Brain Research, 113*, 475-483.
12. Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Boston: MIT.
13. Land, M., & Horwood, J. (1995). Which parts of the road guide steering? *Nature, 377*, 339-340.
14. Lund, A. K., & Williams, A. F. (1985) A review of the literature evaluating the defensive driving course. *Accident Analysis & Prevention, 17,* 449-460.
15. Macdonald, W. A. (1994). *Young driver research program: A review of information on young driver performance characteristics and capacities*, CR 129, Federal Office of Road Safety, Canberra.
16. Redelmeier, R. J., & Tibshirani, D. A. (1997). Association between cellular-telephone calls and motor vehicle collisions, *The New England Journal of Medicine, 336*, 453-458.
17. Riccio, G. E. (1995). Coordination of postural control and vehicular control: implications for multimodal perception and simulation of self-motion. In P. Hancock, J. Flach, J. Caird, and K. Vicente (Eds.), *Local applications of the ecological approach to human-machine systems, Vol. 2.* Mahwah, NJ: Erlbaum.
18. Riccio, G. E., Martin, E. J., & Stoffregen, T. A. (1992). The role of balance dynamics in the active perception of orientation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 624-644.
19. Riley, M. A., Amazeen, E. L., Amazeen, P. G., Treffner, P. J., & Turvey, M. T. (1997). Effects of temporal scaling and attention on the asymmetric dynamics of bimanual coordination. *Motor Control, 1*, 263-283.
20. Rogé, J. (1996). Spatial reference frames and driver performance. *Ergonomics, 39*, 1134-1145.
21. Schiff, W., & Arnone, W. (1995). Perceiving and driving: Where parallel roads meet. In P. Hancock, J. Flach, J. Caird, and K. Vicente (Eds.), *Local applications of the ecological approach to human-machine systems, Vol. 2.* (pp. 1-35). Mahwah, NJ: Erlbaum.
22. Stoffregen, T. A., & Bardy, B. G. (2001). On specification and the senses. *Behavioural and Brain Sciences, 24,* 195-261.
23. Treffner, P. J., Doyle, T. L. A., & Barrett, R. S. (2001). Controlled braking during driving. In G. Burton and R. C. Schmidt (Eds.), *Studies in perception and action VI* (pp. 238-241). Mahwah, NJ: Erlbaum.
24. Treffner, P. J., & Kelso, J. A. S. (1999). Dynamic encounters: Long-memory during functional stabilization. *Ecological Psychology, 11*, 103-137.
25. Treffner, P. J., & Turvey, M. T. (1995). Handedness and the asymmetric dynamics of bimanual rhythmic coordination. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 318-333.
26. Treffner, P. J., & Turvey, M. T. (1996). Symmetry, broken symmetry, and the dynamics of bimanual coordination. *Experimental Brain Research, 107,* 463-478.
27. Warren, W. H. (1995). Self-motion: Visual perception and visual control. In W. Epstein and S. Rogers (Eds.), *Perception of space and motion*. Academic Press.
28. Warren, W. H. (1998). Visually controlled locomotion: 40 years later. Special issue of *Ecological Psychology, 10,* 177-219.
29. Zikovitz, D. C., & Harris, L. R. (1999). Head tilt during driving. *Ergonomics, 42*, 740-746.

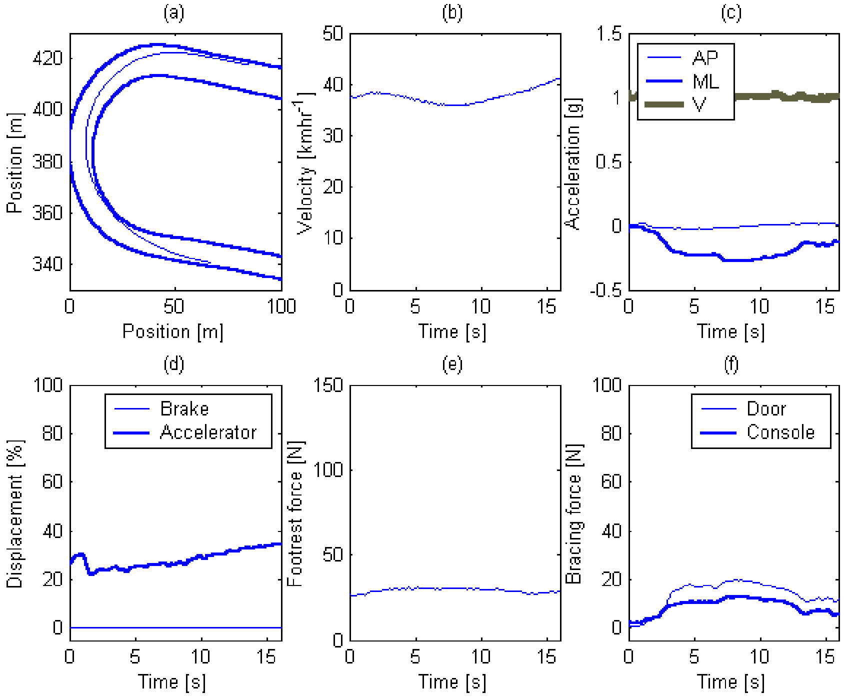

Figure 2. Representative data for an instructor driver performing a left-hand cornering task at 40 kmhr^{-1}. (a) GPS trajectory, (b) Car velocity, (c) Car acceleration in the anterior-posterior (AP), medio-lateral (ML) and vertical (V) directions, (d) Brake and accelerator pedal depression, (e) Footrest force, (f) Door and console bracing force.

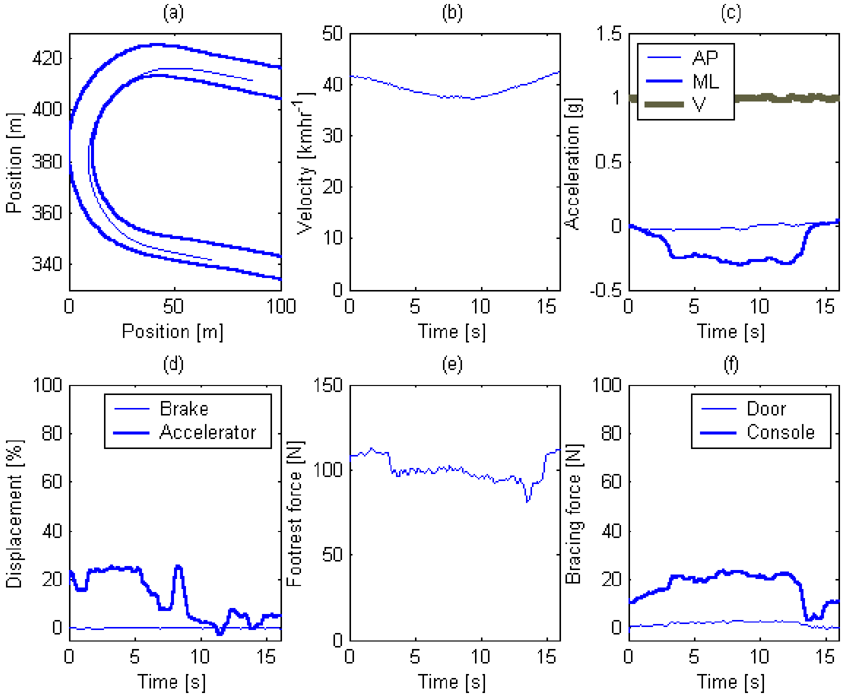

Figure 3. Representative data for an experienced driver performing a left-hand cornering task at 40 kmhr^{-1} (see Fig. 2 caption for details).

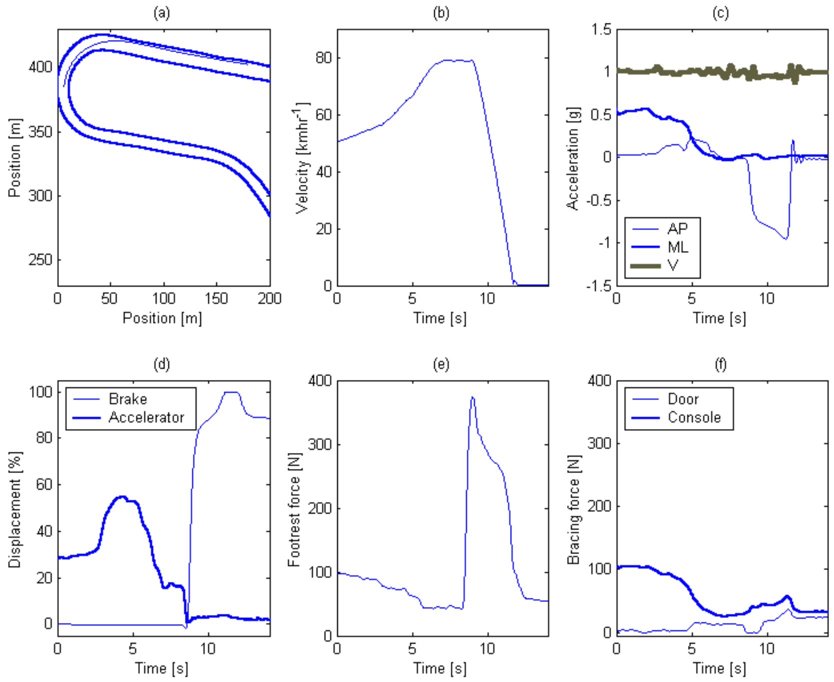

Figure 4. Representative data for an instructor driver performing the emergency braking task at 80 kmhr^{-1}. (a) GPS trajectory with respect to track (braking occurred on the straight after exiting the curve), (b) Car velocity determined from GPS, (c) Car acceleration in the anterior-posterior (AP), medio-lateral (ML) and vertical (V) directions determined from accelerometer, (d) Brake and accelerator pedal depression, (e) Footrest force, (f) Door and console bracing force.

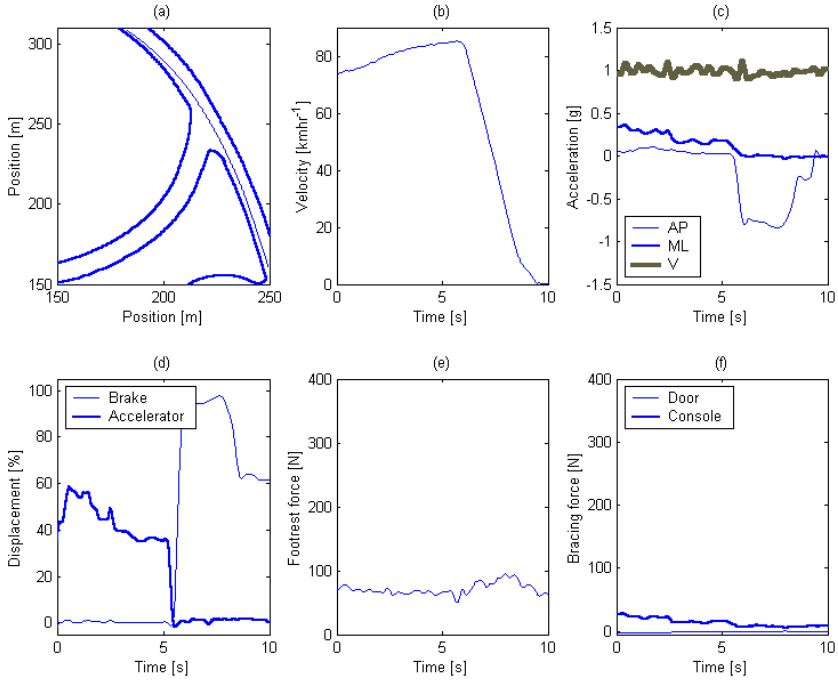

Figure 5. Representative data for an experienced driver performing the emergency braking task at 80 kmhr^{-1} (see Fig. 4 caption for details).

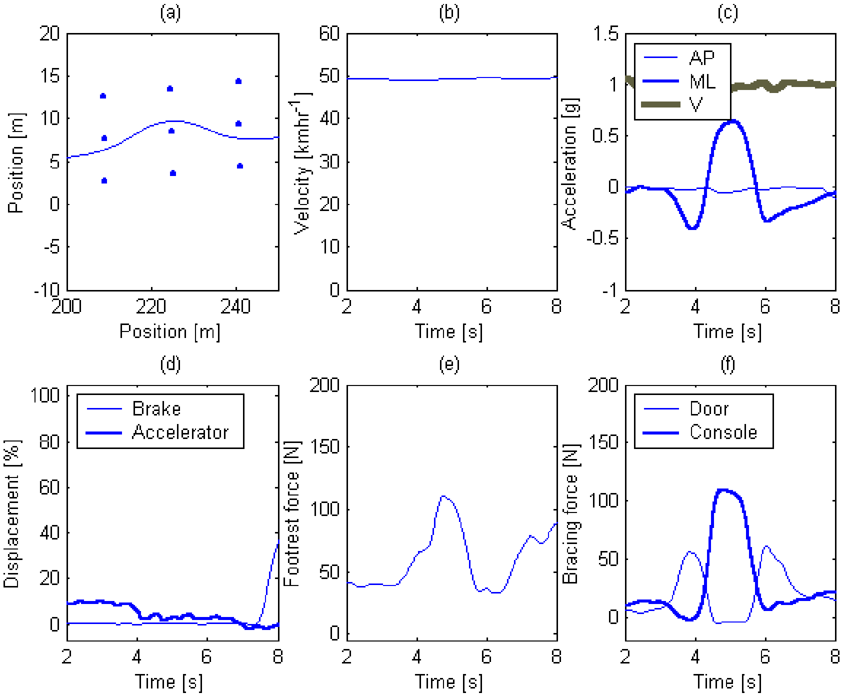

Figure 6. Representative data for an instructor driver entering from the left and performing the swerve and recovery task at 50 kmhr^{-1}. (a) GPS trajectory with respect to markers, (b) Car velocity determined from GPS, (c) Car acceleration in the anterior-posterior (AP), medio-lateral (ML) and vertical (V) directions determined from accelerometer, (d) Brake and accelerator pedal depression, (e) Footrest force, (f) Door and console bracing force.

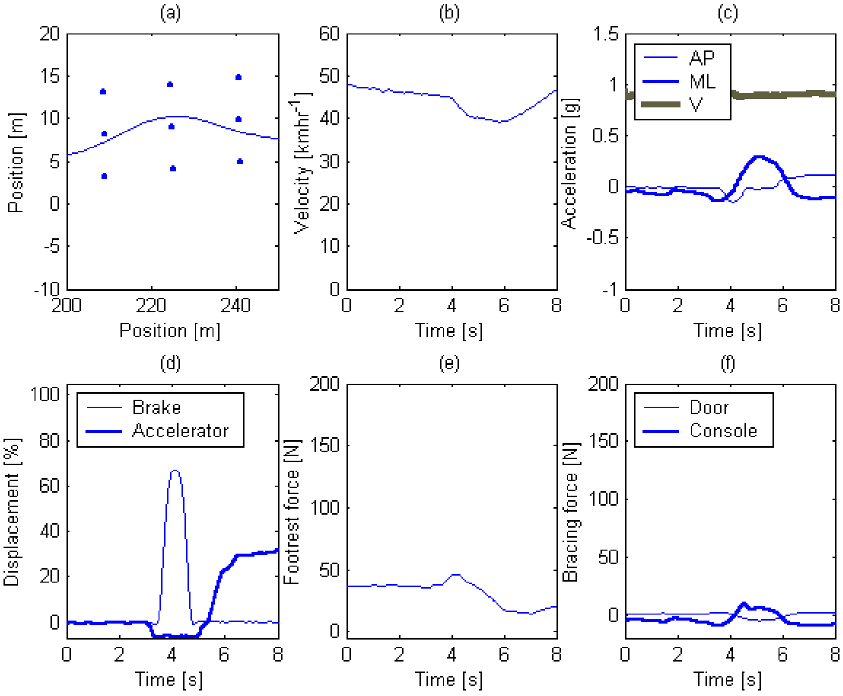

Figure 7. Representative data for an experienced driver entering from the left and performing the swerve and recovery task at 50 kmhr^{-1} (see Fig. 5 caption for details).