BRAKE FORCE DATA - It was observed that all subjects braked (with varying degrees of severity and pedal force) for every event. The range of applied brake pedal forces seen in the first phase of the trial was between 143-1474N, and in the second phase, the brake force ranged from 88-1207N. A highly significant difference (p=0.009) was observed between the mean maximum peak applied brake force for the first phase (770N) and the second phase of the trial (475N). An analysis of the mean vehicle speed prior to the initiation of emergency braking for phase 1 (48.69mph) and phase 2 (45.82 mph), showed no significant difference (p=0.149). However, it can be seen that the mean speed was on average slower in the second phase of the trial, and speed of the vehicle did have an influence on the appearance of the dynamic event. A driver travelling slower than the speed limit would have had more opportunity to anticipate the dynamic event than a driver approaching one of the static events, which always appeared at the same location regardless of the driver's approach speed. The post-trial questionnaires were also reviewed in order to seek an explanation for the difference. In the first phase of the trial, nine of the twelve subjects felt that they had used maximum force on the brake pedal in reaction to the emergency event, compared with only four subjects in the second phase.

The mean braking force for the combined trials was 630N, and a force of 1.5kN in the plantar flexing muscle group would be required to reproduce this. Several studies to date (Manning *et al.*, 1997) (Petit *et al.*, 1996) have used data like this in biomechanical studies, although they have to assume that the ankle pivots about a single fixed axis of rotation. Recent work (Manning *et al.*, 1997) has shown that the influence of active muscle tension on PMHS specimen testing, significantly increases axial loading through the tibia. Recent analyses of lower leg injuries (Morris *et al.*, 1997) have also identified axial loading as a primary mechanism for some of the most impairing lower leg injuries (talar neck, calcaneal and pilon fractures). An implication of this work is that the active tension in the lower leg muscle group due to the action of braking can increase the risk of serious lower leg injury.

It is not known at what point during an accident the ankle or foot is injured. If drivers are braking prior to an accident as suggested by recent accident analyses (Morris et al., 1997), then the results of this study indicate that it would be preferable to study ankle injury mechanisms with the foot in an initial plantar flexed position. However, while our study indicated that the foot is plantar flexed by a mean angle of 15° at the point of peak applied brake force, when occupant kinematics due to vehicle impact deceleration are taken into account, the foot may rotate towards the neutral or a dorsi flexed position as the crash forces exceed the plantar flexing muscle group strength.

The results of this study also indicate that biomechanical evaluations of fracture mechanisms should encompass both initial heel-floor contact and heel-floor separation in the experimental set-up as well as active muscle tension in the lower leg. The indicated 1.5kN of active lower leg muscle force calculated in this study is larger than the passive forces used in previous biomechanical studies (450N - Petit et al., 1996, 960N - Manning et al., 1997). This figure is a good indication of the forces that should be considered for future biomechanical studies to reproduce a biofidelic situation.

Currently the Hybrid III dummy is used in legislative frontal impact testing, and the test procedure specifies that the dummy foot should be placed on the vehicle accelerator pedal at the start of the test. This study indicates that if braking is occurring prior to an accident, the initial position of the dummy lower limb should be carefully considered.

The simulator trial results have demonstrated that there is a significant muscle action applying torque about the ankle to allow the brake pedal to be depressed by the ball of the foot in plantar flexion. This also results in an internal compressive force within the tibia in addition to that created by the knee extension. Therefore the representation of muscle action in the dummy lower leg could prove important, if the risk of lower leg injury is to be assessed in a biofidelic manner. The Advanced Lower Extremity (ALEX II) dummy leg currently under development by NHTSA appears to be addressing this problem by incorporating a device for simulating passive tension in the plantar flexing muscle group. Merely increasing ankle joint stiffness would not induce the increase in tibia compression predicted from this study and would result in artificially high bending moments in the tibial loadcells. Data from studies such as this, could then be used to determine the initial conditions for positioning and tensing the lower leg for legislative tests.

CONCLUSIONS

1. The TRL driving simulator has been successfully used to evaluate the positioning of the drivers' lower legs in an emergency braking situation.
2. All subjects made an attempt to brake when faced with the emergency situation.
3. The mean position of the ankle at the point of peak brake pedal force was found to 15° of plantar flexion from the two trials.
4. The fact that plantar flexion was seen in both phases of the trial is an indication that braking action is generated by contraction of the lower leg muscles in addition to extension at the knee joint.
5. In just under half of the emergency braking manoeuvres, the subjects heel was not in contact with the floorpan at the point of peak applied brake pedal force.
6. The mean peak applied brake pedal force, averaged for the two phases of the trial was 630N.
7. There was a significant difference between the mean peak brake force in phase 1 (770N) compared with that for phase 2 (475N), possibly due to drivers being able to anticipate and react to the dynamic events in phase 2 more quickly than the static events in phase 1.
8. An Achilles tendon force of 1.5kN would be required in a PMHS specimen to reproduce the mean applied braking force in the trial.
9. There was no significant difference between the mean peak brake pedal force for male subjects (636N) and females (626N).

10. For future legislative crash testing, the initial position of the dummy lower limb and the representation of muscle action in the lower leg should be considered, if the risk of lower leg injury is to be assessed in a biofidelic manner.

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REFERENCES

Armstrong, R.W., H.P.Waters, J. P. Stapp. Human Muscular Restraint During Sled Deceleration. in Proceedings of the 12th Stapp Car Crash Conference, 1968, pages 440 - 462

Crandall, J.R., P.G. Martin, C. R. Bass et al. Foot and Ankle Injury: The Roles of Driver Anthropometry, Footwear and Pedal Controls, in 40th Annual Proceedings of the Association for the Advancement of Automotive Medicine, 1996, pages 1-18

Hagedorn, A.V., H.B. Pritz, M.S. Beebe. Design and Development of an Advanced Lower Extremity: ALEX II. in Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles, 1998.

Klopp, G.S., J.R. Crandall, E.M. Sieveka, et al. Simulation of Muscle Tensing in Pre-Impact Bracing. in IRCOBI. 1995, pages 171-182

Manning, P.A., A.K. Roberts, C.J. Owen et al. The Position and Movement of the Foot in Emergency Manoeuvres and the Influence of Tension in the Achilles Tendon. in Proceedings of the 41st Stapp Car Crash Conference, 1997, pages 195-206

Manning, P.A., C.J. Owen, A.K. Roberts et al. Dynamic Response and Injury Mechanism in the Human Foot and Ankle and Dummy Biofidelity. in Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles, 1998.

Morris A., P. Thomas, A.M. Taylor, et al. Mechanisms of Fracture in Ankle and Hind-Foot Injuries to Front Seat Car Occupants - An In-Depth Accident Data Analysis. in Proceedings of the 41st Stapp Car Crash Conference, 1997, pages 181-194

Petit, P., L. Portier, J.Y. Foret-Bruno et al. Quasistatic Characterization of the Human Foot-Ankle Joints in Simulated Tensed State and Updated Accidentological Data. in IRCOBI, 1996, pages 363-376

VTRC Inc. Highlights for ALEX II. in Foot and Ankle Workshop, 1996.