LOWER LIMB

Immobilisation of the knee and ankle and its impact on drivers’ braking times

A DRIVING SIMULATOR STUDY


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The purpose of this study was to investigate the effects of right leg restriction at the knee, ankle or both, on a driver’s braking times. Previous studies have not investigated the effects of knee restriction on braking performance. A total of 23 healthy drivers performed a series of emergency braking tests in a driving simulator in either an above-knee plaster cast, a below-knee cast, or in a knee brace with an increasing range of restriction. The study showed that total braking reaction time was significantly longer when wearing an above-knee plaster cast, a below-knee plaster cast or a knee brace fixed at 0°, compared with braking normally (p < 0.001). Increases in the time taken to move the foot from the accelerator to the brake accounted for some of the increase in the total braking reaction time. Unexpectedly, thinking time also increased with the level of restriction (p < 0.001). The increase in braking time with an above-knee plaster cast in this study would increase the stopping distance at 30 miles per hour by almost 3 m.

These results suggest that all patients wearing any lower-limb plaster cast or knee brace are significantly impaired in their ability to perform an emergency stop. We suggest changes to the legislation to prevent patients from driving with lower-limb plaster casts or knee braces.

Patients with immobilised right lower-limb fractures often seek advice from their treating orthopaedic surgeon as to whether or not they are able to drive. Current United Kingdom legislation states that it is the driver’s responsibility to ensure that they are fit to drive. Studies using questionnaires have shown that the vast majority of consultant orthopaedic surgeons would advise a patient with a right lower-limb plaster cast that they should not drive. However, the response from insurance companies is less clear, and a recent study found that they would advise only on a case-by-case basis. The same study questioned the police, who recommended that orthopaedic surgeons should not give advice, but should refer their patients to the relevant sections of the Highway Code, or to their insurance company if they still have doubts.

Previous studies of reaction times before and after various operations involving the lower limb have produced recommendations on when it is safe for patients to resume driving. The effect of total hip replacement on reaction times suggests a delay of eight weeks, and a similar period is recommended following total knee replacement. In order for reaction times to recover following anterior cruciate ligament reconstruction a period of six weeks is recommended, and following knee arthroscopy the period is one week, which is similar to that after inguinal hernia surgery.

However, it is suggested that patients with right lower-limb immobilisation require empirical data upon which to give evidence-based advice. Kane, Edwards and Hodkinson looked at driver reaction times after right ankle fracture and found that they took two to four weeks after removal of the cast to return to normal, but did not look at reaction times while patients were still in plaster. A recent experimental study by Tremblay et al looked at braking reaction times for patients with below-knee walking casts and Aircast Walkers (DJO Inc., Vista, California), and found increased braking time with both; however, they did not look at the effects of knee immobilisation.

The purpose of this study was to determine the ability of a healthy driver to perform emergency braking when movement of the right leg was restricted at the ankle, the knee or both, using above- or below-knee plaster casts or a knee brace with increasing limitation of movement. The study did not try to control various confounding factors such as pain, analgesia or the location and type of injury.
We hypothesised that increased restriction in movement would increase total braking reaction time and, specifically, the movement time from the accelerator to the brake.

**Patients and Methods**

The hospital ethics committee exempted the study from requirement of approval as no patients were involved.

A total of 23 healthy drivers, 14 men and nine women, with a mean age of 33.2 years (19 to 62), were recruited. All had been driving for at least one year and reported being free from any medical condition that might have impaired their ability to drive.

Data were collected from a driving simulator with a represented road environment and data acquisition system. The simulation system was based on three Evans and Sutherland simFUSION image generators (Evans and Sutherland Computer Corporation, Salt Lake City, Utah) which were projected onto three 2.29 m × 2.50 m screens, with a viewing angle of 180°. The driving rig consisted of a steering wheel, accelerator, brake and clutch pedals and an adjustable car seat. Pedal position was sampled at 1000 Hz and collected using a LabVIEW data acquisition system (National Instruments, Austin, Texas). The measures of reaction time were ‘thinking time’ (time between the lead car braking and the commencement of release of the accelerator), ‘movement time’ (time between accelerator release and the onset of brake pressure), ‘brake travel time’ (time between onset of brake pressure and achieving 100 N of force), and ‘total brake reaction time’ (time between the lead car braking and applying a force of 100 N to the brake) (Fig. 1).

The right leg was assessed in seven conditions of restriction: no restriction (NR); a DonJoy knee brace (DJO Inc.) restricted to 0° to 90° (90B); 0° to 60° (60B); 0° to 30° (30B) or 0° (0B); a below-knee plaster cast (BKP); and an above-knee plaster cast (AKP). Casts were constructed using Scotchcast plaster (3M UK PLC, Bracknell, United Kingdom) and applied by a single author (NJC) in a standard fashion in order to reduce variability. Participants were allowed to seat themselves in the rig and find a comfortable driving position. Each was given a five-minute practice drive to familiarise themselves with the equipment, and then had ten trials of each of the seven experimental conditions. For the simulations the participants were asked to depress the accelerator pedal fully, which ensured a fixed distance between accelerator and brake pedals, and to follow the lead car at a fixed distance of 25 m. These were controlled by the computer programme. The speed of the simulated vehicle was 30 mph. The lead car was programmed to stop at random at a distance of between 120 m and 300 m, causing the subject to perform an emergency stop.

**Statistical analysis.** The results were analysed comparing the mean times recorded in each setting. One-way analysis of variance (ANOVA) was used to investigate the effects of restriction (NR, 90B, 60B, 30B, 0B, BKP, AKP) on reaction time (thinking time, movement time, brake travel time, and total brake reaction time). The individual comparisons between each set of circumstances were statistically tested using the Scheffe test. This was chosen as it analyses the statistical difference between the means of trial groups with unequal group size. In the statistical analyses shown in the results, ANOVA and the Scheffe test are represented as follows: F ((k - 1), Fcritical), where ‘F’ is the test statistic generated by ANOVA. ‘k’ is the number of groups (7 in our study, therefore 6 (k - 1) is used in our tests), and Fcritical is the calculation from the Scheffe test.13

An examination of the relationship between reaction times and the levels of restriction was undertaken using Pearson’s product-moment correlation.14 A p-value < 0.05 was considered statistically significant.

**Results**

A total of 49 trials were discarded for either failing to reach 100 N or releasing the accelerator early, leaving 1361 trials in the study.

A significant difference was found in the thinking time (F (6, 1447) = 24.22, p < 0.001). The thinking times for 0B and BKP were significantly longer than with NR (Scheffe test, p < 0.001), and thinking times for AKP were significantly longer than in every other type of restriction (all, p < 0.001) (Fig. 2).

The movement time was significantly different across conditions (F (6, 1147) = 10.18, p < 0.001). It was found that the movement times with 0B, (p = 0.0022) BKP (p < 0.001) and AKP (p < 0.001) were all significantly longer than with NR. In addition, the movement time in AKP was significantly longer than for 60B (Scheffe test, p = 0.003) and 90B (p = 0.002) (Fig. 3).

A significant difference was also found for brake travel time (F (6, 1147) = 4.83, p < 0.001), with the BKP brake travel time being significantly longer than that with NR (Scheffe test, p = 0.021), 90B (p = 0.001) and, surprisingly AKP (p = 0.01) (Fig. 4).

Total brake reaction times were significantly different across the conditions (F (6, 1147) = 23.76, p < 0.001), with
the specific findings that 0B, BKP and AKP total brake reaction times were all significantly longer than NR times (Scheffe test, all p < 0.001). Also, the total brake reaction times in AKP were significantly longer than in all knee brace trials (90B, p < 0.001; 60B, p < 0.001; 30B, p < 0.001, 0B, p = 0.01) (Fig. 5).

Finally, it was found that a positive relationship existed between an increasing level of restriction and small increases in mean thinking time (r = 0.23, p < 0.001), mean movement time (r = 0.29, p < 0.001), mean brake travel time (r = 0.13, p < 0.001) and mean total brake reaction time (r = 0.27, p < 0.001).

**Discussion**

Our study was designed to assess the potentially harmful effect of the restriction of knee and ankle movement on the safety of driving by investigating braking times in a laboratory simulator. Below-knee plaster casts, above-knee plaster casts, and DonJoy braces with 0° of movement all caused significantly longer total brake reaction times. An unexpected finding was that thinking time increased significantly with increasing levels of restriction. We speculate that with increased restriction a movement of greater effort is required to lift the foot from the accelerator pedal, which may involve additional pre-motor co-ordination.

As predicted, movement time from accelerator to brake increased significantly with increasing restriction. Fully
restricting the knee (0B) or the ankle (BKP) led to longer movement times than when braking without restriction. Restricting both the knee and ankle (AKP) resulted in the longest movement time, but this was not significantly longer than 0B or BKP.

Participants immobilised in BKP had the longest brake pedal travel time (time to apply 100 N force to the brake pedal). Interestingly, participants immobilised in AKP achieved this force more quickly than with BKP. This could be because the hip controlled all lower-limb movement in this group, leading to larger forces being applied to the brake pedal.

No significant differences were found between 0B and BKP in any of the reaction time measurements, indicating that either full knee or ankle restriction could impair performance. However, in order to make the comparisons objective, full knee restriction should be tested by the use of cylinder plaster casts, and full ankle restriction by the use of ankle braces. Braces tend to be more flexible than plasters, and as a result allow increased movement in the individual joint.

Overall, total brake reaction time was found to be significantly longer when the participant was fitted with the brace locked in extension, a below-knee plaster cast or above-knee plaster cast than when they were unrestricted. Our study shows that this is due to a combination of increases in movement time, thinking time and brake pedal travel time. It seems that all components of emergency braking are affected by immobilisation of the lower limb.

The increase in total brake reaction times for 0° brace, below-knee and above-knee plaster casts equates to a vehicle travelling an additional 1.4 m, 1.9 m and 2.8 m while stopping from 30 mph, respectively.

Our study required drivers to depress the accelerator fully to ensure the same distance from accelerator to brake, which is unlike the situation in normal driving, where the accelerator is rarely fully depressed but often requires fine adjustments of position to maintain appropriate speed and following distance. These adjustments may be more difficult to make with the ankle immobilised. Also, inevitably, drivers in this study expected the lead car to brake, and such anticipation has been shown to have a large impact on reaction times.15

This study found a significant increase in reaction time with increasing lower-leg restriction, compared with no restriction. This differs from the findings of Tremblay et al.,12 who measured the effects of ankle immobilisation on brake reaction times using a driving rig of similar design to the one we used. Although they did find an increase in reaction time, it was small and was not found to significantly impair driving performance. The reason for this crucial difference may be due to anticipation. In Tremblay et al’s study the signal to brake came at random between three and five seconds into the drive, a window of only two seconds. In our study, the lead car braked at random after a distance of between 120 m and 300 m. At 30 mph (13.4 metres per second) this creates a window of just over 13 seconds. It may be that driver expectancy during the brief two-second window had a significant effect on reaction time that was not seen with our much longer window.

Another study by Orr et al16 found a significant increase in total brake response times when the driver was immobilised at the ankle with a plaster cast or a controlled-ankle-movement boot, and recommended that patients should be advised not to drive while immobilised in this way.

We have shown that increasing the degree of lower-leg restriction leads to an increase in the total brake reaction time; fully restricting the knee and/or ankle causes a significantly longer total brake reaction time than when the driver is unrestricted, resulting in an increase in stopping distances which approaches 3 m at 30 mph. This supports and adds to previous work suggesting that immobilisation of the ankle results in increased braking times, as well as providing data regarding knee immobilisation for the first time.

Our findings suggest that the legislation governing fitness to drive in the presence of lower-limb immobilisation needs to be reconsidered.

References