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Evaluation of the Protected Position Mobility Aid Securement System for Intercity Buses

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Evaluation of the Protected Position Mobility Aid Securement System for Intercity Buses

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16. Abstract

Making urban and intercity buses accessible for passengers using mobility aids (wheelchairs and scooters) has been a long-standing goal in many countries. In Canada, lifts, securement systems, transfer chairs, and accessible on-board washrooms have been developed and have alleviated many accessibility problems. However, one issue that has not been entirely resolved is the securement of personal mobility aids. While the rear-facing protected position for the securement of mobility aids is in operation in many low-floor transit buses in Europe, and in several Canadian cities, the protected position concept has not been tested in an intercity coach. In the protected position arrangement the passenger backs his mobility aid into an area provided with a fixed back and head supporting panel, a horizontal handrail on the bus wall, and an arm or stanchion on the aisle side to prevent the mobility aid from moving into the aisle.

The purpose of this study was to investigate the safety and comfort of a protected position for an occupied mobility aid on an intercity bus. The specific objectives were to determine the g forces exerted on the mobility aid occupant during severe acceleration, deceleration and sharp lane change manoeuvres; and to observe and record the human factors aspects during a regular intercity bus trip.

For the study, two protected positions were installed adjacent to the wheelchair lift at the rear of an intercity coach. Dynamic tests were conducted using an anthropometric dummy in various wheelchair types, in the bus, on a test track. G forces were measured during acceleration and deceleration to and from 110 km/h. Lateral forces were also measured. The human factors investigation involved 12 test subjects using the protected position while travelling in the bus. An ergonomist observed and recorded reactions and opinions before, during and at the end of the trip.

The results of the tests indicated that passengers who were transported in a rear-facing protected position in an intercity coach, were safe, secure, and comfortable during the test journeys. Modifications to the protected position system are suggested, and recommendations are made for implementation of the system.

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16. Résumé

Dans beaucoup de pays, l'accessibilité des autobus et des autocars aux personnes utilisant des aides à la mobilité (fauteuils roulants et scooters) est un objectif poursuivi depuis longtemps. Au Canada, des plates-formes élévatrices, des systèmes de retenue, des toilettes embarquées et des sièges de transfert ont été développés et ont contribué à atténuer un bon nombre de problèmes d'accessibilité. Or, une difficulté n'a pas encore été aplanie complètement, l'ancrage des aides à la mobilité. Même si en Europe et dans plusieurs villes du Canada des systèmes de retenue pour poste protégé de transport d'aide à la mobilité sont utilisés dans beaucoup d'autobus à plancher surbaissé, ce système reste à être testé dans les autocars. Lorsqu'il arrive au poste protégé, le passager handicapé recule son fauteuil roulant dans un espace équipé d'un panneau fixe de maintien du dos et de la tête et pourvu d'une main courante sur la paroi de l'autocar et d'un bras ou d'une colonne d'appui du côté de l'allée pour empêcher l'aide à la mobilité de s'y déplacer.

La recherche avait pour but d'étudier la sécurité et le confort qu'un poste protégé d'aide à la mobilité peut offrir sur un autocar. D'une manière plus spécifique, les objectifs de l'étude étaient définis comme suit : déterminer les forces auxquelles est soumis l'occupant de l'aide à la mobilité durant des accélérations et des décélérations brutales et des manoeuvres rapides de changement de voie, observer et enregistrer les facteurs humains durant un voyage régulier à bord d'un autocar.

Pour les fins de l'étude, on a installé deux postes protégés à côté de l'élévateur pour fauteuil roulant à l'arrière d'un autocar. Des essais dynamiques ont été effectués sur une piste d'essais à l'aide d'un mannequin assis dans divers types de fauteuils roulants. Les accélérations et les décélérations ont été mesurées lors de départs arrêtés jusqu'à 110 km/h et de freinages amorcés à cette vitesse jusqu'à l'arrêt complet. Ont également été mesurées les forces latérales en présence. Pour la partie de la recherche qui s'intéressait aux facteurs humains, 12 sujets ont fait un voyage en autocar, occupant le poste protégé. Les réactions et les impressions des occupants des aides à la mobilité, avant, durant et après le voyage ont été observées et enregistrées par une personne spécialiste en ergonomie.

Les résultats des essais ont montré que les passagers ayant fait le voyage en autocar dans leur fauteuil roulant dans le poste protégé et tournés vers l'arrière du véhicule, se sentaient en sécurité, confortables et bien immobilisés. Des modifications au système sont proposées et des recommandations sont formulées pour sa mise en place.

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EXECUTIVE SUMMARY

This study investigated the safety and comfort of a Protected Position Securement System (PPSS) for securing occupied mobility aids in intercity buses:

Two specific areas of concern were investigated:

- The effects of g forces on mobility aids in an intercity bus to determine whether an unsecured mobility aid occupant can travel in a rear-facing position that is safe for him/her and for other passengers.
- Human factor aspects such as safety, comfort and convenience for a person facing backwards on a lengthy trip.

In the protected position arrangement the passenger backs his mobility aid into an area provided with a fixed back and head supporting panel, a horizontal handrail on the bus wall, and an arm or stanchion on the aisle side to prevent the mobility aid from moving into the aisle.

G-Force Testing

A Hybrid II test dummy and three types of mobility aids were used to evaluate the effectiveness of a head and back support panel and stanchion, for securing an intercity bus passenger in the protected rear-facing orientation during adverse manoeuvring conditions. The manoeuvres included rapid acceleration from a standing start, evasive lane changes and hard braking. A combination of video and accelerometer data was used to record the response of the dummy during the manoeuvres. Accelerometers were located on the bus floor beside the mobility aid, and in the head and chest of the test dummy.

The head and back support panel was effective in restraining the mobility aid and passenger during the braking tests. During the attempted rapid acceleration of the bus, the mobility aid brakes provided sufficient resistance to prevent movement of the mobility aid.

The evasive lane changes were the most severe of the three manoeuvres included in the test program. The lateral restraining arm of the head and back support did not have sufficient strength to prevent lateral movement of the mobility aid and the dummy during these manoeuvres; as a result, the arm fractured during the first test.

The effects of the vehicle acceleration were hardly perceptible either visually or electronically. The peak resultant spinal acceleration measured on the dummy ranged from 0.14 g to 0.27 g.

During the lane change manoeuvre the dummy's right arm and shoulder came into contact with the wall of the bus resulting in spinal accelerations ranging from 0.91 g to 2.85 g. Upon deceleration of the bus the dummy and/or wheelchair initially compressed the padding on the support panel and subsequently followed the deceleration profile of the bus as it came to a complete stop. The spinal deceleration experienced by the dummy ranged from 0.66 g to 1.17 g.

Human Factors Assessment

Twelve subjects with a range of physical limitations from quadriplegia to rheumatoid arthritis volunteered to ride in the rear-facing PPSS. Two subjects were tested at a time, riding from Ottawa to Montreal or Montreal to Ottawa on a 45' bus. Subjects answered a series of questions regarding their physical and psychological state before, during and at the end of the trip. Approximately one-half of the trip was spent speaking to the researcher; the other half was spent relaxing.

A series of five questions was asked three times during the trip regarding comfort, safety and security, state of relaxation, wellness in general, and opinion of riding backwards. None of these variables showed statistically significant changes over the duration of the trip. Trends in the data suggest that some passengers may have felt less well towards the end of the trip, while opinion of riding backwards improved on average, or at the very least, remained the same. More specific pre-post symptoms questions revealed that the most common complaint was localized muscular pain and discomfort, induced or exacerbated by the motion of the bus. Vibration generally acts to reduce blood flow and increase muscle tension, which can lead to discomfort, especially if the seated position can not be changed frequently.

Only two of the twelve subjects reported symptoms consistent with motion sickness. Background information on age, gender, personality and motion sickness history was collected and compared to reports of discomfort. It was found that a history of motion sickness in cars, buses or trains predicted motion sickness symptoms in this study. While personality indices such as extroversion and neuroticism did not correlate with motion sickness symptoms, the presence of anxiety prior to the trip did correlate highly with ratings of “how susceptible to motion sickness are you” and with feelings of “dizziness”, “headache”, “vertigo”, and “unsafe”.

Age differences were very apparent in the data, and through general observations. Age correlated directly with comfort, relaxation, security, alertness, opinion of riding backwards, as well as overall opinion of the bus experience. These results are consistent with literature which states that motion sickness susceptibility decreases with age. However, it is very important to note that the sample of subjects over 50 years of age was also disproportionately female (the mean age for females was 72 years of age). According to the literature, women have a greater tendency to experience motion sickness symptoms.

The rating of functional independence correlated significantly with the perception of tipping. Generally speaking, individuals with limited upper body strength were rated as having less functional independence. A lack of abdominal and lower back strength resulted in a greater degree of head and torso sway, leading to the greater perception of tipping. Because there were limitations on what could be done to the bus to test the new securement system, lap and shoulder belts could not be provided for passengers to help stabilize them in the chair. The bus was equipped with seat belts, but only for forward-facing mobility aid passengers. One subject with limited torso strength experienced very noticeable back and neck discomfort until a shoulder belt could be improvised.

All but one of the subjects reported that they were able to do the activities they normally enjoy doing on a trip of this length. Some commented that though most of the scenery is the same regardless of the direction of travel, it is not possible to see the road signs to know how far they had travelled. Passengers seemed to have little or no difficulty getting into the protected position by themselves. Ten of the twelve subjects felt that the driver was sufficiently helpful, while two reported they felt he did too much for them. The two passengers who reported that the driver did too much may not have responded that way if the tie-downs were not used for the mobility aids. The rating of the overall experience on the trip was also positive, with a mean of 3.58 on a four-point scale (3 = good; 4 = very good). When asked if they had to decide between riding facing forward or having greater independence by riding backwards, most indicated that they would prefer to ride backwards in this type of securement system. The subjects recognized that club seating would be one way to increase their enjoyment on the trip. Having someone directly across from them to talk with would make the trip more enjoyable, particularly if that person was a companion.

Conclusions & Recommendations

The new Protected Position Securement System (PPSS) has proven to be quite promising in terms of providing an easy to use, safe securement system. During g-force testing, it was established that accelerations to the dummy were consistent with human safety limitations. The system also met with approval by most passengers, allowing a greater sense of independence, while maintaining comfort and safety. However, further improvements are warranted. In order to improve the present design, to improve its comfort and convenience for the passenger, and to alleviate operational and layout deficiencies the following recommendations are proposed:

- Ensure fast removal of the back/head panel structure fasteners which connect the steel frame to the floor tracks with quick deployment/release type fasteners that require no tools.
- Strengthen aisle arm.
- Add padded area to bus wall side to provide soft contact and prevent tipping.
- Provide a horizontal armrest on the bus wall side.
- Create more foot clearance for face à face seated passenger(s) facing mobility aid on left side.
- Integrate a passenger restraint system as an integral part of the back/head panel structure.
- Provide a shaped head rest with side supports to allow the passenger to rest his/her head.
- Eliminate noise from the stored lift.
- Move stored lift in order to clear view to the outside.
- Provide access to washroom.
- Apply human factors engineering criteria and methods to the design of an adjustable head rest or arm rest/lateral restraint.
- Repeat user trials with a larger sample, and compare the unsecured PPSS to a control group using the forward-facing Q-straint system.

- Survey the general population, such as train or bus commuters for example, to obtain normative data on discomfort and motion sickness induced by intercity buses and rear-facing seating.

SOMMAIRE

Les chercheurs se sont intéressés à la sécurité et au confort d'un système de retenue pour poste protégé de transport des aides à la mobilité dans les autocars.

Le projet portait particulièrement sur deux domaines :

- Les effets des forces dues à l'accélération sur les aides à la mobilité dans les autocars, afin de déterminer s'il est possible de faire voyager une personne assise dans une aide à la mobilité orientée vers l'arrière du véhicule sans que cela présente de danger pour cette personne même et pour les autres passagers.
- Les facteurs humains comme la sécurité, le confort et la commodité dans le cas d'une personne faisant face à l'arrière lors des voyages sur de longues distances.

Dans un autocar à poste protégé, le passager recule son aide à la mobilité dans une zone pourvue d'un panneau fixe de maintien du dos et de la tête, d'une main courante horizontale installée sur la paroi de l'autocar et d'un bras ou d'une colonne d'appui, sur côté couloir, destinés à empêcher l'aide à la mobilité de se déplacer dans l'allée.

Effets de l'accélération

Pour évaluer l'efficacité de la colonne d'appui et du panneau de maintien de la tête et du dos durant des manoeuvres difficiles, on s'est servi de trois types d'aides à la mobilité et d'un mannequin Hybrid II. Entre autres manoeuvres effectuées par l'autocar : accélération rapide départ arrêté, changements de voie brusques pour éviter un véhicule et freinage brutal. La tenue du mannequin durant ces manoeuvres a été enregistrée sur support vidéo et au moyen d'accéléromètres placés sur le plancher de l'autocar, à côté de l'aide à la mobilité, ainsi que dans la tête et la poitrine du mannequin.

Le panneau de maintien de la tête et du dos s'est révélé efficace pour retenir l'aide à la mobilité et son occupant en freinage et l'accélération rapide a démontré l'efficacité des freins de l'aide à la mobilité à empêcher tout mouvement de cette dernière.

Des trois types de manoeuvres requises pour la réalisation du programme d'essais, les changements de voie ont été les plus violentes. Le bras de retenue latéral du panneau de maintien de la tête et du dos n'était pas assez robuste pour empêcher le mouvement latéral de l'aide à la mobilité et du mannequin durant ces manoeuvres et il s'est rompu au premier essai.

Les effets de l'accélération du véhicule étaient à peine perceptibles à l'oeil nu ou par les instruments de mesure électroniques. L'accélération mesurée à la colonne vertébrale du mannequin a atteint des pointes comprises entre 0,14 g et 0,27 g.

Durant les manoeuvres de changement de voie, l'épaule et le bras droits du mannequin sont venus en contact avec la paroi de l'autocar, ce qui a produit des accélérations de 0,91 g à 2,85 g. En décélération, le mannequin et/ou le fauteuil roulant ont d'abord comprimé le rembourrage du

panneau de maintien pour ensuite décélérer au même rythme que l'autocar, jusqu'à l'arrêt complet. Les arrêts ont produit une décélération de 0,66 g à 1,17 g mesurée à la colonne vertébrale du mannequin.

Évaluation des facteurs humains

Douze sujets présentant une série de handicaps physiques allant de la quadriplégie à la polyarthrite rhumatoïde ont accepté d'occuper une aide à la mobilité orientée vers l'arrière dans le poste protégé. Les essais étaient menés sur deux sujets en même temps durant le trajet entre Montréal et Ottawa à bord d'un autocar de 45 pieds. On a posé aux sujets une série de questions concernant leurs états physique et psychologique avant, pendant et après le voyage. Ceux-ci ont passé environ la moitié du voyage à parler au chercheur, l'autre moitié ayant été réservée pour la détente.

Les sujets devaient répondre à une série de cinq questions, qui leur ont été posées à trois reprises durant le voyage; les questions portaient sur le confort, la sécurité physique, la relaxation, le bien-être général et l'impression que procure le fait de voyager en faisant face à l'arrière du véhicule. Aucun de ces paramètres n'a changé de manière statistiquement significative au cours du voyage. Les tendances observées portent à croire que certains passagers ont pu se sentir moins bien vers la fin du voyage, alors que l'impression due à l'orientation vers l'arrière est devenue plus favorable dans l'ensemble et demeurée la même dans le pire des cas. Des questions plus spécifiques sur les symptômes pré-post ont révélé que les plaintes les plus fréquentes concernaient une douleur musculaire localisée et un inconfort, induits ou aggravés par le mouvement de l'autocar. En général, les vibrations réduisent le flux sanguin et accroissent la tension musculaire, ce qui peut causer un inconfort, particulièrement s'il est impossible de changer fréquemment de posture lorsqu'on est en position assise.

Seulement deux des douze sujets ont signalé des symptômes correspondant à ceux du mal des transports. Les informations sur l'âge, le genre, la personnalité et les antécédents possibles de mal des transports ont été mises en rapport avec les cas d'inconfort. Il a été découvert que les sujets ayant des antécédents de mal des transports en automobile, en autocar ou en train avaient une prédisposition à en manifester les symptômes. Alors qu'il n'y avait aucune corrélation entre ces symptômes et les traits de personnalité comme l'extraversion et la présence d'affection nerveuse, on en a constaté une entre la manifestation d'anxiété avant le voyage et le degré de susceptibilité au mal des transports et la sensation d'étourdissement, de mal de tête, de vertige et d'insécurité.

Les données révélaient très clairement les différences d'âges entre les sujets, tout comme le faisaient les observations générales. Une corrélation directe a pu être établie entre l'âge et des sensations comme le confort, la détente, la sécurité, la vigilance et l'impression ressentie durant les déplacements en faisant face à l'arrière et l'impression générale que procurait le déplacement par autocar. Les résultats coïncidaient avec ceux de publications consultées, et selon lesquelles la susceptibilité au mal des transports augmente avec l'âge. Or, il faut souligner que l'échantillon de sujets, âgés de plus de 50 ans, était composé surtout de femmes qui avaient en moyenne 72 ans. Toujours selon ces publications, la tendance au mal des transports est plus forte chez les femmes.

On a remarqué une corrélation substantielle entre le degré de capacité fonctionnelle et la perception de basculement. En général, les personnes n'ayant qu'une force limitée au niveau du buste jouissaient, selon les notations, d'une moins grande indépendance fonctionnelle. Le manque de force à l'abdomen et dans le bas du dos s'est traduit par un balancement plus fort de la tête et du torse, ces sujets percevant plus fortement une sensation de basculement. En raison des modifications limitées qu'il est possible d'apporter à l'autocar pour essayer le nouveau système de retenue, les chercheurs n'ont pu utiliser des ceintures à sangles diagonale et sous-abdominale et stabiliser les personnes dans leur fauteuil roulant. L'autocar était muni de ceintures de sécurité, mais seulement pour les occupants d'aides à la mobilité tournées vers l'avant. Une personne ne pouvant utiliser qu'une force limitée au niveau du torse a éprouvé un inconfort très marqué au dos et au cou jusqu'à ce que l'on puisse lui improviser une ceinture diagonale.

Tous les sujets sauf un ont déclaré avoir été en mesure de faire les activités qu'ils font normalement durant un voyage de cette durée. Certains ont fait observer que même si le sens de déplacement ne change rien au paysage, il leur était impossible de voir la signalisation routière et de déterminer où ils étaient rendus. Les passagers semblaient avoir peu ou pas de difficulté à se positionner sans assistance dans le poste protégé. Dix des douze sujets estimaient que le chauffeur les avait suffisamment aidés; deux ont dit que celui-ci en avait trop fait pour eux. Ces deux derniers n'auraient probablement pas donné la même réponse si on n'avait pas utilisé d'attaches pour les aides à la mobilité. Le voyage dans l'ensemble s'est résumé par une évaluation positive, avec une moyenne de 3,58 points sur une échelle de quatre points, la note 3 correspondant à «bien» et la note 4 à «très bien». Lorsqu'on leur a demandé ce qu'ils feraient s'ils avaient à choisir entre le voyage tourné vers l'avant du véhicule et le même voyage en faisant face à l'arrière mais avec une plus grande liberté de mouvements, la plupart des sujets ont répondu qu'ils préféreraient être assis face à l'arrière avec ce type de système de retenue. Tous les sujets ont dit que la disposition face à face des fauteuils contribuerait à donner davantage d'agrément au voyage, que le fait d'avoir une personne à qui parler directement en face de soi rendrait le voyage plus agréable, plus particulièrement s'il s'agit d'un compagnon.

Conclusions et recommandations

Le nouveau système de retenue pour poste protégé d'aide à la mobilité s'est révélé très prometteur aux chapitres de la convivialité et de l'efficacité. Il a été établi que les forces subies par le mannequin durant des essais de comportement en accélération respectaient les limites acceptables pour le corps humain. Le système a également reçu l'approbation de la plupart des passagers, ceux-ci ressentant une plus grande impression d'indépendance sans réduction de confort et de sentiment de sécurité. Néanmoins, le système étudié nécessite d'autres améliorations. Pour améliorer le système actuel, relever le degré de confort et de commodité pour le passager et atténuer les déficiences opérationnelles et de configuration, les chercheurs ont formulé les recommandations ci-après :

- Prévoir l'utilisation de fixations rapides, ne nécessitant pas d'outils, pour accélérer l'enlèvement des attaches servant à fixer l'armature du panneau de maintien de la tête et du dos aux rails de plancher.

- Renforcer le bras de couloir.
- Poser une surface rembourrée contre la paroi de l'autocar afin d'amortir les chocs et d'atténuer la sensation de basculement.
- Installer un appui-bras horizontal sur la paroi de l'autocar.
- Ménager un plus grand dégagement entre l'emplacement de l'aide à la mobilité et les sièges faisant face à celle-ci.
- Installer un système de retenue faisant partie intégrante de la structure du panneau de maintien de la tête et du dos.
- Installer un appui-tête profilé avec supports latéraux pour que le passager puisse y poser la tête.
- Éliminer le bruit provenant de l'élévateur en position escamotée.
- Déplacer l'élévateur afin de ne pas obstruer la vue vers l'extérieur.
- Assurer un accès à la toilette.
- Appliquer des critères et des méthodes ergonomiques pour la conception d'un appui-tête réglable ou d'une retenue latérale/d'un appui-bras réglables.
- Reprendre les essais avec utilisateurs, mais en élargissant la taille de l'échantillon, et comparer les systèmes de postes protégés sans système de retenue avec un groupe témoin utilisant le système d'ancrage Q-Straint orienté vers l'avant.
- Mener un sondage auprès de la population en général, par exemple des usagers du train ou de l'autocar, afin de cueillir des données normatives sur l'inconfort ou sur le mal des transports à bord des autocars et en position tournée vers l'arrière.

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1. INTRODUCTION

The present research is a continuation of work carried out in Europe, adding information required to answer questions concerned with safety and comfort. The following background information describes the previous events and work that have led up to this study.

1.1 Background

There has been a long-standing desire in many countries to make intercity buses accessible for passengers using mobility aids. In Canada, the Transportation Development Centre, together with manufacturers and operators have made great efforts to address this problem. Lifts, securements, transfer chairs and accessible washrooms have been developed and have alleviated many of the difficulties faced by passengers in mobility aids. One issue, which is still not resolved, is the securement of passengers travelling in mobility aids.

There are two main areas which must be addressed:

- the physical and psychological human factors experienced by passengers in a mobility aid;
- the technical and operational aspects of providing safe transport for all mobility aid types, including scooters.

There is an increasing trend of using four-wheel electrical scooters that provide better stability than the three-wheel scooters. Scooters are now being used more by individuals who cannot easily transfer to a seat.

Several securement and restraint systems have been developed over the last 15 years in many countries for passengers in mobility aids travelling on large buses. The results indicate that many principles are either technically or operationally ineffective. The clamp systems cannot be applied to scooters with small wheels. The attempt to develop a standard interface for all mobility aids is not feasible since manufacturers cannot agree on any standard. As well, since individuals' needs vary depending on their lifestyle and degree of physical function, even standard mobility aids are sometimes customized to better suit the user. A docking system developed in the U.S. and requiring the outfitting of mobility aids with special attachments has failed for the same reasons. One principle has survived all others: the attachment of two front and two rear belts to the mobility aid (Q-straint with variations). Although this system has the advantage of being adaptable to almost all mobility aid types, it has several ergonomic problems, mainly the need for assistance by another person, and the handling and storing of belts and hooks by another individual, e.g. driver, or a companion.

In recent years a new solution - the protected position securement system (PPSS) or compartment concept - has been developed for urban low-floor buses for people travelling in mobility aids (Rutenberg, 1995a; 1995b). In this arrangement a mobility aid passenger travels facing toward the rear of the bus with his/her back close to a fixed supporting back panel, a horizontal handrail at waist height at the bus wall to hold onto, and a stanchion on the aisle side to prevent the mobility aid from moving into the aisle. The brakes of the mobility aid must be applied in this position. This system is used in many European countries, has been service-tested in several hundred urban buses, and is considered safe by transportation authorities. For urban buses this systems provides independence for the mobility aid traveller since there is no need for assistance, and it allows the driver to remain at his/her station. These two advantages greatly facilitate the operation and integrate the mobility aid traveller as an equal participant in public transportation.

Passengers must travel for greater distances and durations when using intercity buses. To consider the PPSS approach for an intercity coach application, special emphasis must be placed on the investigation of human factors aspects: assurance of security, proper dimensions required to accommodate all passengers in mobility aids (reach distances, clearances, support panel height, stanchion/armrest position etc.), comfort, possible disorientation (facing rearward), manoeuvring space, stability of stanchions, and support panel.

At present, there are several projects underway to investigate urban and intercity bus securement issues for passengers using mobility aids and scooters.

1) A Ministry of Transport of Ontario study examined the impact on Ontario Transit Systems of operating full-size accessible transit, low-floor or standard lift-equipped buses. Phase I, completed in August 1995, addressed safety issues such as the requirements for emergency doors, service doors and side impact criteria. The second phase began in August 1996 and addressed the protected position securement system concept, suburban /commuter operations, legal, workplace, and human right issues. No testing in buses was carried out.

2) The Transportation Development Centre under a contract with TES Ltd., investigated securement performance requirements for an automated mobility aid securement for use on large buses.

3) The Canadian Urban Transit Association (CUTA) has undertaken several projects to investigate the concept of the protected position securement system (PPSS) on low-floor buses. Although this system is in use and considered a safe way of securing passengers in mobility aids in Europe, several questions remain unanswered for application in a typical Canadian transit environment. CUTA is planning demonstrations and evaluations with several transit operators to address the following issues:

   - safety of the protected position securement system for three-wheel scooters (which are not used on buses in Europe),
   - safety aspects in an suburban environment where buses travel up to 100 km/h,
   - evaluation of front door boarding with front location of protected position securement system versus centre door boarding with centre location of protected position securement system.

4) The STCUM in Montreal is testing the operation of their new Nova low-floor buses. One rear-facing protected position securement system (PPSS) is provided at the centre door curb side with a ramp at the centre door. Operation and effectiveness of this arrangement will be monitored and evaluated.

Although the situation for intercity buses is somewhat different (no frequent boarding/alighting, lift access required), the question arises, if a similar protected position securement system approach can be considered.

No national or international studies or research data are available which have addressed this problem. Therefore, the Transportation Development Centre contracted Rhodes & Associates Inc. to investigate the human factors aspects and G forces on large intercity coaches for the application of the protected position securement system concept.

Two essential issues must be addressed:

- Are the human factor effects for a person facing rear on a lengthy trip acceptable, safe and convenient?

- Do the G forces on an intercity bus affect a mobility aid such that an unsecured mobility aid passenger can travel in a position that is safe for himself/herself and to other passengers.

2. PROBLEM STATEMENT

At this time, accessible intercity buses have two positions for passengers with mobility aids: they are located either near the lift at the rear of the bus, or on the lift platform at the centre of the bus. Mobility aid passengers board/deboard the bus via a built-in lift, which can be located at the centre or rear section of the bus. The operation is carried out by the driver. Typically, two seat benches are moved in floor tracks - one forward, one to the rear - to create the space for the mobility aid passenger. The benches have flip-up seats with two retractable belts connected under the seat frame, one pair to secure for the rear of the mobility aid, the other the front. There are optional belts available for passenger restraint.

The problems with this type of securement are:

- the handling of the securement by the driver who must get on his knees in a very awkward position to connect and disconnect belts and hooks to a mobility aid,
- securing scooters presents a special problem, since they do not have designated or otherwise identifiable anchor points; which can result in an inadequate securement or in damaging components,
- the mobility of the mobility aid passenger to move to the washroom during a trip is restricted since he/she cannot disconnect/connect belts and hooks alone,
- the mobility aid passenger is the only one in the bus whose "seat" is secured by belts, which makes him/her stand out from all other passengers

2.1 Issues to be Investigated

The following human factor and technical issues must be investigated to determine if passengers in mobility aids can face to the rear and be transported in a protected position securement system configuration safely:

(1) **Physical human factor effects for the passenger facing to the rear**:

- Absorption of frontal, longitudinal and lateral forces for persons with different upper body strength in a mobility aid, as well as physical relationships between the user and physical aspects of the design (handrails, stanchions, support panel, etc.) for all sizes and capabilities of passengers in mobility aids will be determined.
- Ranges for minimum reach distances and maximum clearances will be calculated according to standards.
- The physical demands of the manoeuvring tasks will be examined to help determine clearances.

- The acceptable level of stability of all supports and structural units will be evaluated through test and through feedback from test passengers (i.e. do they have enough confidence in the appearance and feel of these components).

- The overall general comfort of the passenger using the protected position securement system will be assessed.

(2) **Psychological effects**:

- e.g. motion sickness,

- assurance of security,

- club seat configuration with and without a companion,

- "stigma" of being the only passenger facing rearward.

(3) **Frontal, lateral, longitudinal G-force effects** apply to a passenger in a mobility aid in a large (12 m) bus driven at 100 km/h on a highway under regular driving conditions, including severe braking, evasive (S-type) manoeuvring, and sharp accelerating.

- Could the mobility aid passenger be transported in a protected position securement system arrangement without the use of belts and hooks?

- How are the different mobility aid types affected by these forces, e.g. manual and electrical wheelchair, and in particular the three-wheel scooter?

(4) Can the protected position securement system principle similar to those in use by European urban transit operators be considered for use in intercity buses? Are there other alternatives for a securement in an intercity bus?

3. OBJECTIVE

The overall purpose of this research is to help provide safe, comfortable and convenient access to intercity buses by all travellers including those using a mobility aid. This has been accomplished by pursuing two main objectives:

- The objective of the G-force testing is to determine which longitudinal and lateral forces a passenger in a mobility aid would experience at these speeds and manoeuvres.

- The objective of the human factors research is to find out how passengers in mobility aids experience a rear-facing position on a 2-hour trip, and to determine how the design of the securement system can enhance safety, comfort and satisfaction of the passengers.

4. SCOPE

Human factor tests carried out with individuals in mobility aids traveling in a protected position securement system on an intercity coach in a non-service operation, excluding severe braking, acceleration and evasive manoeuvring.

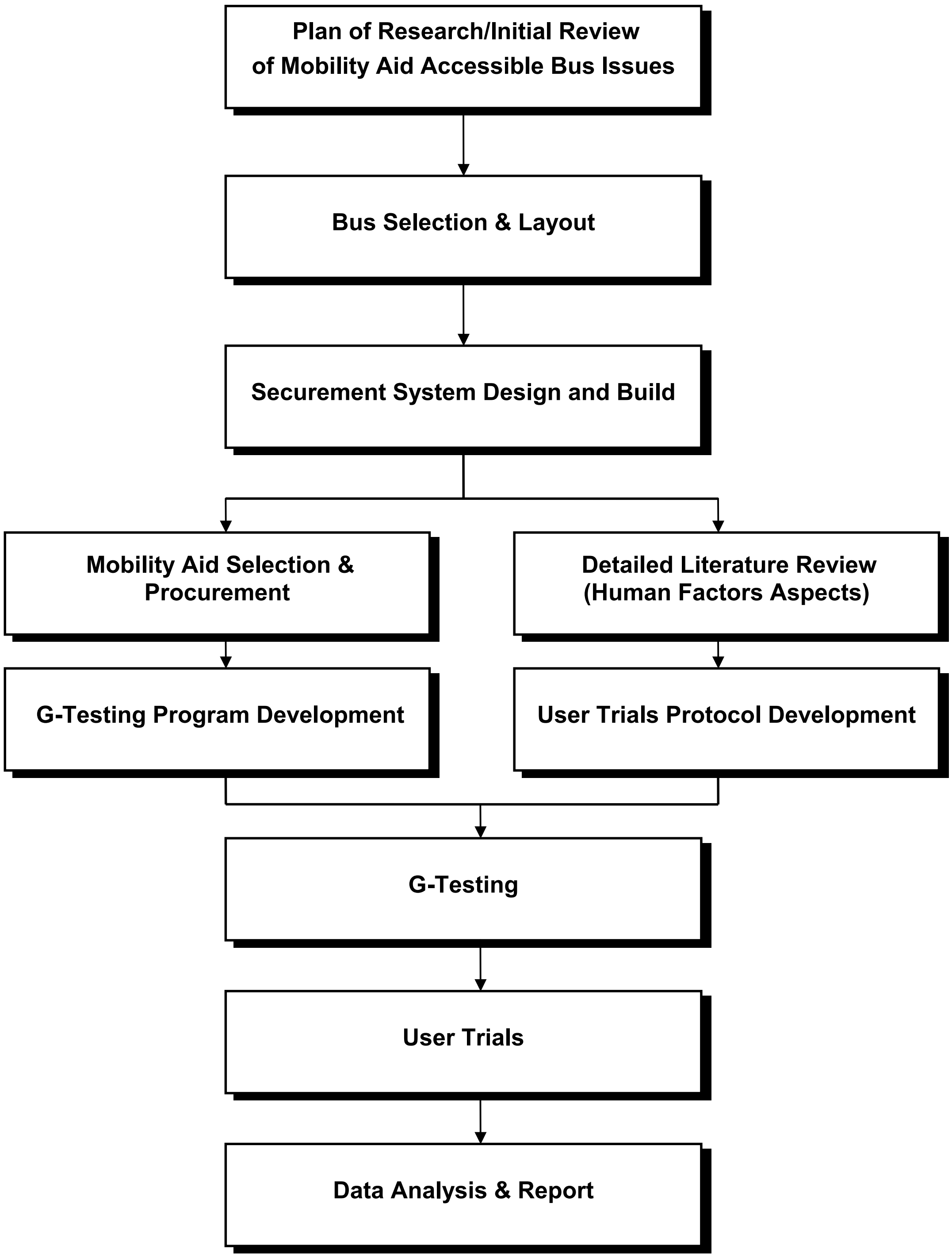
Test for G-force measurements were performed with dummies in different mobility aids in a protected position securement system of up to 100 km/h including severe braking, accelerating and evasive manoeuvring.

Tests did not include roll-over situations.

5. APPROACH

The following was the basic approach to conducting this research:

Figure 5-1: Project Plan



6. TEST SET-UP

6.1 Bus Selection and Layout

An intercity bus had to be selected according to the following criteria:

- The bus must be lift-equipped for boarding and alighting passengers in mobility aids.
- The operation must be non-service operation on a typical highway for test trips lasting between 1.5 and 2 hours.
- The driver must be familiar with transporting passengers in mobility aids and able to operate a lift and securement equipment.
- The bus layout must be modifiable to accommodate two mobility aid positions facing to the rear.
- The bus must be driven on a test track and carry-out testing manoeuvres.
- The layout must be arranged for at least one club (face- -face) seating.

A bus operator was contracted who met the criteria. Autocar Orleans Express Inc. of Montreal made a 45' Prevost accessible intercity coach with a driver available for a three-day testing schedule. This bus has a built-in rear lift and two rear positions for passengers in mobility aids. In their present operation mobility aid passengers face forward and are secured by two front and two rear tension belts which are connected to floor receptacle. Each position also has a shoulder and lap belt if the passenger desires to use the restraint. To make room for the mobility aid position, one bench with a fold-up seat is moved in floor tracks to the front against the back of the next bench.

For the purpose of this project, the mobility aid positions were modified in the following way. In each position the folding/removable bench was removed to make room for the rear-facing head and back panel support, to allow for more manoeuvring space and for foot clearance in the club seating arrangement. The result was two rear-facing positions, one on the left side with a face- -face seating, and one at the right side adjacent to the stored lift. At each position, a cushioned head and backrest panel mounted on a steelframe was positioned close to the back of the following bench. See Figure 6-1 for dimensions and layout of the area where the PPSS were installed on the bus.

6.2 Securement Design

The design of the back/head panel frame was based on the principles used in low-floor buses for a rear-facing design position which does not require belts and hooks to secure the mobility aid. This design has been proven in urban buses in Europe and has been accepted as a safe way of transporting mobility aid passengers. A similar design is in use in Hamilton, Ontario and in Montreal, Quebec.

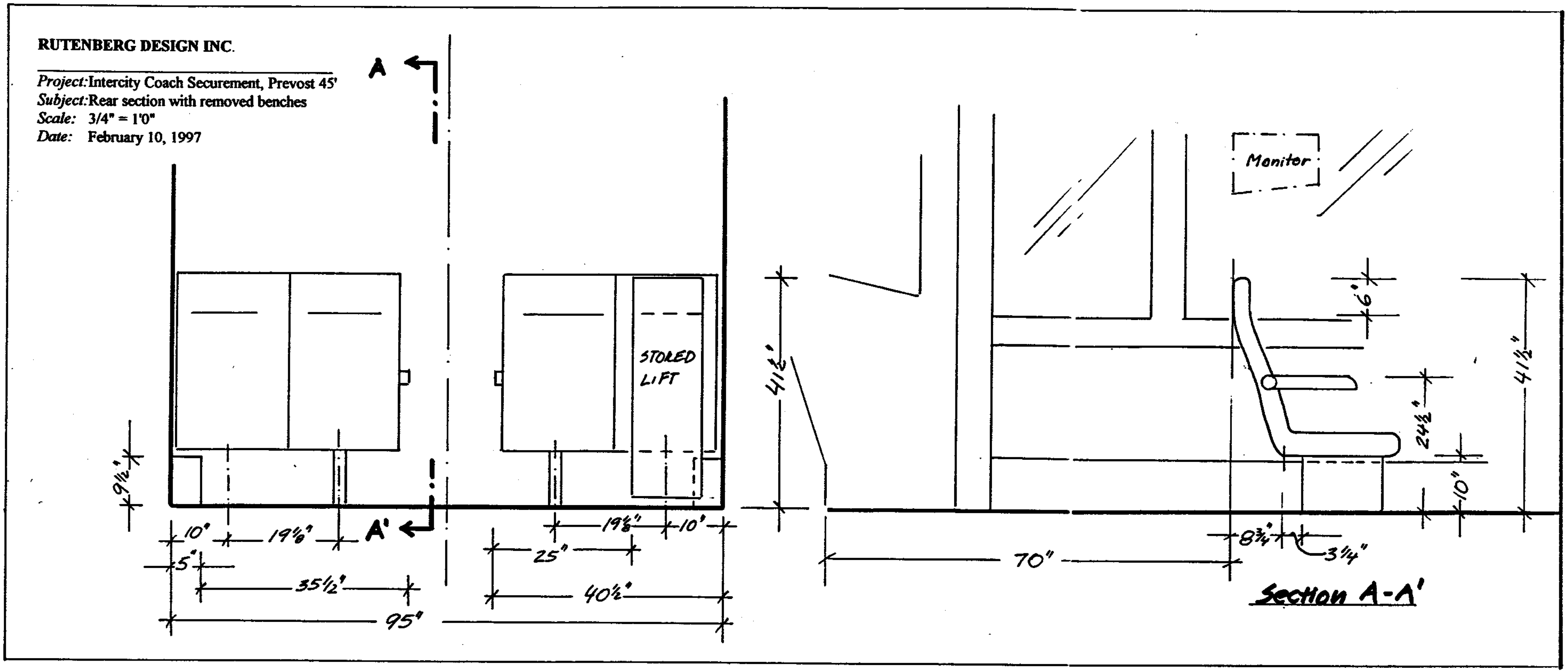


Figure 6-1: Dimensions and Layout for Area of Installation for the PPD

There were several necessary changes made to the original protected position securement system:

- The panel's steel structure had to be free-standing, because no modifications to the bus ceiling or floor were allowed for these tests (typically the panel's frame is connected to the ceiling and floor of a bus).
- For the same reason, no aisle facing stanchion could be used.
- No horizontal handrail along the bus wall could be attached.

The design therefore was modified to provide a free-standing steel frame with four anchor points connected to the floor tracks. To prevent the mobility aid from moving into the aisle, a steel arm was attached to the main frame providing a pivot of 360^o perpendicular to the panel and making it adjustable to different widths of mobility aids. Dimensions for the mobility aid were calculated in order to accommodate a maximum of 813 mm (32") wide chairs, and to be centered from the bus wall's heating duct on one side and the stored lift on the other side. See Figure 6-2 for the dimensions of the PPSS. Figures 3 and 4 of Appendix B show the actual PPSS in the bus.

<u>Support Panel</u>

The support panel was made of a plywood core with a firm foam cushion on the passenger's side, and upholstered with fabric. The height of the panel was determined for a 98 percentile user sitting in a mobility aid at a seat height of 457 mm (18") with his/her head supported. The clearance of the panel from the floor accommodated the protrusion of battery boxes, wheels and frame/stabilizing parts of different mobility aids. The width of the panel, 304 mm (12"), is according to the clearance required between handle bars to allow the passengers's back to come as close as possible to the panel.

<u>Steel Frame</u>

The steelframe was made of 28.5 mm (1.125") diameter, gauge 12, tube stock, and 90^o pre-fab corners welded into place. Open ended tubes were closed off with black plastic caps. Both vertical tubes supporting the panel were designed to withstand the forces generated in a deceleration situation with 250 lb (113.6kg) of the body weight pushing against the lower part of the panel at 1 G maximum. The resultant force would be distributed into four steel legs, two vertical and two inclined at 25^o. Each leg was separately secured by a .5" (1.2cm) T- bolt, washer and nut to the steel floor track. The steelframe was attached to the panel at four points by .125" (.3cm) steel bolts to an insert nut in the plywood panel. The steel frame was primed and painted in glossy yellow.

<u>Aisle Arm</u>

The aisle arm protection was attached to the rear of the steelframe at armrest height, 660 mm (26") above the floor. Two brackets holding the arm in place were designed in such a way that the rotation angle of the arm could be adjusted as well as the width for different mobility aid types. The rotation angle would allow the arm to adapt to different mobility aid types, either coming in contact with a large wheel or the side frame of the chair. The end of the arm that faced the aisle was covered with an end cap and a foam cover at a length of 254 mm (10") to protect the mobility aid frame/wheel from direct metal-to-metal contact.

RUTENBERG DESIGN INC.

Project: Intercity Coach Securement, Prevost 45'
Subject: Rear-facing panel and frame
Scale: 3/4" = 1'0"
Date: February 10, 1997

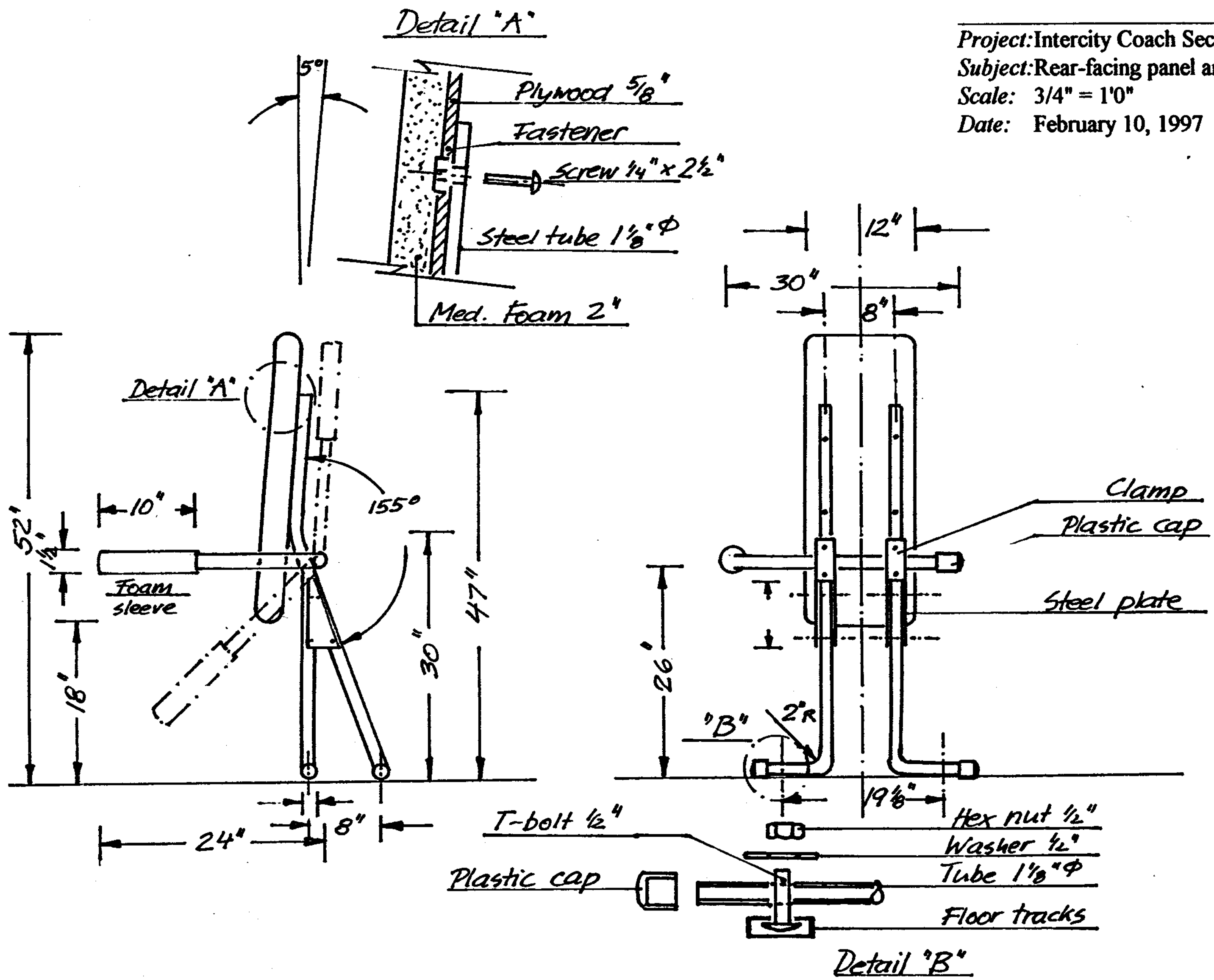


Figure 6-2: Dimensions of the Protected Position Design (PPD)

Two complete head and back support panels with frame and arms were built and installed in the bus. See Figure 6-3 for the layout and dimensions of the PPSS setup from a top view, and Figure 6-4 to see the same from side and front views. Figures 3 to 4 of Appendix B show the actual PPSS in place and Figures 5 to 6 show the g-test setup. Figure 7 shows the face--face seating arrangement on the left side of the bus.

6.3 Design Constraints

No mechanical modifications to the bus floor, walls or ceiling were allowed (e.g. drilling holes or cutting parts, etc.). The two floor tracks as well as floor receptacles were usable.

G-testing had to be completed in one day, due to the availability of the test track in Blainville and budget limitations. The number of test subjects for the user trials had to be limited to twelve due to the availability of the bus for two additional days and the costs for renting the bus.

6.4 Mobility Aid Selection and Procurement

According to research carried out for the Ministry of Transportation of Ontario (Delcan, Study of Implementation of Accessible Urban Transit Buses in Ontario Transit Systems, Phase 2, March 1997), the most commonly used mobility aids in North America are the standard manual wheelchair, sports chairs, electric converted, power electric and three-wheel scooters. Recently, new models have entered the market which seem to indicate an increased tendency for larger and heavier three- and four-wheel scooters. Both models have increased lengths and turning radii, making them more difficult to fit into typical mobility aid position presently provided by transit and intercity operators.

Four models were therefore selected for this test, two from the commonly used mobility aids and two from the newer generation. These models included:

- A standard manual wheelchair, 610 mm (24") wide, 1 067 mm (42") long, about 22.7 kg (50 lb.).
- An electric power chair with front casters, 635 mm (25") wide, 1 067 mm (42") long, about 109 kg (240 lb.).
- A medium weight three-wheel scooter, 635 mm (25") wide, 1 143 mm (45") long, about 82 kg (180 lb.).
- A four-wheel scooter, 635 mm (25") wide, 1 372 mm (54") long, about 113 kg (250 lb.).

The four models were rented from AMEDCO Inc. in Montreal for the purpose of carrying out the tests with instrumented dummies at the Blainville test centre.

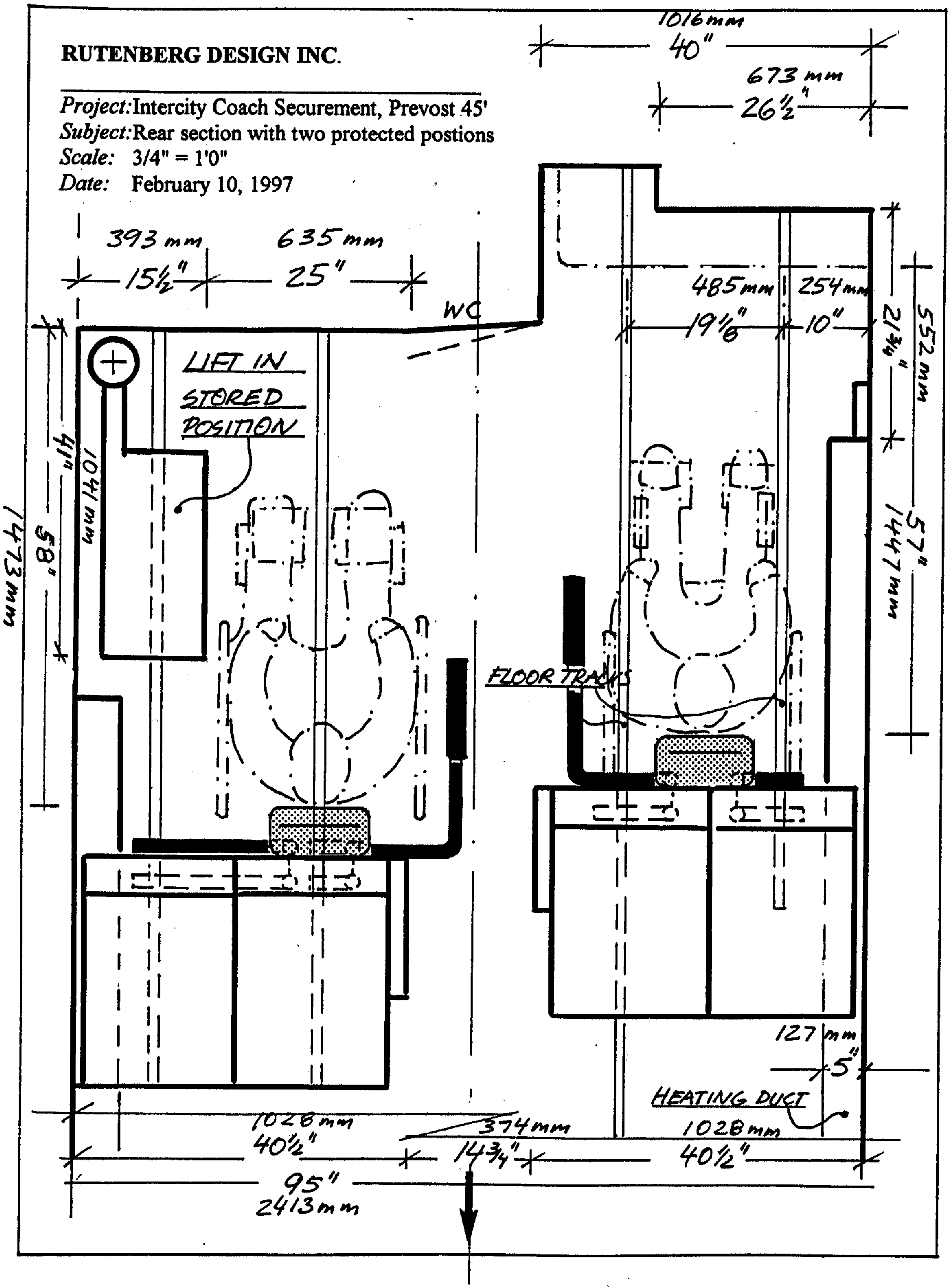


Figure 6-3: Top view of the installed PPD

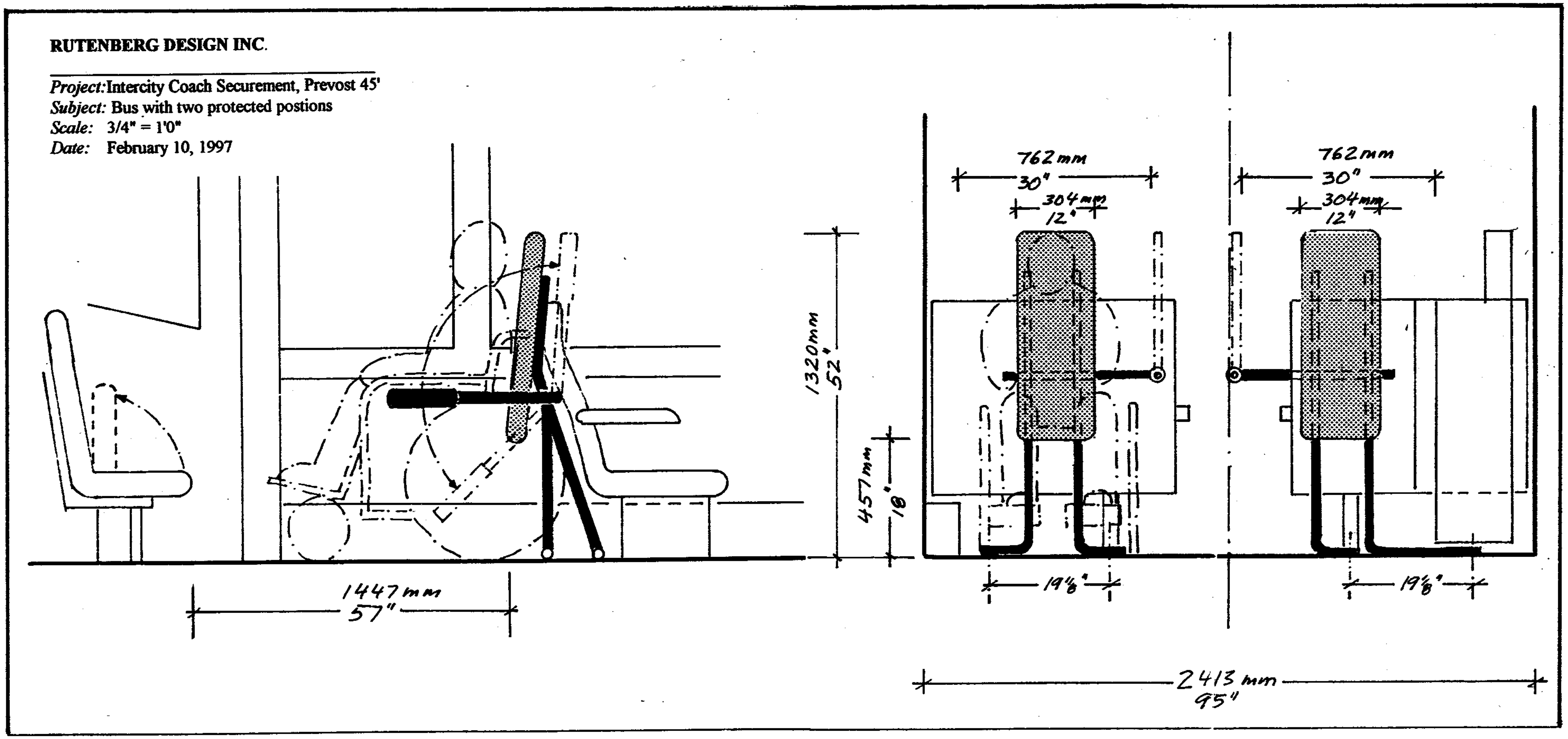


Figure 6-4: Dimensions and Layout for the PPD - Side and Front Views

6.5 Literature Review

Various sources were accessed to obtain references relevant to this study. The following collections and databases were searched:

- University of Toronto Library collection
- Medline database
- ERIC database
- Worldwide Web and usenet groups using Excite, Yahoo, Altavista, Magellan, Lycos and Webcrawler

Keywords used during the database searches included, but were not limited to, the following:

- wheelchair
- mobility aids
- disability
- securement systems
- tie-down system
- restraints
- transportation
- transit
- buses
- rearward facing
- backward

In addition to these sources, individuals with experience in the areas of either motion sickness or transportation accessability design were contacted. These people or organizations included the following:

- Uwe Rutenberg
- Paul Green, University of Michigan
- Dr. Ron Heslegrave, University of Toronto
- Project ACTION
- Disable Hotline

6.6 User Trial Protocol Development

Because of the limited number of subjects and the limited time available for testing, a pre-experimental, pre-post research design was used. An extensive questionnaire was developed and administered to subjects. This questionnaire collected background information, as well as comfort and well-being data at the start and end of the bus trip. For more detailed information on the questionnaire, refer to section 6.9, or to Appendix C to see the full questionnaire.

The subject group consisted of seven men and five women. Since the number of subjects was relatively small, a group which could be representative of the degree of abilities and limitations of the entire mobility aid user population could not be realized. Also, since the study involved an extensive questionnaire, individuals with cognitive or developmental limitations were not included within the subject pool. Table 6-1 shows the distribution of subject demographic and disability characteristics. A large proportion of subjects were either paraplegic or elderly with arthritic conditions that limited mobility.

A variable of particular importance to comfort and stability in vehicles such as buses is upper body strength. Five of the twelve subjects reported spinal cord injuries (acute or chronic) above the T7 vertebra; meaning there was complete or partial loss of function of the abdominal muscles.

A subjective Functional Independence Measurement (Hecox et al. 1994) was made of the subjects to help categorize and compare their responses to the bus trip. Please refer to page 1 of the questionnaire in Appendix C for the scale used to rate functional independence.

Table 6-1: Subject Characteristics

Subject #	Seat	Gender	Disability	Limited Torso Strength	Limited Arm Strength	Balance & Stability Difficulties	Age	Func. Indep. Rating
1	1	F	Arthritis - Rheumatoid	X	X	X	50	6
2	2	F	Arthritis		X	X	85	6
3	1	F	Orthopedic		X		77	6
4	2	F	Arthritis - in remission		X		77	7
5	1	F	Arthritis/Orthopedic		X	X	73	5
6	2	M	Paraplegic	X	X	X	39	5
7	2	M	Paraplegic				38	6
8	1	M	Quadriplegic	X	X	X	40	4
9	1	M	Paraplegic	X			29	6
10	2	M	Paraplegic				31	6
11	2	M	Limited Mobility	X	X		78	5
12	1	M	Paraplegic		X		65	5

6.7 G-Force Testing

6.7.1 Human Surrogate

A Hybrid II anthropomorphic test dummy was used as the human surrogate for this test series. The Hybrid II, which is representative of a 50th percentile male subject, is widely used by the automotive industry in the evaluation of vehicle crash worthiness.

The dummy was seated in an upright posture with its hands placed on the thighs and the feet positioned on the mobility aid's foot supports. To stabilize the dummy in the seated posture, the dummy's joints were tightened sufficiently to prevent rotation when loaded by the weight of the dummy's limbs. See Figure 2-1 in Appendix A for the g-test setup.

6.7.2 Accelerometers

High sensitivity accelerometers were used to measure the dynamic response of the bus and the Hybrid II chest. These were capable of measuring the low acceleration and frequency levels associated with this type of testing.

A triaxial accelerometer mounted on the floor of the bus immediately in front of the mobility aids measured the fore-aft (x), lateral (y) and vertical (z) accelerations during the vehicle manoeuvres. Two accelerometers, mounted in the Hybrid II spine box, measured the fore-aft (X) and lateral (Y) acceleration of the dummy's upper body during the same manoeuvres. The directions of positive accelerations relative to the bus and the dummy are shown in Figure 3-1 in Appendix A.

6.7.3 Data Acquisition System

A portable computer-based data acquisition system was used to collect data from the accelerometers on the bus and those in the Hybrid II spine box. Data was collected at a rate of 30 Hz for a total duration of up to 30 seconds per vehicle manoeuvre. The data was then saved to disk in ASCII format.

6.7.4 Video

Video documentation of each test was acquired with two super VHS video cameras. One camera provide a lateral view of the test set-up. The second camera was placed on the bus at the rearmost position possible to obtain a frontal view of the dummy. A problem with the second camera, which unfortunately was not detected until after the second test, resulted in a loss of video footage for the first two tests.

6.8 G-test Methodology

The mobility aid and occupant were secured in the bus, as described in Section 6.7.1, and subjected to three manoeuvres. The test program and the sequence of vehicle manoeuvres are summarized in Table 6-2.

Table 6-2: Sequence of Tests

Test No.	Mobility aid Type	Manoeuvre
1A	Manual	Rapid Acceleration to 110 km/hr
1C	Manual	Lane change: left then right at 110 km/hr
1B	Manual	Hard braking from 110 to 0 km/hr
2A	2000 FS 3-wheel scooter	Rapid Acceleration to 110 km/hr
2C	2000 FS 3-wheel scooter	Lane change: left then right at 110 km/hr
2B	2000 FS 3-wheel scooter	Hard braking from 110 to 0 km/hr
3A	1744 FS 4-wheel scooter	Rapid Acceleration to 110 km/hr
3C	1744 FS 4-wheel scooter	Lane change: left then right at 110 km/hr
3B	1744 FS 4-wheel scooter	Hard braking from 110 to 0 km/hr
4A	760 FS power electric	Rapid Acceleration to 110 km/hr
4C	760 FS power electric	Lane change: left then right at 110 km/hr
4B	760 FS power electric	Hard braking from 110 to 0 km/hr
The letter code associated with each test number is indicative of the manoeuvre. i.e. A - acceleration C - lane change B - braking		

The test numbers indicated in Table 6 are visible in the video recordings as an indication of the vehicle manoeuvre being performed. The quick removal of a scarf draped over the dummy's shoulder signifies the initiation of the vehicle manoeuvres. Time "zero" in the data traces coincide with the removal of the scarf.

Results from the three different vehicle manoeuvres are discussed in the following sections.

An instrumented dummy was placed in three different mobility aids and tested in a rear-facing orientation located at the left side aft of a 45' (13.8m) intercity coach.

The g-tests were undertaken on the high speed test track of PMG Technologies in Blainville, Quebec. For each mobility aid, three (3) test scenarios were carried out;

- a full throttle acceleration from 0 - 100 km/h,
- a forceful evasive left and right turn at 100km/h, and
- severe braking from 100km/h to 0 km/h.

In each mobility aid the dummy was placed as close in contact as possible with the panel with the brakes on the mobility aid applied.

6.9 User Trials Methodology

Several trips in the intercity coach were carried out between Ottawa and Montreal on Highway 417 with a variety of passengers using mobility aids. The trip duration each way was approximately 1 hour and 45 minutes. 12 subjects were tested, 2 per trip leg. Due to an unexpected subject cancellation, one of the mobility aid passenger's companions volunteered to serve as a subject. She was not a mobility aid user, but sat in a mobility aid for the duration of the trip.

The test days were overcast and sunny, with temperatures from about -5^{o}C to about +5^{o}C. The road surface varied from dry to partial wet and light snow dusting. The road condition varied from stretches of recently paved parts to repetitive bumpy lengths. The 417 highway has a great number of left and right curves which vary from about 10^{o} to about 60^{o}. There are several moderate up-hill and down-hill inclinations.

The questionnaire contained the following components (see the entire questionnaire in Appendix C):

- Description of the protocol
- Informed consent form
- Demographic, ability, and general background information
- Stanford Sleepiness Scale (pre and post) (Thorne et al. 1985)
- Travel-specific wellness questions
- Mood scale (pre and post) (based on Viemero, 1991)
- Open-ended questions related to traveling comfort
- Components of the Pensacola Motion History Questionnaire (Reason and Brand, 1975)
- Components of the Motion History Questionnaire (Kennedy et al. 1990)
- Modified Eysenck Extraversion / Neurotocism Questionnaire (Eysenck, 1964)
- Bus experience questions

- Mobility aid securement experience questions
- Open and close-ended questions related to the bus trip
- Ratings of comfort, safety, calmness, wellness, and opinion of rear-facing travel (pre-during-post)

7. LITERATURE REVIEW

7.1 Safety

Despite the extensive search, very little information was found in the areas of rider comfort during rearward facing travel and mobility aid securement systems.

Some reseachers point to the importance, not only of securement system design, but also its proper use as a major safety concern for mobility aid passenger (Katherine et al., 1995). In fact, Tolliver (1994) reported that "improper use of mobility securement is the primary cause of injuries when transporting mobility aid users".

7.2 Motion Sickness

Motion sickness is a reality for many bus passengers. What makes the issue of motion sickness a greater concern in this case is the fact that mobility aid passengers would be riding backwards to the direction of travel. Although no research papers or even references within articles could be found relating to the issue of riding backwards, it seems to be common knowledge among researchers and medical professionals that this increases the chance of feeling motion sickness.

7.3 Signs, Symptoms & Etiology

Motion sickness can be defined as an adverse response to real or apparent motion to which a person has not adapted (Dobie & May, 1994). It has long been understood that motion sickness arises from a mismatch between the senses of sight, balance and proprioception, awareness of the position of the body in space (Johnson et al., 1950). Nuclear medicine has been used to study cerebral blood flow and power spectral electroencephalographic recordings during motion sickness have served to increase our understanding of this common problem. While activity in higher brain centres is decreased during motion sickness, blood flow increases to the central cerebellum, which is linked to the reticular system. The increased activity in the cerebellum triggers neural unit recruitment in the reticular system, thus induces vomitting (Wood et al., 1994).

Habituation to motion stimuli was shown to be slowed by the use of antinauseants (Wood et al., 1994). An alternative to medication is cognitive-behavioural counselling to control motion sickness symptoms. Dobie & May (1995) showed that such counselling can be very effective in improving tolerance to motion sickness stimuli, and reducing the severity of motion sickness symptoms.

Some researchers have divided motion sickness into two separate syndromes:

The symptoms may include the following (Wright et al., 1995):

Table 7-1: Motion Sickness Signs & Symptoms

Nausea Syndrome	Sopite Syndrome
• Nausea • Dizziness • Increased salivation • Vertigo • Pallor • Sweating	• Drowsiness • Fatigue • Reduced attention & concentration on performance task

To a lesser degree, symptoms such as apathy, general discomfort, headaches, stomach awareness, increased salivation and prostration may also be reported.

Though the exact mechanism for motion sickness has not yet been determined, it is believed to be a result of changing acceleration acting on the labyrinth of the inner ear (Dobie & May, 1994). This is indicated by a close relationship between the incidence of motion sickness and the degree of acceleration, as well as the fact that individuals without functioning labyrinths seem to be immune to motion sickness. Motion sickness is believed to occur when there is a mismatch between the sense of motion in the labyrinth, and the eyes, and the proprioceptors in the muscles which would indicate that the body is moving. When we walk or jump all of the signals to the brain indicate motion. However, if we are sitting still but our environment is moving, the discrepency in the signals can trigger physical response to adapt to the stimuli. This adaptation process can take a considerable amount of time.

7.4 Prevalence and Susceptibility to Motion Sickness

The incidence of motion sickness varies depending upon the environment and the population in question. Hill (1936) cited in Dobie & May (1994) indicated that over 90 percent of experienced ocean liner passengers experienced seasickness in very rough sea conditions, while only 25-30 percent felt seasick in moderate seas.

Lentz & Collins (1977) studied a large group (N = 3 618) of college students using the motion sickness questionnaire. They reported the susceptibility index of various vehicles and activities. All subjects averaged a score of 0.38, where 0 is never sick, 1 is rarely sick and 4 is always sick. By comparison, Large Ships scored 0.61, Automobiles scored 0.53, and Other Carnival Rides scored 0.98, the average highest index of all activities. Note that all of these averages are less than 1.0 which represents “rarely sick”. These results also indicated that of the individuals who reported being moderately or very susceptible to motion sickness, over 40 percent indicated that they thought the tendency for motion sickness decreased after age 12. While 68 percent of those considered unsusceptible reported no change and 19 percent of very susceptible subjects reported an increase in susceptibility. A greater proportion of women than men reported an increase in susceptibility to motion sickness with age.

7.5 Predicting Motion Sickness & Validating Research Tools

There have been several motion sickness history questionnaires developed by researches in a effort to predict the effects of a provocative environment, such as sailing or zero-gravity, on an individual (Kennedy et al., 1990). The two main types of questionnaires used by researchers have been the Pensacola Motion History Questionnaire (MHQ) (Kennedy et al., 1990), and the Motion Sickness Questionnaire (MSQ) (Reason & Brand, 1975). Kennedy et al. (1992) validated three versions of the Motion History Questionnaire, predicting simulator sickness in airforce and navy pilots. They found that a new seven-point scoring system was most accurate in predicting which individuals would actually become sick.

Questionnaires are the easiest way of testing for motion sickness susceptibility because they require no equipment and do not cause the subjects any discomfort, as the provocative tests would.

7.6 Individual Differences in Susceptibility

Many authors report that there is a gender difference in susceptibility to motion sickness. Lentz & Collins (1977) studied a large group (N = 3 618) of college students using the motion sickness questionnaire. They found that significantly greater portions of men reported low susceptibility to motion sickness, while significantly higher proportions of women reported high susceptibility to motion sickness. This study also showed a test-retest reliability of 0.84.

Age differences have also been well documented (Griffin, M.J., 1990; Kennedy et al., 1992, Lawther & Griffin, 1988). Typically, motion sickness is not present in infants up to age two. Then the incidence and severity increases with age up to approximately age 12. From age 12 and older, there is a decline, but even the elderly are not entirely immune to motion sickness.

Research has shown an association between the incidence of motion sickness and personality. Gordon et al., (1994) found a significant relationship between low susceptibility to seasickness, as measured by the Pensacola Motion Sickness Questionnaire, and psychotocism scores from the Eysenk Personality Questionnaire.

Lentz & Collins (1977) found that the proportion of individuals reporting fear of heights and fear of darkness was higher in subjects reported to be very susceptible to motion sickness compared to unsusceptible subjects.

7.7 Preventing/Managing Motion Sickness

The direction and amplitude of motion has a significant impact on the incidence of motion sickness. Wiker et al., (1979) found that subjects reported significantly more seasickness symptoms when the ship was steaming into port bow or starboard bow seas. Therefore, minimizing motion is one way of reducing the risk of motion sickness. On a bus, motion sickness can be reduced by sitting closer to the middle of the bus, where there is less motion. Many sources recommend not riding backwards as one way of reducing the likelihood of motion sickness (Casano, 1996); however, no research could be found to substantiate this notion. Other methods of reducing the risk or severity of motion sickness include lying supine (or at least reclining); focusing on a distant object whose position changes because of its relative position to the vehicle, not due to the translational motion of the vehicle; and minimizing head movements (Griffin, 1990). Reseachers have found success with cognitive-behavioural counselling as well (Eden & Zuk, 1995; Dobie & May 1994). By increasing feelings of self-efficacy and promoting relaxation, subjects reported less motion sickness symptoms.

Since motion sickness involves a mismatch or confusion between the vestibular, visual and proprioceptive systems, therapy is directed towards decreasing conflicting sensory input, controlling nausea, and speeding the process of adaptation (Noel & Norris, 1996).

8. RESULTS & FINDINGS

8.1 G-force Tests

8.1.1 Results of Rapid Vehicle Accelerations up to 110 km/h

The bus was not able to attain the desired velocity of 110 km/h, when accelerating from a stand-still, within the 30 seconds allotted for each manoeuvre. Needless to say, the effects of the vehicle acceleration on the occupant or the mobility aid were hardly perceptible either visually or electronically with the instrumentation. The peak resultant spinal accelerations measure on the dummy ranged from 0.14 g to 0.27 g.

During the rapid acceleration of the bus the mobility aid brakes provided sufficient resistance to prevent movement of the mobility aid.

8.1.2 Results of Lane Change Manoeuvres at 110 km/h

While travelling at a velocity of 110 km/h the bus performed an evasive lane change to the left followed, several seconds later, by a second evasive lane change to the right. Of the three manoeuvres being performed, the lane changes were the most severe, causing damage to the head and back support system and resulting in the withdrawal of one mobility aid from the test program.

The lateral restraining arm of the head and back support system fractured during the lane change manoeuvres with the manual mobility aid (Test no. 1A) causing the mobility aid to rotate towards the centre isle of the bus. The fractured restraining arm is shown in Figure 4-1 in Appendix A.

A replacement restraining arm was not available, therefore, for subsequent tests a strap was used to prevent lateral movement of the mobility aids during the evasive lane change manoeuvres.

Tests number's 3A, 3C and 3B with the 4-wheel scooter were cancelled following the 3-wheel scooter tests. The 3-wheel scooter and the scooter's seat post were unstable during the left and right lane changes, allowing the dummy to rock back and forth unnecessarily. The rocking in itself was not cause for concern, however, the possibility of the seat post failing as a result of the rocking was. Since the seat post on the 4-wheel scooter was of similar design to that of the 3-wheel scooter, it was decided to withdraw the 4-wheel scooter from the test program and avoid potentially damaging the mobility aid and the instrumentation.

During the lane change manoeuvre the dummy's right arm and shoulder came into contact with the wall of the bus resulting in spinal accelerations ranging from 0.91 g to 2.85 g.

8.1.3 Results of Hard Braking From 110 km/h to 0 km/h

In all the braking test the head and back support panel was effective in supporting the dummy and/or the mobility aid. Upon deceleration of the bus the dummy and/or mobility aid initially compressed the padding on support panel and subsequently followed the deceleration profile of the bus as it came to a complete stop. The spinal accelerations experienced by the dummy ranged from 0.66 g to 1.17 g.

8.1.4 Summary of Measured Accelerations

The bus acceleration traces and the spinal acceleration traces for all tests for each mobility aid type are presented in Appendices A, B and C of the Biokinetics report found in Appendix A of this report.

The peak resultant spinal accelerations and the peak resultant bus accelerations are summarized in Tables 8-1 and 8-2 respectively.

Table 8-1: Summary of Peak Resultant Spinal Accelerations

Mobility aid Type	Peak Resultant Spinal Accelerations (g)		
	Acceleration to 110 km/h	Evasive Lane at 110 km/h	Braking from 100 km/h
Manual	0.27	0.91	0.66
2000 FS 3 wheel scooter	0.25	2.85 contact with wall	1.17
760 FS power electric	0.14	1.29	0.66

Table 8-2: Summary of Peak Resultant Bus Accelerations

Mobility aid Type	Peak Resultant Bus Accelerations (g)		
	Acceleration to 110 km/h	Evasive Lane at 110 km/h	Braking from 100 km/h
Manual	1.08	1.21	0.95
2000 FS 3 wheel scooter	1.18	1.00	0.82
760 FS power electric	0.96	1.53	1.38

In should be noted that the relatively high peak resultant bus acceleration (Table 8-2) during the acceleration manoeuvre is the result of short duration peaks caused by vibration of the bus chassis. They are not indicative of the buses overall poor ability to accelerate quickly.

All other discrepancies between the bus and the spinal accelerations can be attributed to a combination of relative movement or contact between the dummy and the bus and vehicle vibrations.

8.1.5 Manual Wheelchair (about 50 pounds [22.75 kg.])

The results indicated that the manual wheelchair experienced no visible longitudinal movements or lifting of (front) wheels during acceleration and deceleration. During deceleration, the dummy's head would rest against the panel. During evasive manoeuvring the wheelchair swayed towards the bus wall with the dummy's upper body contacting the window, it then swayed into the aisle, breaking the aisle-facing support, but not tipping the mobility aid passenger. In fact, the dummy sat quite stable within the chair.

8.1.6 Three-Wheel Scooter (about 180 pounds [81.8 kg.])

The scooter did not show any moving, swaying or lifting during acceleration or deceleration, although the upper part of the dummy showed signs of swinging due to the facts that (I) the scooter's seat was mounted on a singular central tube, and (II) the vertical movements of the bus at the rear were quite significant. As a precaution, the scooter was secured with an aisle-side belt to prevent it from moving into the aisle, since the restraining arm was not operational.

8.1.7 Electric Power Chair (about 240 pounds [109.10 kg.])

The power chair did not show any signs of moving, swaying or lifting during acceleration and deceleration. The chair had a horizontal handle bar mounted to the back of the seat, thus preventing the back of the passenger coming close to the panel. Nevertheless, the back of the chair withstood the deceleration forces without damage.

During evasive manoeuvring the upper body of the dummy swayed towards the window and back into the aisle but without an indication of tipping. This chair was also secured on the aisle side to prevent moving into the aisle.

8.1.8 Four-Wheel Scooter

The four-wheel scooter was not tested due to its fragile seat mount of a single tube (1" [2.54cm] diameter). It was feared that the seat would break off during the evasive manoeuring and damage the chair and dummy.

8.2 User Trials Results

8.2.1 Changes in Variables over the Trip

The subjects were asked to choose the appropriate condition that applied to them at the time (see grades in Appendix C). For example, the subject was asked to choose <u>one</u> of the following: not at all, just a little, somewhat, definitely; or poor, fair, good, very good. Table 8-3 shows the means for the periodic ratings of the four variables. None of these periodic variables showed statistically significant changes over the course of the trip.

Table 8-3 : Changes in Comfort, Mood, Wellness and Opinion of Riding Backwards Over the Duration of the Bus Trip

Variable Rated	Pretest	During	Post-test
Comfortable (0 -3)	2.58	2.67	2.58
Safe & Secure (0-3)	2.58	2.67	2.67
Calm & Relaxed (0-3)	2.92	2.83	2.75
Well in general (0-3)	2.92	2.75	2.75
Opinion of riding backwards (0-4)	2.88	3.13	3.08

8.2.1.1 Comfort

There were no significant differences in the mean comfort ratings reported over the course of the bus trips. Within the group of pre-post wellness questions, the mean rating of localized pain and discomfort increased from the start to the end of the trip, though not significantly.

8.2.1.2 Mood

Mood scale questions asked at the beginning and end of the trip were analyzed for differences using a t-test. Pretest and post-test means are presented in figure 8-1. The results indicate a possible trend for increased feelings of safety, tiredness and happiness; while comfort and calmness decrease. However, none of these differences proved to be statistically significant.

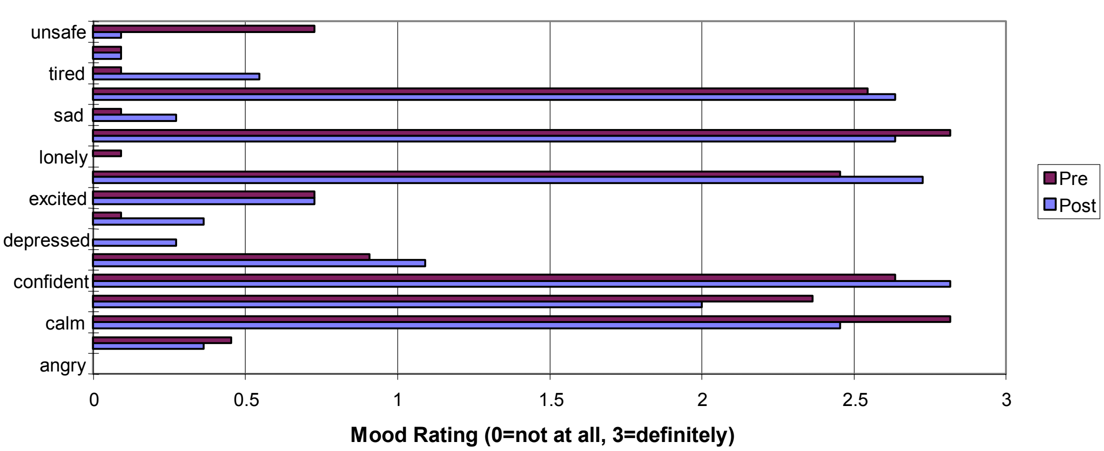


Figure 8-1: Pretest/Post-test Mood Ratings

8.2.1.3 Wellness

Symptoms of motion sickness, such as nausea and fatigue, as well as complaints of localized pain were studied at the beginning and end of the trip. Relatively few symptoms were reported by the subjects. Six of the twelve subjects reported no physical complaints at any time. The most common complaint was localized pain and discomfort, experienced both at the beginning and end of the trip, three and five times, respectively. Only two subjects reported symptoms which would suggest motion sickness. Since the number of any one type of complaint was insignificant, a symptom index was developed by adding the ratings (0 -3 : not at all through very noticeable) for the following symptoms:

- nausea
- dizziness
- headache
- vertigo
- fatigue
- localized pain or discomfort
- other symptoms

Though the index mean did increase from 0.67 to 2.08 (out of a possible 21), this increase was not statistically significant.

8.2.1.4 Sleepiness

Fatigue has been shown to be a major motion sickness symptom. The Stanford Sleepiness Scale (Thorne et al., 1995) mean changed 1.42 to 1.50 from the beginning to end of the trip. Since one (1) this seven-point scale indicates the subject is wide awake, the results indicate that the trip had no significant fatigue-inducing effect.

8.2.1.5 Opinion of Riding Backwards

The mean ratings (1=poor, 4=very good) of the subject's opinions of riding backwards at the beginning, middle and end of the trip increased from 2.88, to 3.13, and to 3.08, respectively. These changes were not statistically significant. However they do suggest that once passengers have had a chance to experience riding backwards, their opinion of this way of traveling tends to improve, or at the very least, remains "good".

8.2.2 Comparitive Analysis

8.2.2.1 Motion Sickness History

The subjects' motion sicknesss history effectively predicted passenger comfort and well-being. Dizziness, headaches and vertigo at the end of the trip correlated perfectly with the frequency of motion sickness experienced in the past in cars, transit buses and coaches, and trains (r = 1.00). However, it is important to note that only two of the passengers reported the motion sickness symptoms listed above during the trip. It would take a much larger subject pool and a control group to determine whether the incidence and degree of motion sickness in forward and rearward facing travel is the comparable.

8.2.2.2 Age

There are age-related differences in response to the rear-facing experience. However, it is important to stress that the following relationships are correlational, not causitive. One significant intervening variable may be gender. Unfortunately, the female passengers volunteering in this study were disproportionately older when compared to the male passengers. Of the five female passengers, the mean age was 72 (range = 50 to 85). The mean male passenger age was 46 (range = 29 to 78).

A correlation coefficient of 0.708 is considered significant at $p = 0.01$ level, and represents 46.8 percent shared variance between the variables. Age had a significant negative correlation of -0.71 with feeling unsafe when asked initially; that is, younger passengers tended to feel less safe than the older passengers. Older passengers also tended to feel more comfortable and secure when asked at the beginning of the trip, as shown by correlations of 0.73 and 0.71, respectively.

The age-comfort relationship persisted through to the end of the trip, indicated by a correlation of 0.75. There were no significant age-safety or age-security relationships at the end of the trip. This may be due to the fact that the mean for feeling unsafe decreased following the experience to almost 0.

While there were no significant age and sleepiness relationships at the start of the trip, results indicated that younger passengers had a greater tendency to feel more sleepy (age-sleepiness scale = -0.75, age-tired = -0.78) when asked at the end of the trip. Younger passengers also reported being less comfortable and relaxed at the end of the trip (age-comfort = 0.75, age-relaxed correlation = 0.70). These results may be affected by the fact that the two subjects reporting motion sickness symptoms were under 39 and 29 years of age, 29 being the youngest age within this sample. These results are consistent with the literature.

There was a positive relationship between age and overall opinion of the bus trip as well ($r = 0.71$).

Results also indicated a direct relationship between age and a favourable rating of the backwards-riding experience ($r = 0.78$ before, and $r = 0.76$ after).

Older subjects (over 50 years of age) had virtually no complaints and consistently indicated positive responses with ratings at the extreme end of the scale. Figure 8-2 shows how younger passengers' responses often changed over the course of the trip, while the older group remained almost constant.

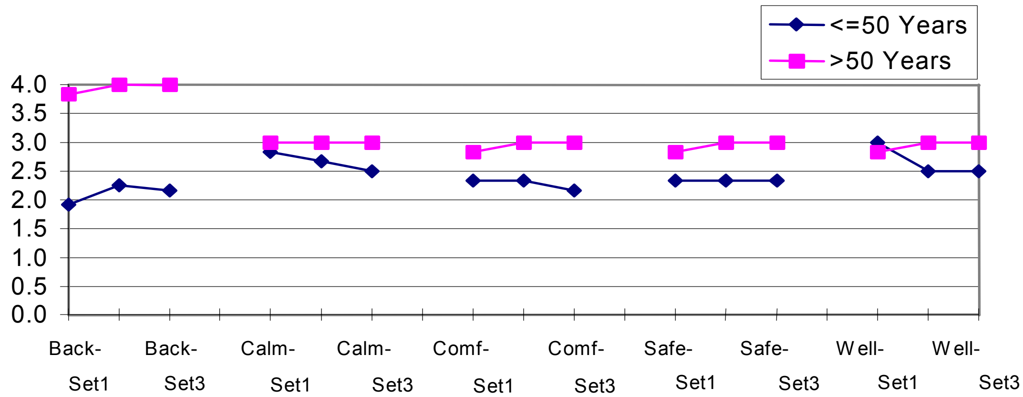


Figure 8-2: Age Differences in Opinion of Backwards Travel, Mood and Well-being

8.2.2.3 Gender

As mentioned above, the five female subjects were an average of 26 years older than the male subjects, so it is difficult to report results based purely on gender.

8.2.2.4 Personality and Psychological State

Contrary to literature findings, the Eysenck Neurotocism and Extraversion indicators did not correlate significantly with motion sickness symptoms at the end of the trip.

The passengers' self rating of feelings of anxiety correlated strongly with several motion sickness indicators. In fact, the correlation between "anxious" feelings and "how susceptible to motion sickness are you" was 1.00. As might be expected, feeling "anxious" also showed a strong relationship with feeling "insecure" and "uncertain" ($r = 0.90$) at the beginning and end of the trip. Feeling "anxious" at the beginning of the trip showed a strong relationship with initial feelings of "nausea" "headache", "vertigo", and "fatigue". Feeling "anxious" at the beginning of the trip also showed a direct relationship with feelings of "dizziness", "headaches", "vertigo" and "unsafe" at the end of the trip ($r = 0.90$, $p = 0.01$). Feelings of fatigue, and hunger (intended as a catch question) also showed a small but significant relationship with anxiety ($r = 0.56$ and $r = 0.58$, respectively, $p = 0.05$). Feeling anxious also had a negative relationship with the overall experience and wellness ratings at the end of the trip.

8.2.2.5 Disability Type

Data analysis showed that there was a significant relationship between the level of functional independence and the perception of tipping ($r = -0.63$, $p = 0.05$). Generally speaking, individuals with limited upper body strength were rated with less functional independence. A lack of abdominal strength resulted in a greater degree of head and torso sway, leading to the greater perception of tipping. Subjects with a higher independence rating tended to report being more calm and relaxed ($r = 0.64$, $p = 0.05$) during the initial mood question set and the second periodic question set. However, feeling "anxious" did not correlate with functional independence ($r = 0.03$).

8.2.2.6 Seat

The data shows that the seat (left or right) had no effect on most variables, as might be expected with random assignment. However, the mean ratings for mood, wellness and opinion of riding backwards at the very end of the trip were consistently higher for the subjects in seat #2, the right side of the bus (lift side). Subjects seated on the left side (seat number 1) also consistently reported more movement sensations (vibration, tipping, lateral and backward/forward motion) compared to the other passengers. This is contrary to expectations, since it was believed that the rattling mobility aid lift may cause those closest to it to feel least comfortable and least secure, however the data trends suggest the opposite.

One possible explanation for these observed differences might be the level of disability of the subjects randomly seated in either of the two seats. Only one subject of the 12 classified himself as a quadraplegic (C5/6 fracture) and he was seated in seat 1. However, there were three other subjects who, when questioned, revealed that they had limited upper body strength due to spine injury above T7. A subject reporting serious rheumatoid arthritis with C3 slipping, and a paraplegic subject with a fracture at T6 also sat in seat 1. Whereas, seat 2 was occupied by only one subject with spine injury at the T4/T5 level. These assignments may have skewed the data .

Another possible explanation may be the fact that the passengers in the right hand seat had a better view of the stationary outside world, and thus perceived more motion.

8.3 Subject Comments and General Observations

8.3.1 Securement System Comments

For most subjects, this was the first time they had ridden on a mobility aid-accessible bus. Several passengers, particularly the elderly subjects, had little or no experience with securement systems of any kind.

Of those who had experiences with various securement systems, opinions were mixed about these systems. One subject had been on a Vancouver bus where a bracket through the wheels secures the chair, but it was said to be not as stable as a Q-straint device. Another subject commented that bus drivers often do too much in handling and securing the mobility aid, preferring to get on the bus and secure himself. And in his experience, the driver has also improperly secured the mobility aid. Yet two other subjects commented that they never had a negative experience with the strap securement system.

8.3.2 Passenger Stability

Two factors contributed to increasing the degree of motion of the passengers on this bus. First, because the mobility aid positions are at the back and close to the sides of the bus, there is a greater amplitude of motion, compared to an aisle seat at the centre of the bus (bus dimensions = 45’ X 8’4”). Furthermore, this was a very tall bus, with the floor being approximately 2.5 m (100 inches) above the ground. This is higher than most urban transit buses, and therefore increases the amount of passenger motion, increasing the risk of motion discomfort.

It was pointed out that most mobility aids position the body in a more upright position compared to the bus seats, reducing body stability when the bus was in motion. Individuals with limited abdominal and torso strength suggested that they would feel more stable and secure with a lap and/or shoulder belt. One subject experienced considerable discomfort due to the uncontrollable sway of the upper body. A shoulder belt was then improvised to provide additional support.

Others suggested that there should be an arm rest or grab bar that one could grasp for additional stability and a greater sense of security (see Figures 8 and 9 in Appendix B).

Most subjects could not make effective use of the backrest as it was obstructed by the back of the chair. One subject recommended that it be adjustable. This would be beneficial as the bus motion demands considerable upper body and neck muscle effort to maintain an upright and steady posture over a long trip. Adjustable headrests or upper back support that can be moved toward the back of the head and shoulder area might be investigated as feasible designs.

8.3.3 Safety Issues

Two subjects reported that having the lift next to the seated position was a little intimidating, and would have preferred to see it moved or better secured. The rattling of the mobility aid lift was a great annoyance to all passengers. It is recommended that it be covered with a noise dampening cover and the rattling components secured or redesigned. One of the companions who served as a subject noted that there was more noise on the trip to Montreal than to Ottawa.

Because of the experiences during the G-force testing, subjects' mobility aid were tied down for their additional safety. This made it impossible to comment on the degree of movement in all of the chairs, relative to the bus floor. One subject with a customized sports wheelchair volunteered to have his tie-downs removed half-way through the trip. The floor and wheel were marked with tape to help identify any movement of the chair. Throughout the bumpy ride, and even during relatively sharp turns on the off ramp and city streets, the chair showed no signs of movement. It would appear that during normal driving conditions, the wheelchair breaks and backrest are sufficient in securing the mobility aid.

There is a seat belt available to secure the passenger while on the lift. However, the driver seemed to forget to use it the first time. The passenger suggested a system which would be inoperable unless all of the safety devices have been applied (e.g., lift doesn't operate unless the belt clicks).

8.3.4 Independence

One subject commented that the strapless system is good, but one still has to have the lift operated by the driver, so there is still not complete independence. Furthermore, mobility aid passengers should have the option of transferring to a regular seat where they may feel more comfortable and secure than in their mobility aid.

8.3.5 Normal Passenger Activities

One subject suggested that providing an extended view of the bus should be considered. Design options such as a back window or a closed circuit camera showing the forward view outside the bus would be beneficial, reducing boredom and increasing the field of view.

The tests showed that a two-hour trip consists of a variety of activities the passenger wants to carry out, including:

- reading or writing (very difficult at the rear of the bus on a road with bumps and potholes)
- observing landscape (limited time only, due to straining neck muscles)
- day dreaming (limited time only)
- resting/sleeping (head support required)
- eating (snack, drink - cup holder might help)
- conversing with companion/other passenger
- moving around in seat to avoid sore spots
- resting arm/hand along window

8.3.6 Preferences for Forward or Backward Seating

Several subjects, particularly the elderly subjects, indicated that they found almost no difference between travelling facing forward compared to rearward. A few commented that when riding backwards, one could not see upcoming road signs and therefore missed knowing where they were during the trip. Others simply stated that riding backwards feels different. Some of these passengers spoke of problems experienced with non-accessible buses, such as "being carried up like a sack of potatoes". If given a choice between the seat direction and greater independence, most prefered the greater independence over forward seating.

8.3.7 Passenger Comfort

Several subjects with arthritic conditions indicated that having sufficient knee space, as there was on this bus, made a trip more comfortable.

There did seem to be an age effect. Older subjects were very happy initially and had next to no complaints throughout the trip.

One subject did report increased discomfort in the neck from having to keep the head turned to look out the window in seat #2 (right, lift side of the bus).

Other factors influencing comfort include:

- temperature
- noise

- ambient and task lighting
- own chair suspension and shock absorbing seat cushion

8.3.8 Face--face Seating

The subjects recognized that face--face seating would be one way to increase their enjoyment on the trip. Having someone directly across from them to talk with would make the trip more enjoyable, particularly if that person was a companion.

8.3.9 Intervening Variables

One subject indicated that if not for the experimenter's questions, he probably would have fallen asleep. This indicates that the presence of the experimenter did bias the results to some degree. Still, most individuals indicated that talking to other people on the bus was an activity they enjoyed, suggesting the experimenter involvement may have contributed to the realism of the experience.

9. CONCLUSIONS

9.1 Design Consequences

The purpose of the head and back panel rear-facing design was to answer the following questions:

Part 1: Which forces will be applied to an instrumented dummy in different mobility aids in extreme situations in a large intercity bus at speeds of up to 100 km/h, during severe acceleration, deceleration and evasive manoeuvres, and which technical specifications would result for the design of such a system?

Part 2: How would passengers in mobility aids react and feel in a rear-facing position in a large bus during a trip of approximately two hours on a highway at a travelling speed of about 100 km/h not being secured by belts and hooks?

Part 1

The consequences for the design resulting from these tests indicate that from a technical point of view the passenger in a mobility aid in a rear-facing position is well protected even against severe acceleration and deceleration forces. The steel frame with its four mounting points as well as the panel showed no signs of weakness and withstood all loading tests without damage, except for the aisle support. It is clear that these are extreme forces which would not be experienced during regular driving conditions. G tests also indicated that the lateral forces experienced were much higher than anticipated and that there is a definite need to provide a strong, aisle-facing support which prevents the mobility aid from moving into the aisle. The lateral movement of the dummy also indicated that the gap between the mobility aid and the bus wall is too large and may add to the tipping of the mobility aid to this side. This gap of about 127 mm - 203 mm (5-8"), was due to the protrusion of the heating duct at floor level, preventing the mobility aid to be positioned next to the bus wall. The present aisle arm design was not strong enough. Since the arm broke at a welding point, it is possible that the welding was defective. Test data will determine against which lateral forces the aisle arm must be designed. The aisle support might be better as a robust panel which will provide greater support in the event of lateral forces to the chair and occupant.

Part 2

Accommodation of mobility aid types in the rear-facing system indicated that all test subjects with their varying types of mobility aids had no difficulties being accommodated in both positions. The length of the position for both locations is approximately 1 447 mm (57"). In the right hand position, the last seat must be folded up in order to make room for the mobility aid. For boarding some passengers preferred to be positioned on the lift platform facing away from the bus and thus moved into the position in the bus, facing backwards. This manoeuvre requires less space. The driver, who operated the lift also preferred this manoeuvre because it is the most direct movement into the mobility aid location. To move the mobility aid passenger into position, the aisle arm was moved into the vertical position in order to make room for manoeuvring.

The mobility aid passenger was placed with his/her back close to the back/head panel. In two cases this could not be accomplished, in one instance a passenger did not like to have direct contact with the panel because her back was very sensitive to pressure, and in the other the mobility aid (electric power chair) had a horizontal handle bar across the back which prevented the seat back coming close to the panel.

The driver applied the brakes on each mobility aid, except for two passengers who used sport chairs which did not have brakes. During the test trip each mobility aid was tied down by tension belts (as a precaution) with a slight slack of 25 mm (1") to observe possible movements of the chairs. In one case, a passenger volunteered to carry out a *regular* acceleration, deceleration and evasive manoeuvring test without using the tie-down on the highway at 100 km/h. As a precaution, a tie-down was nevertheless attached with a slack of 75 mm (3").The passenger felt safe and noticed only the lateral forces on his upper body, which were insignificant. But this passenger had good upper body strength. The same may not apply to passengers with lesser upper body strength.

Through direct observations and informal questions of the volunteers, valuable information was recorded on the effectiveness and shortcomings of the PPSS. Though some comments were made by only one subject, the insight was often applicable to a wide range of passengers with special needs. The following are observations that were made during the testing of the passenger:

- lack of arm/hand rest or rail on bus wall
- lack of shaped headrest to allow for resting/sleeping
- lack of shoulder belt for support of upper body, e.g. for quadriplegic passengers
- annoying noise from rattling of the stored lift
- lack of face- -face seating on right side, feeling of isolation and boredom
- lack of access to washroom caused by a door that is too narrow and an interior space which is too small for manoeuvring a mobility aid
- lack of unobstructed view on right side
- two subjects stated that they would still prefer to transfer to a regular seat instead of riding in their mobility aid
- one passenger felt her back was too close to panel and created pressure

The pros and cons of the rear-facing position are summarized in the following paragraph.

<u>Pros</u>

The test indicated that the position is technically feasible; the position is safe for the passenger and there seems to be no problems for the passenger facing to the rear. Such a design would make it unnecessary for the driver to kneel on the floor, find the right belts and receptacles and work from an awkward position on his/her knees. The advantage for the operator would be not to have to carry, maintain and service belt components. For the passenger in a mobility aid, especially the one who travels with a companion, the face—face seating provides a pleasant arrangement to communicate and socialize. Of great importance is the ability of the passenger to be independent.

Mobility aid passengers with limited abdominal and torso strength are often unable to right themselves if they fall forward. With the conventional forward-facing seats, passengers are potentially exposed to greater G forces due to deceleration than acceleration. Sudden braking may cause a passenger to fall forward. Therefore the rear-facing PPSS may be safer and more comfortable for mobility aid users with spine damage above T7.

Cons

From an operators point of view this solution would require the removal of two seat benches (one for each position) from the bus and the installation of two back/head panel structures. On the right side, the stored lift would have to be turned away from the window towards the washroom wall to clear the view to the outside. Ideally, at least one face--face seat should be installed to face the mobility aid passenger. With the present layout such a seat does not seem to be feasible. Removed seats benches and back/head structures could be stored on-board in the cargo hold area or in the garage, and the lift be used to transport them to and from storage. This task may require a second person to assist.

10. RECOMMENDATIONS

10.1 Securement System Design & Bus Layout

In order to improve the present design, to improve its comfort and convenience for the passenger, and to alleviate operational and layout deficiencies, the following improvements are proposed:

- for the fast removal of the back/head panel structure fasteners which connect the steel frame to the floor tracks must be of quick deployment/release type without the need to use tools
- aisle arm must be stronger
- padded area on bus wall side is required to provide soft contact and prevent tipping of the mobility aid
- a horizontal armrest on the bus wall side must be provided
- more foot clearance is required for face--face seated passenger(s) facing mobility aid on left side
- a passenger optional restraint system must be an integral part of the back/head panel structure
- a shaped head rest with side supports is required to allow the passenger to rest his/her head
- noise from the stored lift must be eliminated
- stored lift must be moved to clear view to the outside
- access to washroom must be provided

10.2 Further Study

The new Protected Position Securement System (PPSS) has proven to be quite promising in terms of providing an easy to use, safe securement system. Once an improved prototype has been developed, it is recommended that user trials be repeated with a larger sample, comparing the unsecured PPSS to a control group using the forward facing Q-straint system.

Very little data exist on the prevalence of motion sickness on buses and, particularly for backward facing travel. A survey of the general population, such as train or bus commuters for example, would be very helpful in determining whether the PPSS evokes significantly more motion sickness incidents.

Furthermore, human factors engineering criteria and methods should be applied to the design of an adjustable headrest or armrest/lateral restraint. In order for a safety feature to be effective, it must be easy to use properly, otherwise it may in fact, create a greater hazard. Usability testing of all PPSS components is strongly recommended.

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APPENDIX A: Biokinetics Report

(Not available in electronic format
Non disponible en format électronique)

APPENDIX B: Photographic Test Recordings

(Not available in electronic format
Non disponible en format électronique)

APPENDIX C: Human Factors Questionnaire

CERTIFICATE OF INFORMED CONSENT

Wheelchair Securement System Evaluation

I, the undersigned, do hereby acknowledge:

that I have read the attached written description of the protocol that will be used for the evaluation of a prototype wheelchair securement system; that I have been informed of the possible anticipated risks, and that I understand and accept them.

my understanding that I may ask any questions or request further explanation or information about the procedures at any time before, during, and after the evaluation.

that in the event of any circumstance requiring medical attention, I will rely on the trials analyst directing the evaluation to arrange for medical attention and to institute whatever measures are considered necessary for my safety and well being.

that I have freely consented to participate in this evaluation, without any compulsion or coercion of any kind, and that I understand that I may withdraw from the evaluation at any time.

that I hereby release Rhodes & Associates Inc., its agents, associates, officers, and employees from any liability with respect to any damage or injury that I may suffer during the administration of the evaluation, except where the damage or injury is caused by the negligence of Rhodes & Associates Inc., its agents, associates, officers, or employees acting within the scope of their duties.

__________________________ ____________________

Signature of Volunteer Date

__________________________ ____________________

Signature of Witness Date
(other than the trials analyst)

Wheelchair Securement System Evaluation

Description of the Protocol

The Setup
You have volunteered to participate in a study of the effectiveness of a rear-ward facing "confined-space" wheelchair securement system. This system allows the passenger to wheel the chair into a protected space surrounded on three sides by panels. The passenger then applies the brakes on the wheelchair. The system requires no straps or belts.

Your Participation
You are to be a passenger on an intercity bus, and are expected to use the prototype "confined space" securement system. You will be traveling one way either to Montreal or to Ottawa. Once the destination has been reached and a series of questions have been answered, the trial will be completed. The trials analyst will administer a questionnaire at the beginning of your trip, that will ask about basic personal data, and will inquire about various aspects about your physical and mental state. This information will be very useful to help us understand how this new way of traveling will affect you. Also, the analyst will ask you at certain times during the trip about your comfort, physical and mental well-being and the physical effects of the bus ride.

Potential Risks
The bus trip you will be taking will be no more eventful or different in most respects than any other intercity bus ride. The main differences are that you will be one of three passengers (including another volunteer and the trials analyst), and the securement system you will be using does not have straps or belts. Although many people find bus travel to be comfortable and enjoyable, some people may experience motion sickness or discomfort due to the bus motion. The risks you will face will be the same as those faced by any other bus or train passenger who is not secured by belts or straps. Only your own physical state and abilities will vary from other passengers as is the case for all passengers.

If you have any special health considerations pertaining to bus travel, you are obliged to inform the trials analyst. Efforts will be made to ensure your safety and reasonable comfort.

WHEELCHAIR SECUREMENT USER TESTING
BACKGROUND INFORMATION

Please answer the following questions as accurately as possible by checking the appropriate circle(s). Feel free to write any comments beside your responses if you think it is necessary. All information you provide will be kept strictly confidential.

Name :			**Subject #**
Date:	**Time:**	**Trip:**	**Seat:**
Gender : ○ Male ○ Female		**Age :**	

Type of mobility aid used:

Type of Disability:

○ Paraplegic ○ Quadraplegic ○ Hemiplegic

○ Spinabifida ○ Multiple Sclerosis ○ Orthopedic Disorder

○ Cerebral Palsy ○ Arthritis ○ ALS

○ Amputee ○ Other (specify):

Other Physical Limitations? Comments

○ Limited torso strength?

○ Limited arm strength?

○ Inner Ear disorders?

○ Balance and stability difficulties?

○ Coordination difficulties?

○ Sight limitations?

○ Other conditions affecting mobility?

Do you have any other physical or mental conditions which MAY affect your comfort or safety on this bus trip?
(eg. Cold or Flu, Epilepsy or seizures , swallowing difficulties, breathing difficulties, abdominal upset or pain)

Which of the following medications and/or substances have you used in the past 24 hours?

○ Sedatives or tranquillizers ○ Decongestants ○ Anti-histamines
○ Other (specify):

In case of an emergency who should we contact on your behalf?

Name : Telephone Number:

Functional Independence Rating

	Amount of Assistance Required	**Amount of individual participation in Activity**
7	complete independence (no helper)	all tasks performed safely, without aids, within reasonable time
6	modified independence (no helper)	activity requires assistive device, more than reasonable time, safety consid.
5	supervisor or set up required	helper sets up needed items, or provides standby assistance
4	minimal contact assistance (requires helper)	subject expends at least 75% effort but requires touching assist
3	moderate contact assistance (req. helper)	subject expends 50 - 75% effort or requires more help than touching
2	maximum contact assistance (req. helper)	subject expends 25-49% effort and requires physical contact assist
1	total assistance (requires helper)	subject expends less than 25% effort and requires physical contact assist

Subject :

PSYCHOPHYSICAL FACTORS
Pre-test

Stanford Sleepiness Scale	
1	Feel active and vital; alert; wide awake
2	Functioning at a high level, but not at peak; able to concentrate
3	Relaxed; awake; not at full alertness; responsive
4	A little foggy; not at peak; let down
5	Fogginess; beginning to lose interest in staying awake; slowed down
6	Sleepiness; prefer to be lying down; fighting sleep; woozy
7	Almost reverie; sleep onset soon; lost struggle to remain awake

Please rate how you are feeling today.	not at all	just noticeable	noticeable	very noticeable
Nausea	O	O	O	O
Dizziness	O	O	O	O
Headache	O	O	O	O
Hunger	O	O	O	O
Vertigo (head spinning)	O	O	O	O
Fatigue	O	O	O	O
Localized pain or discomfort (specify)	O	O	O	O
Other symptoms?	O	O	O	O

Please rate your mood	Not at all	just a little	somewhat	definitely
tired	O	O	O	O
excited	O	O	O	O
depressed	O	O	O	O
relaxed	O	O	O	O
angry	O	O	O	O
unsafe	O	O	O	O
happy	O	O	O	O
uncertain	O	O	O	O
lonely	O	O	O	O
calm	O	O	O	O
confident	O	O	O	O
different from others	O	O	O	O
anxious	O	O	O	O
sad	O	O	O	O
confined	O	O	O	O
comfortable	O	O	O	O
secure	O	O	O	O

What makes your trip less comfortable?____

What do you do to enhance your comfort while traveling by bus?

____

PENSACOLA MOTION HISTORY QUESTIONNAIRE

Motion Sickness Questionnaire **

1) Indicate approximately how often you travelled on each type of vehicle by using one of the following numbers:

	cars	w/c acc. taxis	transit buses	"wheeltrans"	intercity coach	trains	airplanes	small boats	ships	swings, rides, etc.	other
0 = no experience											
1 = less than 5 trips											
2 = between 5 to 10 trips											
3 = more than 10 trips											

Considering only those types of transport that you have marked 1,2 or 3 (ie. those you have travelled on), go on to answer the two questions below. (Use the following letters to indicate the appropriate category of response):

	Never	Rarely	Sometime	Frequently	Always
2) How Often did you *feel* sick whilst travelling, (ie. queasy or nauseated)?					
3) How often were you *actually* sick whilst travelling (ie. vomiting)?					

** Based on the Motion Sickness Questionnaire (MSQ) (Reason, 1968)

1. Have you ever been motion sick under conditions other than the ones listed so far?
   No _____ Yes _____ If so, under what conditions?
   ____

2. In general, how susceptible to motion sickness are you?
   Extremely _____ Very _____ Moderately _____ Minimally _____ Not at all _____

3. Have you been nauseated FOR ANY REASON during the past eight weeks?
   No _____ Yes _____ If yes, explain.
   ____
   ____

4. When you were nauseated for any reason (including flu, alcohol, etc.) did you vomit?
   Easily _____ Only with difficulty _____ Retch and finally vomited with great difficulty _____

5. If you vomited while experiencing motion sickness, did you:

a. Feel better and remain so? _____
b. Feel better temporarily, then vomit again? _____
c. Feel no better, but not vomit again? _____
d. Other, specify. _____

6. Listed below are a number of situations in which people have reported motion sickness symptoms. In the space provided, check (a) your PREFERENCE for each activity (that is, how much you like to engage in that activity) and (b) any symptom(s) you may have experienced at any time, past or present.

MOTION HISTORY QUESTIONNAIRE *

SITUATIONS	PREFERENCE			SYMPTOMS																
	like	neutral	dislike	vomited	nausea	stomach awareness	increased salivation	dizziness	tingling sensation	dry mouth	drowsiness	sweating	hunger	diarrhea	pallor	vertigo (head spinning	awareness of breathin	headache	other symptoms	none
Airplanes																				
Virtual Reality Environment																				
Roller Coasters, etc.																				
Automobiles																				
Long Train Rides																				
"Wheeltrans" buses																				
Other City Transit Buses																				
Inter-city Buses (Coach)																				
Taxi																				
Boat or Ship																				
Elevators																				
Wheelchair or Scooter																				

* Based on the Pensacola Motion History Questionnaire (George, 1990)

Here are some questions regarding the way you behave, feel and act. Try to decide which response option represents your usual way of acting or feeling. There are no right or wrong answers to any of the questions: your immediate reaction is what we want. Please check that you have answered all the questions. (Circle one number for each).

	Not at all	Quite seldom	Quite often	Almost always
Do you like plenty of excitement and bustle around you?	○	○	○	○
Does your mood go up and down?	○	○	○	○
Are you rather lively?	○	○	○	○
Do you feel “just miserable” for no good reason?	○	○	○	○
Do you like mixing with people?	○	○	○	○
When you get annoyed do you need some one friendly to talk to?	○	○	○	○
Would you call yourself happy-go-lucky?	○	○	○	○
Are you troubled about feelings of guilt?	○	○	○	○
Can you let yourself go and enjoy a lot at a party?	○	○	○	○
Would you call yourself tense or “high strung”?	○	○	○	○
Do you like practical jokes?	○	○	○	○
Do you suffer from sleeplessness?	○	○	○	○

What type of buses did you ride?	Please rate your overall experience			
	Poor	Fair	Good	Very Good
O specialized wheelchair transportation buses	O	O	O	O
O city transit buses with wheelchair sections	O	O	O	O
O inter-city passenger buses with wheelchair sections	O	O	O	O
O standard bus without wheelchair location	O	O	O	O
O other	O	O	O	O
Please rate your previous experiences on the bus(es) above.	Poor	Fair	Good	Very Good
Ease of getting in and out of position (ingress/egress)?	O	O	O	O
Comfort?	O	O	O	O
Stability	O	O	O	O
Security?	O	O	O	O
Independence?	O	O	O	O

Please describe your experience(s) with other Wheelchair securement systems.

On the bus trips described above, was the bus driver sufficiently helpful? Explain

O did too much
O just right
O did not help enough (explain further)

What types of activities do you enjoy doing when riding a bus or a train?
(eg. Talk to passengers, talk to driver, look at scenery, read, listen to music, work activities, sleep, play a game, think, nothing)

Do you have a preference for the location of your seat on a bus?

O near the front
O near the middle
O at the very back
O near the driver
O near the back
O anywhere is fine

FOLLOW-UP QUESTIONS

Stanford Sleepiness Scale	
1	Feel active and vital; alert; wide awake
2	Functioning at a high level, but not at peak; able to concentrate
3	Relaxed; awake; not at full alertness; responsive
4	A little foggy; not at peak; let down
5	Fogginess; beginning to lose interest in staying awake; slowed down
6	Sleepiness; prefer to be lying down; fighting sleep; woozy
7	Almost reverie; sleep onset soon; lost struggle to remain awake

	Please rate your mood			
	Not at all	just a little	somewhat	definitely
confident	○	○	○	○
anxious	○	○	○	○
secure	○	○	○	○
calm	○	○	○	○
depressed	○	○	○	○
tired	○	○	○	○
angry	○	○	○	○
comfortable	○	○	○	○
lonely	○	○	○	○
unsafe	○	○	○	○
happy	○	○	○	○
confined	○	○	○	○
sad	○	○	○	○
different from others	○	○	○	○
excited	○	○	○	○
relaxed	○	○	○	○
happy	○	○	○	○
uncertain	○	○	○	○

Please rate your experiences during this bus trip.

	not at all	just noticeable	noticeable	very noticeable
Nausea	O	O	O	O
Dizziness	O	O	O	O
Headache	O	O	O	O
Fatigue	O	O	O	O
Hunger	O	O	O	O
Vertigo (head spinning)	O	O	O	O
Localized pain or discomfort (specify)	O	O	O	O
Other symptoms?	O	O	O	O
was there excessive side to side (lateral) motion?	O	O	O	O
was there excessive forward/backward motion?	O	O	O	O
was there excessive vibration?	O	O	O	O
was there excessive twisting?	O	O	O	O
was there excessive tipping?	O	O	O	O
was there excessive sliding?	O	O	O	O
was there excessive rattling?	O	O	O	O

Was the bus driver sufficiently helpful?

- O did too much
- O just right
- O did not help enough (explain further)

Was the head rest adjusted properly for your comfort? O Yes O No

Was the side panel adjusted properly for your comfort? O Yes O No

How would you rate your overall experience on this trip?

- O very enjoyable
- O enjoyable
- O fair
- O poor

Were you able to do the things you normally enjoy doing during a trip of this length? O Yes O No

Do you have any additional comments?

Do you have any suggestions for improving this wheelchair securement system?

Do you feel comfortable?

not at all	just a little	somewhat	definitely
☹	🙁	😐	☺

Do you feel safe and secure?

not at all	just a little	somewhat	definitely
☹	🙁	😐	☺

Do you feel calm and relaxed?

not at all	just a little	somewhat	definitely
☹	🙁	😐	☺

Do you feel well in general?

not at all	just a little	somewhat	definitely
☹	🙁	😐	☺

What is your opinion of riding backwards?

poor	fair	good	very good
☹	🙁	😐	☺