ANALYSIS AND PREVENTION OF CHILD EJECTIONS FROM GOLF CARS AND PERSONAL TRANSPORT VEHICLES

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ANALYSIS AND PREVENTION OF CHILD EJECTIONS FROM GOLF CARS AND PERSONAL TRANSPORT VEHICLES

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Paper Number 09-0186

ABSTRACT

United States Consumer Products Safety Commission statistics indicate there are approximately 13,000 golf car related emergency room visits in the United States annually. Of these, approximately 40% involve children (i.e. age < 16) and 50% of these involve a fall from a moving car. Evidence also indicates that many passenger ejections occur during left turns. Children are especially susceptible to ejection because of their small size and reliance upon the hip restraint for stability. While adult ejections have been studied, the present study analyzes mechanisms of child ejection during left turns. Dynamic tests are presented wherein an anthropomorphic Hybrid III 6 year old dummy in the front passenger seat is ejected during a moderate left turn and ejection kinematics are analyzed. An Articulated Total Body (ATB) occupant simulation is also presented, which compares favorably with experimental results. Additional simulations are presented wherein a seatbelt is found to be effective in preventing ejection with minimal belt force requirements. While experimental and simulated occupant dummies do not include muscular reactions, the potentially rapid onset of vehicle acceleration indicates that real occupants, particularly young children, may not have time to react before the ejection process has begun. Results indicate that current hip restraints are not large enough to prevent the ejection of small children during a moderate left turn. Additionally, seatbelts or straps are effective in preventing ejection during driver induced accelerations. The small belt force requirements indicate that seatbelts designed for use in automobiles and meeting Federal Motor Vehicle Safety Standards (FMVSS) may not be necessary. Based on these results, it is recommended that children be prohibited from riding in golf cars without a seatbelt type restraint when driven on golf courses and that seatbelt type restraints be provided for each occupant, especially children, when driving outside the golf course setting.

INTRODUCTION

Research and data compiled across the country indicate that the use of golf cars[1] and Personal Transport Vehicles (PTVs) is rapidly expanding, as are the numbers or injuries related to their use. Recent research conducted by the University of Alabama at Birmingham [1] has indicated that about 1,000 Americans are injured in golf car related accidents each month. Another study completed by the Center for Injury Research and Policy at Nationwide Children's hospital in Columbus, Ohio [2] stated that annual injury rates for golf cars increased 130 percent over 16 years ending in 2006. This study suggested that rules should be in place banning children under 6 years old from riding in golf cars. These studies and their underlying data also indicate that passenger ejection is a dominant mode of injury in golf car and PTV accidents, especially when children are involved. The testing and simulations in the present study investigate the effectiveness and load requirements for preventing ejection of children seated in golf cars.

In addition to golf cars operated on golf courses, resort and retirement communities in the United States, as well as other local municipalities, now allow golf cars and Personal Transport Vehicles (PTVs) on streets as primary means of local transportation [3, 4, 5, 6]. In fact, local transportation of passengers is the express purpose of PTVs. Advertising for many PTVs produced by the major manufacturers (i.e. Club Car, E-Z-Go and Yamaha) specifically indicates that these vehicles are intended for "playing golf or cruising your neighborhood" [7] and "hauling kids" [8] and feature photos of young children riding in the vehicles. In response to the trend of using golf cars and PTVs off the golf course,

[1] While the term ''golf cart'' is used by general public, the manufacturers of those vehicles use the term ''golf car.''

the U.S. National Highway Traffic Safety Administration implemented requirements for safety equipment on Low Speed Vehicles (LSVs) that operate on public roads including mandatory seatbelts for all passengers [9, 10, 11]. However, these regulations define a Low Speed Vehicle as one having a top speed between 32 and 40 kph (20 and 25 mph). As a result, vehicles with top speeds below 32 kph (20 mph), such as golf cars and PTVs remain unregulated.

Golf cars and Personal Transport Vehicles are often substantially similar, are manufactured by the same group of companies, and are virtually indistinguishable to the common observer. However, the manufacturers differentiate these vehicles based on maximum speed and intended usage, which can lead to confusing or ambiguous distinctions. For the purposes of this study, it is sufficient to understand that according to American National Standards Institute (ANSI) standards, the term "golf car" applies to vehicles with a top speed of less than 15 mph that are "specifically intended for and used on golf courses for transporting golfers and their equipment" [12] while "Personal Transport Vehicle" (PTV) applies to vehicles with a top speed of less than 20 mph which are "operated on designated roadways, or within a closed community where permitted by law or by regulatory authority rules" not including golf cars [13].

Previous research performed by Seluga et al [14] and Long et al [15] has demonstrated the ineffectiveness of most hip or handhold restraint systems typically found on existing golf cars and PTVs. In fact, it has been demonstrated that these types of restraints can exacerbate the problem by acting as a tripping mechanism, increasing the likelihood that an ejected occupant will strike the ground head first. Additionally, the documented increase in golf car and PTV injuries is consistent with the data presented by Long et al [15], which indicated an increase in the number of injuries due to increased vehicle usage and the lack of any seatbelt requirements. This study also demonstrated the effectiveness of seatbelts in preventing passenger ejections. Thus, if seatbelts were provided and users exhibited comparable compliance rates to those for automobiles (i.e. approximately 80% [16,17]), then approximately 80% of ejection accidents could be prevented by providing seatbelts.

The debate concerning restraint systems on golf cars and PTVs has had opposing opinions both for and against seatbelts. The opinion that golf cars and PTVs should not have any type of seatbelt system has been primarily put forth by the National Golf Car Manufacturers Association (NGCMA), a non-profit corporation consisting exclusively of golf car manufacturers and organized "to promote the common business interest of its members" [18]. During the 1997 NHTSA rulemaking process related to the newly designated motor vehicle category of "Low Speed Vehicle" (LSV) [9], the NGCMA viewed the seatbelt requirement as "antithetical to the personal safety of drivers and occupants of golf cars" [10] and cited ANSI/NGCMA Z 130.1-1993 [19] which required a Rollover Protective Structure (ROPS) for any golf car containing seatbelts. Additionally, the NGCMA suggested that existing hip restraints do not prevent occupants from jumping or leaping out of golf cars to avoid injury when the car is about to rollover. Accordingly, the NGCMA Golf Course Safety Guidelines [20] state that "use of seatbelts without adequate overhead protection may result in severe injury or death." The investigation by NHTSA regarding the establishment of the "Low Speed Vehicle" (LSV) classification included research of golf car safety; until it was determined that NHTSA would only regulate Low Speed Vehicles intended for on-road use and with a minimum speed of 20 mph. Hence golf cars and PTVs with a maximum speed of less than 20 mph are not currently regulated by any federal agency and the decision to require seatbelts in golf cars and PTVs is left to state and local jurisdictions. It should also be noted that NHTSA in its final ruling concluded that "the conjecture by some commenters that it would be valuable to be able to jump out of an LSV are unsubstantiated speculation that is especially unpersuasive given the volume of data showing that ejection is extremely dangerous and that seatbelts are remarkably effective at preventing ejection" [10].

Accident Statistics

It is estimated that there were, on average, approximately 13,000 golf car related injuries requiring emergency room treatment in the United States per year from 2002 to 2007, not including fatalities that did not involve emergency room treatment. The estimated number of accidents steadily increased from roughly 11,000 in 2002 to over 17,000 in 2007 [21]. Of these, approximately 40% (i.e. over 5,000 per year) involved an ejection from a moving car, representing by far the most common type of accident. In cases where the location of the injury was reported, approximately 70% occurred at sports or recreational facilities (e.g. golf courses) while the remainder occurred at locations such as private homes or public streets, indicating that these statistics do not make the distinction between golf cars and PTVs that the NGCMA does. When this data is filtered to include only children (i.e. age < 16 years), it is found that this age group is involved in approximately 40% (i.e. over 5,000 per year) of all documented accidents. Furthermore, children are substantially more susceptible to ejection than adults based on the fact that slightly over 50% of child accidents (i.e. over 2,600 per year) involve a fall from a moving car. Of these child ejection accidents, approximately 50% occurred at a sports or recreational facility, while the remaining 50% occurred either at home, on a street, or at some other public property. In light of these statistics, ejections from a moving car represent a significant number of serious golf car and PTV accidents involving children, the reduction of which would significantly improve occupant safety [1,2,22]. It should also be noted that according to the same statistics, approximately 10% of golf car and PTV accidents involve a rollover. Therefore, even if seatbelts did present some increased danger for passengers in rollover events as supposed by the NGCMA, the relative number of ejections accidents to rollover accidents (i.e. approximately 4 to 1) indicates that the addition of seatbelts could still offer an overall improvement of golf car and PTV safety. Furthermore, there are design opportunities available for reducing the number of rollover events [23].

In addition to the statistical injury data, CPSC case narratives also include some details regarding each accident. One common scenario for a passenger ejection accident is when a golf car or PTV, traveling near its maximum speed, is turned to the left. CPSC data from 2002-2007 contains many accident narratives that match this scenario closely, such as "riding with dad in golf cart, dad made a sharp turn and [patient] fell out" or "patient on golf cart at home, brother turned and threw him off cart." Many more of the "fall from cart" type accidents may also involve ejection during a left turn, but the accident narratives are too vague to make this determination in most cases. This theme is repeated in numerous news articles that report many serious head injuries, including some fatalities, that involve both child and adult passengers falling out of a golf car or PTV during a left turn [24, 25, 26, 27, 28, 29].

Current Designs and Standards

The major golf car and PTV manufacturers (i.e. Club Car, E-Z-Go and Yamaha) do not provide seatbelts as standard equipment with their golf cars and PTVs, though personal communications with many authorized dealers indicated that they will provide a seatbelt if the customer requests one. While it may be generally assumed that golf car users on a golf course are not likely to make use of seatbelts due to their need to frequently exit and re-enter the vehicle, the same may not be true for a PTV or a golf car used away from the golf course. In support of this contention, many private communities and municipalities where golf cars and PTVs are used as the primary means of transportation do require seatbelts. Obtaining some form of a seatbelt for a golf car or PTV is not difficult, since most golf car and PTV outfitters offer after market seatbelts [30,31] to meet the market demands for seatbelts that are not being met by the original equipment manufacturers. The community of Palm Desert in California was a pioneer in recognizing the use of golf cars on their roadways and adopted a transportation plan in 1993 requiring seatbelts in golf cars. Some communities, such as Bald Head Island, North Carolina, have recognized the safety benefits of seatbelts but rather than requiring belts on all vehicles, they only recommend that occupants utilize them if present. It should be noted that, contrary to the supposition of the NGCMA that "use of seatbelts without adequate overhead protection may result in severe injury or death," the authors are not aware of any incidences at these or other communities, where the use of a seatbelt had a negative impact on the injury outcomes of a rollover accident.

Unlike the Federal Motor Vehicle Safety Standard (FMVSS) #500 for Low Speed Vehicles, which requires a seatbelt be provided for each intended occupant, neither ANSI standard Z130.1-2004 "Golf Cars – Safety and Performance Specifications" [12] nor ANSI Z135-2004 "Personal Transport Vehicles – Safety and Performance Specifications" [13] require that any seatbelts be provided. In lieu of seatbelts, ANSI Z130.1 and Z135 require "a hand hold or combination hand hold/hip restraint, anchored securely to the [vehicle], creating a barrier to help prevent an occupant from sliding outside of the [vehicle]" [12, 13]. However, these ANSI standards provided neither design requirements nor test procedures to determine the effectiveness of the provided restraints. It has previously been shown experimentally and analytically that the existing restrains, typically no more than 6" tall and 12" long are ineffective for preventing passenger ejections [14, 15]. In addition to the fact that the top of the handhold is often lower than the seated occupant's center of gravity, the location of the handhold (i.e. at the outboard edge of the seat) is the fulcrum about which an ejected passenger will tend to rotate. As a result, this type of handhold does not provide the passenger sufficient leverage to prevent ejection. Due to the ineffectiveness of these designs, occupant ejections are by far the most common type of golf car/PTV accident. Furthermore, the ANSI standards do not require the manufacturer to provide a recommended minimum occupant age. While both standards require a warning label to be affixed to all vehicles stating "remain fully seated and hold on when in motion," it is highly foreseeable that occupants will not always hold on while the car is in motion, which is especially true with regard to children. Additionally, small children whose feet cannot reach the floor may not have sufficient strength to prevent ejection during a moderate turn.

METHODS

Dynamic Child Dummy Testing

A series of tests were conducted utilizing a 2004 Club Car Villager PTV and a Hybrid III 6 year old dummy weighing 21.4 kg (47 lb). The test vehicle had designated seating positions for four occupants, two facing forward and two facing rearward. In each test, the child dummy was placed unrestrained in the right front seated position with a driver (see Figure 1).

Figure 1: Test vehicle with Hybrid III dummy

The vehicle in each test was brought up to full speed (i.e. approximately 21 kph [13 mph]) by the driver and the accelerator was then released and the car steered into a moderate but easily controllable left turn. In each test the occupant kinematics were recorded with digital video and still images.

Two methods of collecting performance data for the tests were employed. A tri-axial array of accelerometers (IC Sensors 3031-050) was affixed near the vehicle's center of gravity. All accelerometer data were collected following SAE Recommended Practice: Instrumentation for Impact Test – J211/1Mar95. The axis system was in accordance with SAE J1733 Information Report with positive X, Y and Z axes forward, rightward, and downward, respectively. All accelerometer data were collected at 1000 Hz and filtered using a SAE Class 60 filter. In addition to the accelerometer data, vehicle performance data were measured using a GPS-based system (VBOX, Racelogic LTD, Buckingham, England). Three-dimensional speed and positional data were collected at 100 Hz.

Biomechanical Simulations

Three-dimensional computer simulations of the test vehicle and the child dummy were created using the Articulated Total Body (ATB) simulation software [32, 33] for comparison with the experimental results. ATB is a simulation program that models the dynamic response of systems of connected or free bodies such as the human body during a dynamic event. It can be used to model a dynamic environment of surfaces and bodies that interact with one another according to the physical laws of motion and has been used previously to study ejections during motor vehicle accidents [34]. In addition to providing detailed numerical force and motion results, the program also produces graphical depictions of the simulation results.

To simulate the dynamic ejection experiments, a model of the test vehicle was combined with a model of a child dummy occupant based upon the geometry of each. The child occupant model was created using the Generator of Body Data (GEBOD), which is a companion program to ATB that generates a model of the human body for use in ATB simulations [35]. GEBOD utilizes regression equations to calculate the geometric and inertial properties of body segments based on the proportions associated with a 50th percentile child of a given age, height and weight [36]. The relevant geometry of the test vehicle (primarily the seat and hip restraint geometry) was measured directly from the test vehicle. Some of the relevant measurements are shown in Figure 2.

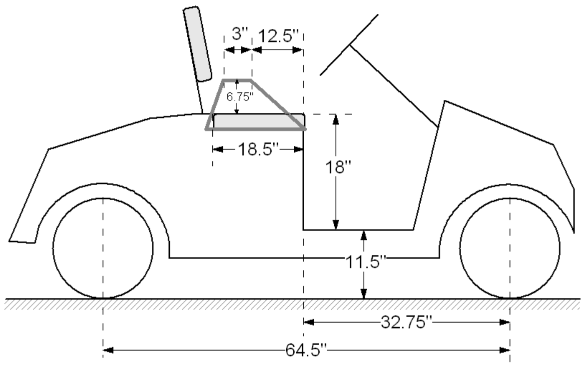

Figure 2: Test vehicle dimensions

The motion of the simulated vehicle was obtained from the experimental vehicle acceleration data described above. The coefficient of friction between the simulated passenger and seat was 0.5 based on averages obtained from testing typical clothing materials on PTV seat surfaces.

The simulations were first conducted with no attachments between the passenger and the vehicle (i.e. occupant not tethered or holding on) for comparison with the dummy experiment. For the purposes of these and all subsequent simulations, ejection was defined as a condition where the passenger's lower torso body segment moved over or around the hip restraint and traveled outside of the car. Next, the simulations were repeated with a spring-damper connection added between the occupant's right hand and the hip restraint, representing an occupant holding onto the hip restraint. These simulations were used to determine the effect of the occupant holding onto the hip restraint. Subsequent simulations were completed with a spring-damper connection between the passenger's left hand and the center of the seat, simulating the occupant holding onto a handhold, strap or the equivalent mounted near the center of the bench seat, though such a handhold was not provided on the test vehicle. Center seat handholds have been previously investigated [14] and these simulations were used to determine the grip and arm strength necessary to prevent child ejection in conjunction with such a device. The necessary grip strength was then compared to typical child strength capabilities to determine if it was feasible for a child occupant to avoid ejection by making use of a central handhold. Finally, additional ATB simulations were created wherein a simulated lap seatbelt was added to determine its effectiveness in preventing ejections and to quantify the belt strength requirements necessary to prevent ejection.

RESULTS AND DISCUSSION

Vehicle Dynamics/Occupant Kinematics

In Test 1 the PTV was brought up to a speed of approximately 21 kph (13 mph) followed by a moderate left turn which produced peak lateral accelerations of approximately 0.6 g (see Figure 3). This peak lateral acceleration was reached approximately 0.5 seconds after the onset of noticeable lateral accelerations. It should also be noted that during the left turn maneuver peak longitudinal decelerations of approximately 0.1 g were developed. The radius of the resulting turn was approximately 20 ft.

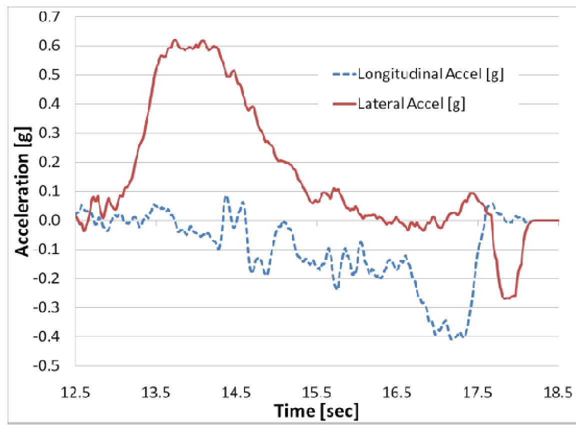

Figure 3: Test 1 recorded vehicle acceleration

The occupant kinematics demonstrated in the test show the child dummy moving laterally initially followed by a combined movement of the dummy moving laterally and forward (see Figure 4).

Figure 4: Test 1 observed occupant kinematics

The hip restraint during the ejection phase acts as a tripping mechanism placing the child dummy into a head first dive onto the asphalt track. Due to the lower inertial properties of the child dummy relative to an adult dummy, the ejection process is of a significantly shorter duration than that observed by the authors in adult ejections. This rapid onset of ejection and subsequent trip produced by the hip restraint leaves the occupant little remedy in avoiding ejection. It should also be noted that due to a child's small stature, an active child would have little opportunity to jump from the vehicle by pushing off the floorboards since the child's feet cannot reach the floorboards.

In Test 2 the PTV was again brought up to a speed of approximately 21 kph (13 mph) followed by a moderate left turn, but in this sequence, one potential driver response to the child dummy ejection was demonstrated. During the turn the driver remained watching the child dummy and at the first observable signs of a potential ejection, the driver commenced maximum effort braking. This maneuver produced peak lateral accelerations of approximately 0.5 g's along a turning radius of 27 ft followed by brake induced longitudinal decelerations of approximately 0.5 g's (see Figure 5).

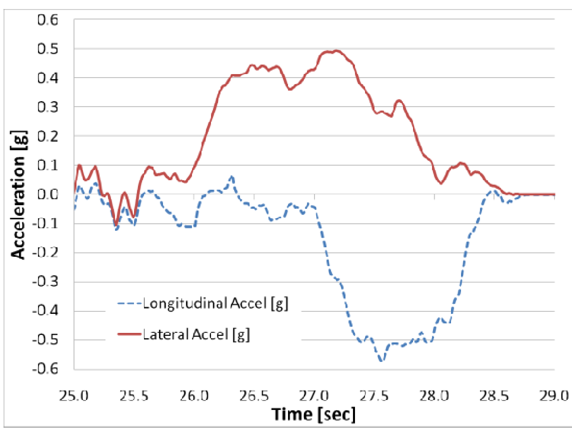

Figure 5: Test 2 recorded vehicle acceleration

Once again, as demonstrated in the previous test, the hip restraint acts as tripping mechanism putting the child dummy into a head first dive onto the test track (Figure 6). Additionally demonstrated in this test is that once the ejection process has started, a braking action by the driver will not prevent an ejection.

Figure 6: Test 2 observed occupant kinematics

These experiments demonstrate the effects of a moderate left turn and the resulting lateral and longitudinal accelerations which act upon a right front passenger and lead to ejection. Passenger ejection is most likely to occur during a left turn, since a right turn will tend to force the passenger to his left, towards the center of the car. Child passengers are especially susceptible to ejection because of their small size and consequent reliance upon the hip restraint to prevent ejection. While the experimental child dummy occupant does not include muscular reactions, the potentially rapid onset of vehicle acceleration (i.e. 0.5 seconds or less) indicates that real occupants, particularly young children, may not have time to react before the ejection process has begun. The results of these experiments indicate that current hip restraints are not large enough to prevent the ejection of small children during moderate left turns. It should be noted that driver ejections, while still possible, are generally less likely due to the fact the driver will inherently anticipate all steering maneuvers and is also able to use the steering wheel as a handhold.

Biomechanical Simulations

Unbelted Occupant

The simulated kinematics of the unbelted occupant ejection show excellent correlation to the experimental dummy results from both tests, as can be seen by comparing Figure 4 and Figure 6 with Figure 7 and Figure 8 (see Appendix A). Both the direction and the timing of the simulated occupant motions match the experiments. In the simulation of Test 1, the unbelted occupant leans and slides towards the passenger side hip restraint, due to the lateral acceleration generated by the turning vehicle. Next, the occupant rotates over the top and around the front of the hip restraint and is ejected out the passenger side of the vehicle. Following ejection, the occupant's head strikes the ground. It should be noted that although the experimental and simulated dummy rest orientations are somewhat different (i.e. the dummy's feet are facing in different directions after it comes to rest), these differences occur after the impact with the ground. The occupant kinematics during the ejection phase and at ground impact show close correlation.

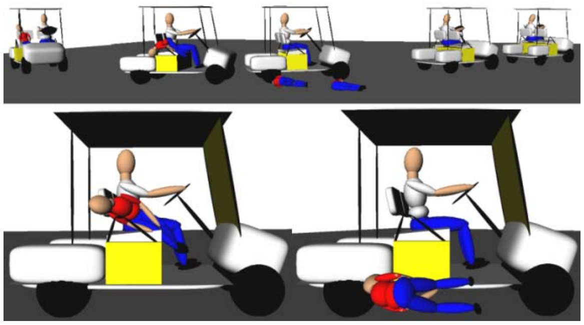

Figure 7: Test 1 simulated occupant kinematics (unbelted and untethered)

In the simulation of Test 2, the unbelted occupant again initially leans and slides towards the passenger side of the vehicle due to the lateral acceleration. Then, as a result of the braking induced longitudinal deceleration, the occupant slides forward, beyond the highest portion of the hip restraint, which is only 3 inches long. Finally, as in Test 1, the occupant rotates over the hip restraint and is ejected out the passenger side of the vehicle, striking his head on the ground.

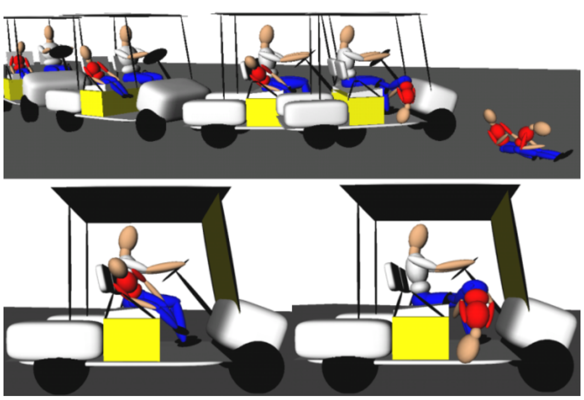

Figure 8: Test 2 simulated occupant kinematics (unbelted and untethered)

The close correlation between the experimental occupant kinematics and the simulated motions indicate that the ATB model can be utilized to accurately simulate golf car and PTV occupant ejection motions. These simulations also reveal that just before impact, the occupant's head has a speed of approximately 15-25 kph (9-15 mph), including a vertical component of velocity of approximately 10-12 kph (6-7 mph) which is equivalent to a fall height of 0.4-.5 meters (1.4-1.5 ft). Research regarding fatal falls from play equipment indicates that children who fall from heights as low as 0.6 meters (2 ft) onto soil or grass can receive fatal head injuries [37]. Thus, the ejection of a child from a golf car or PTV poses significant risk of serious, possibly fatal head injury, especially if the child lands on a paved surface.

Occupant Holding Outboard Hip Restraint

The simulated kinematics of the unbelted occupant holding the outboard hip restraint demonstrated a high risk of ejection, consistent with the findings of a previous study [14]. The ejection process of a child holding onto the hip restraint is depicted in Figure 9.

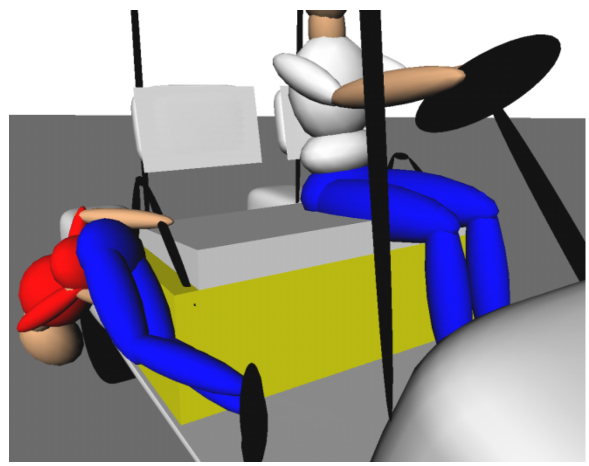

Figure 9: Test 1 simulated occupant kinematics (unbelted and tethered to hip restraint)

As can be seen from the simulated occupant motion, holding onto the hip restraint handhold located at the outboard edge of the seat is ineffective because that point is also the fulcrum about which an ejected passenger will tend to rotate. Therefore, this arrangement requires the occupant to generate large torques about the hand hole to counteract the lateral acceleration forces, which will be difficult since the point of force application (i.e. the outboard handhold) offers very little leverage about the occupant's center of rotation over the top of the handhold. Generating such torques will be difficult for adults and even more difficult for small children, since they are less likely to be able to attain a "power grip" around the handhold (i.e. fingers flexed around the handhold to form a clamp against the palm) due to its size relative to their hands. Therefore, this type of outboard handhold may not provide the passenger sufficient leverage to prevent ejection, regardless of the occupant's grip strength.

Occupant Holding Central Handhold

The simulated kinematics of the unbelted occupant holding the proposed centrally located handhold demonstrated that with sufficient grip strength, such a handhold could effectively mitigate the risk of ejection (see Figure 10).

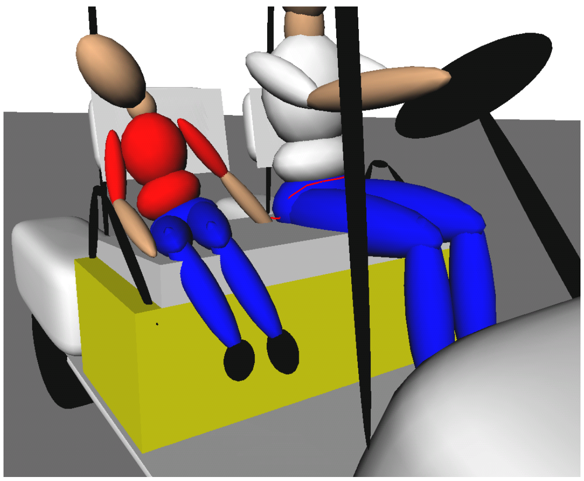

Figure 10: Test 1 simulated occupant kinematics (unbelted and tethered to central handhold)

In this case, the minimum peak hand force required to prevent passenger ejection was simulated for each test. For the simulated 21 kg (47 lb) 6 year old occupant, a peak hand force of approximately 67-107 N (15-24 lb) was required to prevent ejection. It should also be noted that during the simulated left turn, the central handhold caused the occupants left arm to be loaded in tension. Therefore, the only action required of the occupant is to hold onto the handhold, since active shoulder and elbow efforts are not necessary to prevent ejection. Child strength data indicates that children as young as 3-5 years old are routinely capable of hanging from a bar with arms straight for 45-90 seconds [38]. This data indicates that children are capable of supporting roughly half their body weight with each arm under tension when a sufficient handhold is provided, on par with the tensile arm force required to prevent ejection with a central handhold. Since the recorded lateral vehicle accelerations during a left turn last only 3 seconds, it is reasonable to assume that many children would have sufficient strength to hold themselves in a golf car or PTV during a moderate left turn if a centrally mounted handhold were provided. Therefore, a center-mounted left handhold would be an effective countermeasure for mitigating the risk of ejection and seems to be a prudent and inexpensive safety feature that also facilitates compliance with ANSI standard Z130.1. The limitation of such a handhold is that it is not a passive safety device as it does require that the occupant utilize the handhold.

Belted Occupant

Finally, the occupant simulations with a safety belt included demonstrated that a seatbelt is extremely effective at preventing the ejection of even a passive occupant (see Figure 11).

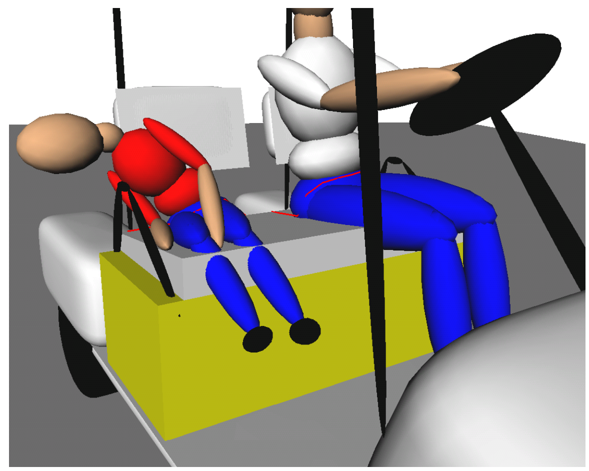

Figure 11: Test 1 simulated occupant kinematics (belted)

This is also consistent with previous dynamic dummy testing [15]. Furthermore, the simulations indicate that the peak force at the inboard seatbelt anchor point is approximately 220-490 N (50-110 lb) for the simulated 21 kg (47 lb) occupant (i.e. approximately 1-2 times the occupant's weight, see Figure 12). Simulated belt forces at the outboard anchor point are negligible. One explanation for the inboard lab belt forces sometimes exceeding the occupant weight is that the geometry of the seatbelt causes the tension to act at non-horizontal angle, requiring larger forces to generate the necessary horizontal loads to prevent ejection. The initial slack in the belt and the resulting magnitude of the interaction between the hip restraint and the occupant also play a role in how much force must be provided by the seat belt to prevent ejection.

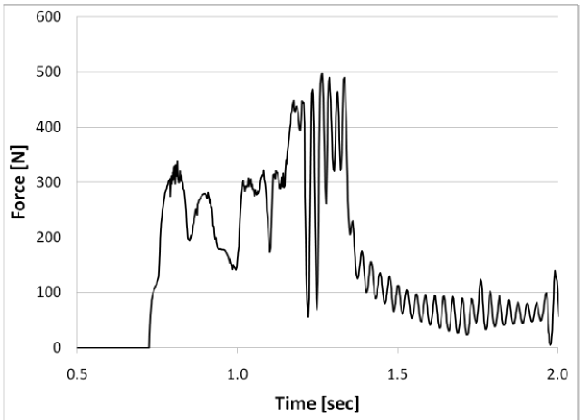

Figure 12: Test 1 Simulated inboard belt force

This belt load is significantly less than the loads experienced by automobile belts during impact events. Therefore, the strength of a golf car or PTV lap belt need not be build to automotive standards to be effective in preventing occupant ejection. Since, if a lap belt is provided, it would be desirable to provide one that could also prevent adult ejections, additional simulations were conducted using a 95 kg (209 lb) 95% simulated adult male occupant to characterize the peak belt loads that would be generated by a larger occupant. These simulations resulted in peak belt loads of approximately 980 N (220 lb), again indicating that an automotive strength belt need not be provided if the goal of the design is to prevent ejections during driver induced accelerations and not to offer protection in collisions. In fact, providing a safety strap that will break free under high acceleration conditions may be more appropriate since the proposed safety strap/belt's purpose is solely to prevent an occupant ejection during a maneuver and not to offer crash protection.

CONCLUSIONS

Summary

The coordinated experimental dynamic dummy testing and biomechanical computer simulation program presented in this study indicate that current golf car and PTV designs create a situation where young passengers are especially susceptible to ejection during moderate left turns. Furthermore, when passengers use the provided outboard hip restraint as a handhold, little protection is provided because the ejected passenger can easily rotate about the hip restraint due to the small size of the hip restraint and the insufficient leverage provided when holding onto the outboard handhold with the right hand. While a previously proposed center-mounted left handhold does offer better ejection protection when used, this feature cannot protect a passive occupant. Therefore, a lap belt restraint, which is extremely effective at preventing ejection, is the best method for preventing child ejections. Furthermore, the lap belt need only withstand minimal forces to prevent ejection during a non-impact event and thus automotive strength seatbelts meeting current Federal Motor Vehicle Safety Standards are not necessary to prevent occupant ejections.

Recommendations

In light of these results, it is recommended that children be prohibited from riding in golf cars without seatbelt type restraints when used on golf courses. If children are allowed to ride on golf cars with no seatbelts then, at the very least, a centrally mounted handhold should be provided to reduce the likelihood of ejection. Furthermore, passive hip restraint effectiveness should be improved on all golf cars and PTVs by increasing the size of the restraint in order to improve occupant retention when a seatbelt is either not provided or not used. When golf cars or PTVs are driven outside a golf course setting, seatbelt type restraints should be provided for all occupants, especially when those occupants are children. The community of Palm Desert in California offers one example of the type of safety rules that should be implemented in local communities.

APPENDIX A: ENLARGED KINEMATICS FIGURES

Figure 4: Test 1 observed occupant kinematics

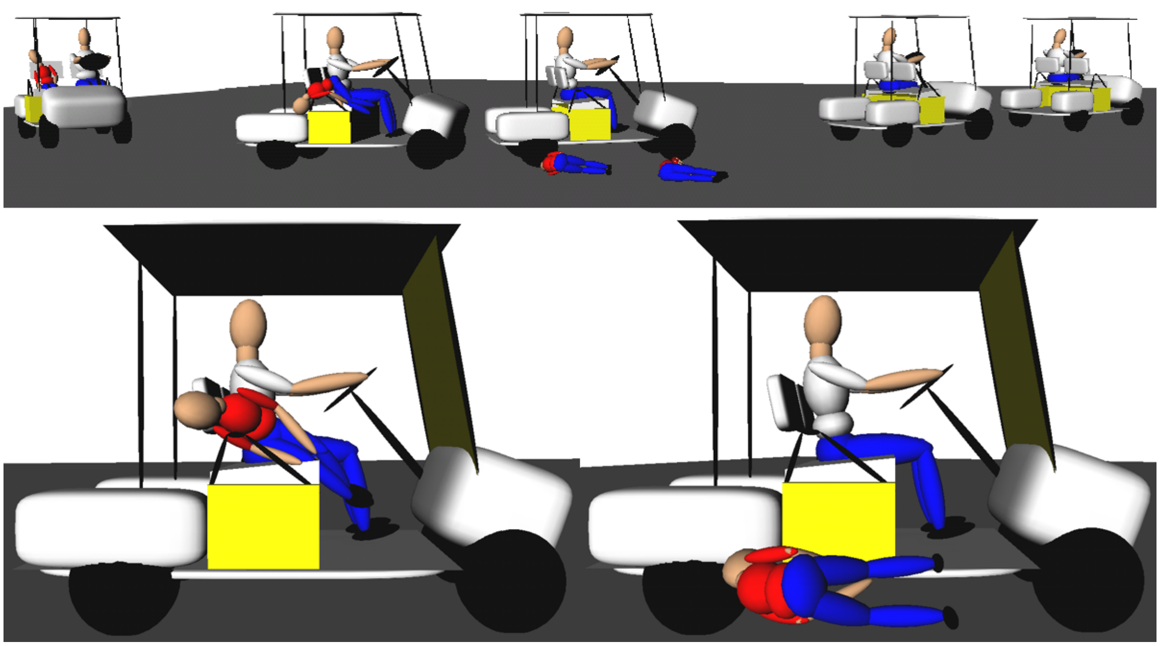

Figure 7: Test 1 simulated occupant kinematics (unbelted and untethered)

Figure 6: Test 2 observed occupant kinematics

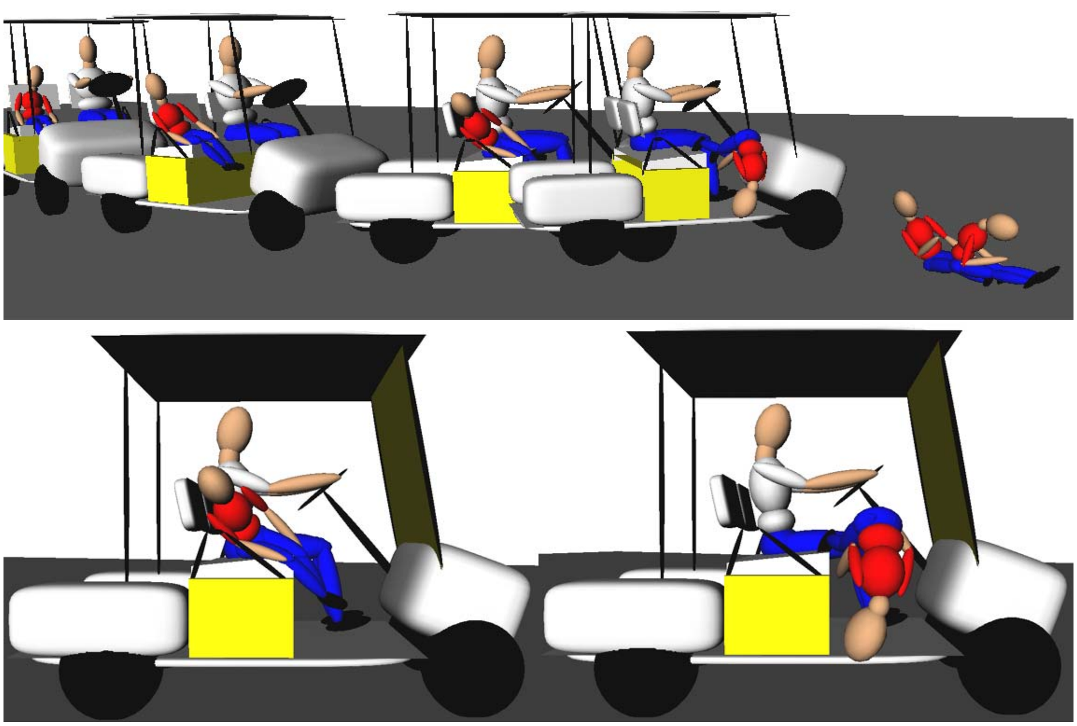

Figure 8: Test 2 simulated occupant kinematics (unbelted and untethered)

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