Design of a Roller Coaster Restraint System to Make Lap Bar Restraints More Inclusive for People with Lower-Body Limb Differences

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Abstract: This paper describes the design of, and rationale for, a new type of roller-coaster restraint device that would make lap bar style safety systems secure for people with lower-body limb differences, such as those with bilateral leg amputations. Currently, lap bar style restraints do not protect these individuals, or others with similar proportions. However, by examining the directional forces that make lap bars inadequate, it becomes clear that it would be fairly easy to implement a solution without retro-fitting existing thrill-rides. While this paper contains the description of one original design, any product that addresses the safety issues brought up here could also help to address the problem of lap bar inadequacy, and make thrill rides more inclusive for riders with all body types.

Introduction

The design in this paper began as a project of personal interest, and in June-December of 2019 was funded by the UCF Innovation-Corps (I-Corps) training award under the university's NSF prime award number CNS-1735841. This funding was provided to further develop the plan for building and marketing a product that would address the issue of certain roller-coaster restraint systems not serving the population of individuals with lower-body limb differences, such as double leg (or bilateral) amputees. While this paper presents one concrete solution to the issue, it also includes enough background on the problem and rationale for this particular solution, that anyone reading may be able to come up with similar solutions.

Background

Roller coasters and related thrill rides are a safe way to get a taste of danger. The sensation of falling, without the accompanying risk of bodily injury, draws many people to visit such attractions. Riders enjoy the experience, knowing that they are kept securely in place by the safety restraints. However, some riders are actually at risk. Lap bar restraints, while perfectly safe for most people, are actually not equipped to protect those with certain body proportions. One such group who cannot rely on the safety of lap bars, is double-leg amputees.

A brief examination of lap bars shows that they are adequate for most riders. A lap bar is a certain type of safety restraint used in many coasters, including some that become inverted. Often, lap bar seats do not have any additional restraints. While some may not believe that a single bar could be enough protection, a lap bar is extremely safe for most people.

See Figure 1.

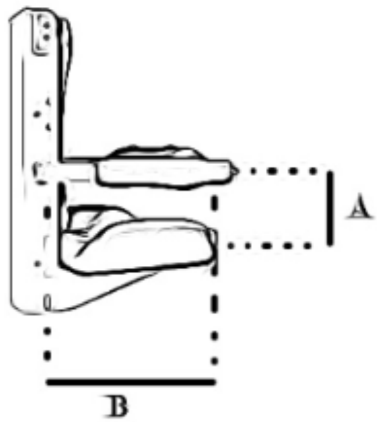

Figure 1: a lap bar seat with height measurement A and width measurement B.

The safety of these devices relies on two measurements: the height of the lap bar from the seat (Figure 1 Measurement A) and the distance between the lap bar and the back of the seat (Figure 1 Measurement B). Both measurements are ideally as small as possible with taking into account the rider's size.

When a rider's legs are shorter than the ratio of the distance between measurements A and B, they are no longer being secured by the safety restraints. Hereafter, we will consider a person's critical measurement to be the length of their straightened legs. With this in mind, it is necessary to consider a safe "hypotenuse" created by the aforementioned measurements A and B. See Figure 2.

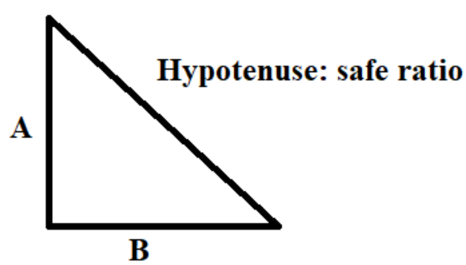

Figure 2: The safe "hypotenuse"

The safe hypotenuse represents the ratio of the measurements. If the hypotenuse is ever larger than a person's own critical measurement, the person no longer safely secured by the lap bar. People with measurements less than the safe hypotenuse would account for roller coaster ejection accidents other than those caused by a failed locking mechanism.

As lap bars are adjustable, this type of mechanism is designed to be suitable for a range of riders. The ones who are at risk, tend to have unexpected proportions which either lower their own critical measurement such as extremely short riders or increase measurements A and B such as is the case with obese riders. It is these two groups of riders who are most often failed by lap bar safety restraints. Double-leg amputees fall into the first category, as their critical measurement would be lowered by the loss of their legs. To that end it is important to examine ways to ensure the safety of all riders, not just most.

Prior Accidents

Accidents while wearing roller coaster restraints are, sadly, not just hypothetical. While locking mechanisms can fail and restraints can come undone, this targeted review will focus only on situations which cause risk without failure of any mechanical devices. That is, accidents where people have been ejected from rides while their lap bar remained locked and in place. Thankfully, those incidents are few and far between.

One such case involved a rider who lost her life on a water ride (Casey, 2006; Gottlieb, 2001). A larger-than-average rider, she secured herself with a lap bar before beginning the ride which was billed as both the tallest and steepest water-based attraction. Unfortunately, her body dimensions required that the lap bar be placed further forward than that of most riders, in order to accommodate her size. This increase in the safe hypotenuse of the restraint meant that she was no longer secured by the lap bar. She was thrown from the ride. There was no mechanical failure involved as the lap bar was still engaged when the ride stopped. The lap bar did exactly what is was designed to do: stay in place securely until unlocked. Unfortunately, the rider's dimensions meant that the lap bar was not an adequate restraint. A taller rider, with a larger critical measurement, would have been safe in the seat even with a lap bar pushed out. However the rider was short in height compared to her width, which created dangerous proportions for the roller coaster.

Another incident involved a double-leg amputee who was thrown from the Ride of Steel roller coaster (Duprey, 2011). Due to his amputations, the war veteran had a very short critical measurement. Despite the lap bar being snug, he too had disproportionate measurements based not on a larger than average width, but on a much shorter than average critical measurement. Both of these riders had uncommon but not unheard-of proportions. In both cases, ride operators should have been aware that the lap bar was not an adequate safety restraint.

Why these Accidents Happened

It is worth noting – again – that most riders are safe with a lap bar. While the vast majority of people have proportions that allow for safe riding, it is important to consider that most rides are safe even for those with a lower critical measurement than the safe hypotenuse. That is to say, many rides are not dangerous even if the lap bar does not adequately secure the rider. Some parks have even admitted that the lap bar is not there to protect riders from accidental falls, but to ensure that they do not try to stand. In order to be dangerous in the case of an inadequate lap bar, the ride must have negative G-forces (also considered "airtime", such as when a cart goes upside down or experiences a fast, sharp drop). It is only during movement along the Z Axis (vertical movement) when riders are even able to slip out of lap bars, regardless of proportions. Forces in the Z Axis are created while going up and down the coaster's hills and valleys and their intensity is measured for each ride by the Standardized Amusement Ride Characterization or SARC test (The National Association Of Amusement Ride Safety Officials, 2015). See Figure 3.

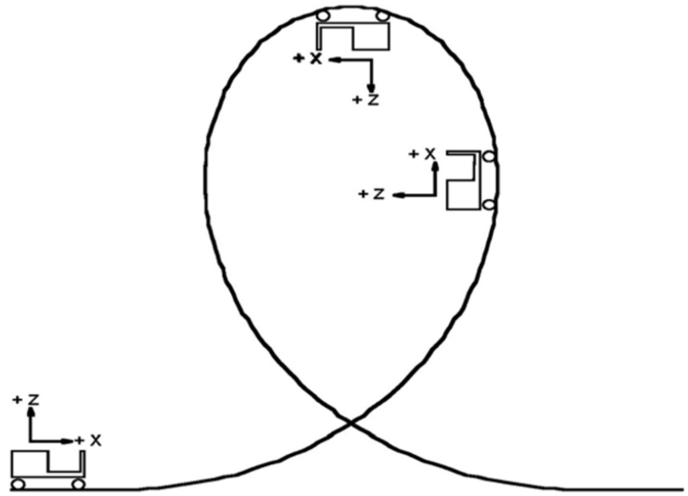

Figure 3: When the Z force is in the downward direction, such as upside down or travelling down the steep second half of the loop, lap bars are inadequate for certain riders whose proportions are uncommon.

Again, here the ratio between the rider's legs and the safe hypotenuse is important. Even when upside down, held only by a lap bar, most riders would still not physically be able to slip through the space between the edge of the bar and the back of the seat. The dimensions of their legs would simply not allow it. However, those with extremely short lower limbs, as in the case of individuals with lower-limb differences, would be able to fit through that space. See Figure 4.

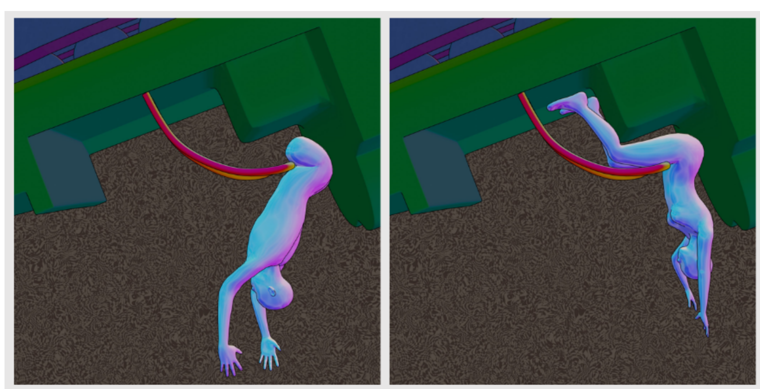

Figure 4: Two riders are shown here restrained by lap bars while upside down, with the rider on the left having bilateral leg amputations.

Limb Differences

While there are several potential causes for the uneven proportions that might make someone a poor candidate for a ride secured with a lap bar, one of particular interest s double-leg amputees. Most ride operators are prepared for the other common risk factors such as height or size. Many rides have height restrictions clearly posted at the entrance to the ride. Some have weight restrictions, which can often be researched before arriving at a theme park. However, a double-leg amputee might not be informed of the danger. Their weight is often less than the stated maximum, especially due to the loss of two heavy limbs. The height limit, too, is often not considered as they might use their measurements before their loss of limbs, or they might arrive in a wheelchair or wearing prosthetics. These factors put them in danger, more so than other groups, of riding a roller coaster with inadequate safety restraints.

These factors lead to one critical question: how can lap bar rides be made safe for double-leg amputees? While retrofitting the ride with more restraints is possible, it would be a costly endeavor which would benefit only a few riders. While the American's with Disability Act does have exceptions, which allow that theme parks are within their rights to turn away customers with amputations, many riders are unhappy with that solution (Moorer, 2018). Roller coaster restraints should be made to fit all riders.

A preliminary survey was sent to people with lower body limb differences. Respondents included either double or single leg amputees with a range of partial limbs. Of the responses, nine were usable survey responses. Though this is a relatively small number in terms of statistical significance, the target population is difficult to reach and subjects with lower body limb differences are rare. Thus, the nine responses were analyzed. Of the nine, four had been turned away from a roller coaster or thrill ride due to their limb differences. This is a fairly large proportion, as some of those who had not experienced this situation, were not roller coaster riders and had never attempted to ride one. The fact that four out of nine wanted a chance to ride a roller coaster and were denied that opportunity, speaks volumes. Six out of the nine subjects responded that they would feel safer in a restraint designed for someone with their specific limb difference. This number highlights the demand for such a product. While it is a small population, the right to ride and feel safe on a roller coaster should not be denied to anyone.

A Proposed Solution

From the information provided here, it should be fairly clear that the potential inadequacies of lap bar restraint systems rely on several criteria. First, an individual rider must have proportions such that their legs are shorter than the "safe hypotenuse" described earlier. Second, the coaster must involve force along the Z axis, such as going upside down or experiencing a steep drop. Third, there must not be additional restraints over the rider's shoulders that would prevent riders from being able to slip upwards and out of the cart, which is the unprotected gap left by lap bars. The first two cannot be changed. However, additional restraints could turn a lap bar restraint, which is unsafe for individuals with the proportions discussed earlier, into a shoulder restraint, which *is* safe for those same riders.

Perhaps the simplest solution would be a way to make a lap bar safe for a double-leg amputee only if, and when, it is needed. Rather than retrofitting all existing seats on multiple rides, a theme park could invest in portable equipment that could travel, with the rider, to whichever attraction they wanted to experience. To meet these criteria, the equipment would have to be detachable, relatively small, and light. One such design would be a portable device which adds the safety factors of both shoulder-based restraints, and average-length legs. See Figure 5.

This restraint would need to be a solid material (though could be padded for comfort). It would be worn around the back of a rider's neck, and travel down the front of their chest ending around the end of their torso, though it would not need to be an exact match. According to the Dreyfuss Humanscale (1966), the human torso tends to vary in length from 14 to 21 inches, so a few lengths would be required. At the point where the individual's torso meets their hips, the restraint would bend around 90 degrees, traveling the length of the seat or slightly further, before bending again and traveling to the floor of the ride cart. It would not need to reach necessarily to the floor, but would need to be long enough to mimic average human legs, and thus affording the user with the protections that most riders already have.

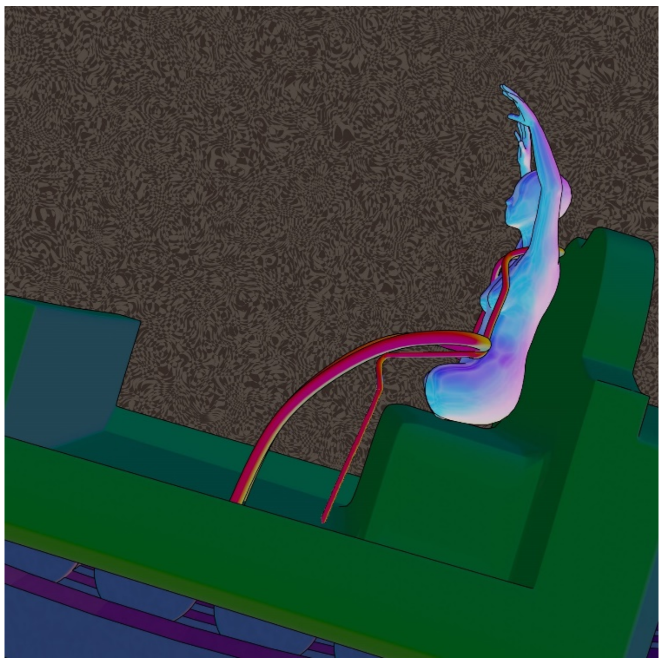

Figure 5: A portable restraint device which would make lap-bars more inclusive for riders with limb differences.

This restraint system would not need to connect to the lap bar at all and would therefore work for a variety of widths of lap bars. It also would require no additional hardware to be added to the original restraint system, eliminating the need to retrofit current rides, and allowing the user the freedom to choose their own seat. Additionally, its portable nature would allow amusement parks to invest in only a few of each size, which could be used at any ride, rather than keeping each size of restraint system on hand for every ride where it might be needed. This would help to make some types of rides more inclusive for rarer populations, without placing undue burden on amusement park owners.

Conclusion

This paper presents one solution to the problem of lap-bar inadequacy for people with different body proportions. However, it also shares the background information which lead to the design of this particular solution. Accessibility is a collaborative, not competitive, process, and my hope is that by sharing this information, more solutions to this and other, similar issues may arise. While most restraint systems are designed to accommodate the majority of riders, adding options for inclusivity need not be cumbersome, expensive, or difficult.

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