Astrowheelie: A Nintendo Wii based Fitness System for Manual Wheelchairs

John Hickok  
Georgia Institute of Technology  
College of Architecture  
Atlanta, Georgia 30332  
hickok@gatech.edu

Christina O’Neill, Deepak Zambre, Michael Boyce  
Georgia Institute of Technology  
College of Computing  
Atlanta, Georgia 30332  
{coneill, deepak.zambre, mboyce} @gatech.edu

ABSTRACT:

This paper is a follow-up of the existing project Astrowheelie, focusing on the manual wheelchair as an input device in the promotion of wheelchair fitness and quality of life. Analyzing results of the first user study we were able to find areas of improvement. These include variable difficulty levels to accommodate ability, more quantitative data, and improved universal design with regard to the holsters. Through consultation with Shepherd Center professionals we were able to establish measures of direct clinical benefit and laying the foundation for future projects involving sip and puff interfaces along with other rehabilitation specific assistive devices.

ACM CLASSIFICATION:
H 5.2 [Information interfaces and presentation]: User Interfaces. – Interaction Styles.

GENERAL TERMS:
Design, Human Factors

KEYWORDS:
Astrowheelie, rehabilitation, wheelchair, fitness, interface

INTRODUCTION:

On October 3rd 2008, the Astrowheelie team conducted a user study involving 13 spinal cord injury patients. These patients played Astrowheelie as well as some participants playing an adapted version of Pac Man. The goal of the study was to establish if Astrowheelie is a viable methodology for fitness among manual wheelchair users. If the goal is successful, possible in home implementation of the Astrowheelie system can support rehabilitation outside the therapy room. In an effort to gain the individual perspectives each participant fills out a questionnaire related to their personal experiences and workload effort while playing the game.

The NASA TLX is the tool of choice for the evaluation of workload. Examining the responses of the questionnaires, although the Astrowheelie interface provides a level of exercise, the level of exercises varies depending upon the ability level of the participant. In some cases the interface provides too much assistance, making the game easy and unchallenging. While at the opposite end of the spectrum are individuals who due to their physical limitations have great difficulty simply moving their personal wheelchair, let alone playing a gaming interface with it. Therefore, in order to increase the usability of the interface difficulty modification levels are essential.

Being that the Astrowheelie interface has rehabilitation at the heart of its design goals, input from rehabilitation professionals can impact future iterations of the design and the practicality in the rehabilitation setting. The researchers decide to make plans for the next iteration of the project to meet with individuals at the Shepherd Center and establish what the particular needs of their patients are and how existing technologies could be a foundation for greater progress in the field of rehabilitation. If nothing else, this meeting would help to direct the research done in the field beyond the duration of this project.

Another finding that is particularly useful when dealing with manual wheelchair users is the diversity of wheelchair wheels to which our system attaches. Although the researchers have knowledge of wheelchair wheels both from personal experience and team investigation, specifics for universal design need to be part of the consideration process when improving the interface design. Several of the participant’s wheelchair tires are of a specialized nature, geared for heavy athletic usage, while other wheel types include power assists for patients who struggle to move themselves in their chairs. The wide range of wheelchair sizes and types prove to make attaching Astrowheelie holsters into a trying experience.

Participant comments reflect that although they enjoy having an interface such as Astrowheelie at their disposal, they require an easier way to attach and remove the Astrowheelie attachments. This is primarily due to fine motor limitations which are common in spinal cord injuries. One of the primary goals for these patients is to ensure the maximum level of independence for themselves regardless of their disability level. The setup difficulty would lower the usability of the interface and make it more difficult for the target population. Easier setup can be a benefit within rehabilitation center environments as time is constantly limited.

Another design related issue is the stability of the Astrowheelie system during game play. As participants play the game and proceed to perform more rapid movements the laptop on the lap of the participant slides almost to the point of falling. The researchers make a temporary fix by attaching a strap around the laptop screen.
which ties around the back of the wheelchair of the participant. This strategy however needs something more permanent and durable for use with participants. The challenging part of design is a setup that both restrains the computer and gives freedom to the participant to move.

Related to the concept of stability, the pouches in which the Wii remotes reside move excessively during wheel motion, especially quick jerking movements. This is due to the fact that within the holsters there is room to allow for ease of insertion and removal of the Wii remote. This apparently cosmetic difficulty also contains within it difficulty in data gathering due to motion within the Wii remotes which induce variable noise into the data logs and motion calculations. Finally without the individual weights of each of the participants, a calculation determining actual energy expenditure is virtually impossible using this methodology.

In experiments retrieving specific data metrics is important, however in the researcher’s first user study the data they receive from participants appears to be less quantitative and more qualitative. They receive information on their experiences and recommendations for future iterations of the game, yet with the exception of the data from the NASA TLX very little concrete data. This is one of the potential flaws in the study design by the research team because specific metrics are not defined by the design team in favor of just gathering as much data as possible and running analysis at a later time.

RELATED WORK:

Leder et al were at the forefront of using games for the purpose of rehabilitation. They created a virtual pong game for use with stroke victims. More recently, the Playstation 2 EyeToy has been used to show improvements in motor recovery. Therapeutic video games have also been developed to assist patients with cerebral palsy to improve their motor skills [1, 4, and 5].

Tolerico et al investigated mobility trends of manual wheelchair users in an active setting (National Veterans Wheelchair Games) versus a residential setting by logging the distance traveled by chair users. They found that active manual wheelchair users who were employed covered more distance and traveled at greater speeds than those who were not. The researchers demonstrated that those wheelchair users with an active lifestyle were better able to maneuver their chairs than those with a more sedentary one.

Mueller and Agamanolis focused on the concept of fitness through distance gaming via cameras that accounted for velocity and position of a ball against a fixed target area. Their goal was to establish an exertion interface where individuals could receive a collaborative workout experience without physically being in one location [8]. Mokka et al created a virtual fitness center where the user is exploring new surroundings or playing a fitness game in a virtual environment. According to their findings using actual body control contributed to the overall user experience [7].

EXISTING SYSTEM:

Addressing the connection between wheelchair fitness and gaming, Stephen Cuzzort created Astrowheelie [2]. Astrowheelie takes the traditional arcade game asteroids and applies it to a manual wheelchair, through the use of Nintendo Wii controllers. The Wii controllers are placed in customizable holsters that are attached to the spokes of the manual wheelchair. Using the built-in Wii remote technology, the system makes a Bluetooth connection with a Bluetooth enabled laptop running the game. The game then receives the motions of the wheels and based on the distance apart between the two Wii remotes it can assess whether to cause the asteroids spaceship to go forward, boost, or turn in a left or right direction. The firing mechanism is enabled by tapping the hand rims of the wheelchair. The computer is attached to the user via a lap tray which attaches by Velcro to the bottom of the laptop in use.

OUR WORK:

Meeting With Shepherd Center:

As the researchers begin brainstorming about the best way to enhance upon the product of project 1, they realize that in order to make any significant progress in the area of rehabilitation fitness technology and the possible procurement of funding for future research, there is a strong need to firmly establish some of the difficulties facing Shepherd Center patients. Together with researchers at Shepherd the Astrowheelie team met with providers at the center. These included representatives from Assistive Technology, Therapeutic Recreation, Occupational Therapy, and Inpatient Physical Therapy. The end goal is establishing possible areas of future research maximizing patient benefit.

Three significant findings developing from the discussions are: 1. The need to provide low functioning or recently injured individuals with assistive technology that they can use. 2. The development of therapy assisting wearable devices allowing preprogrammed instruction on how to perform various exercises. 3. Improved social interaction technologies allowing for consideration of the ability level of the individual participant. The consensus from the group remains that even small advances in these particular areas could go a long way toward assisting individuals with disabilities. Furthermore this meeting facilitates collaboration between various entities of the center that otherwise may not have interacted.

When an individual first experiences a spinal cord injury they may have almost no motor functionality. One of the technologies that is available to assist spinal cord injury patients is sip and puff interfaces. These interfaces work by allowing patients to control devices using only their mouth. Depending on whether they blow (puff) or sip on a straw they can simulate various movements and actions such as controlling a wheelchair or changing a song on an iPod. If games could be developed using the sip and puff
technology, small advancements in fitness could occur when mobility is limited.

During the recovery process from an injury a patient must go through an intensive therapy program in an effort to regain as much functionality as possible. This often requires retraining of muscles to react appropriately due to the disruption of neuromuscular brain signals. Much of this retraining occurs in repetitive exercise in which a therapist will instruct and correct a patient as to the proper muscle position and movement. If a wearable device such as a vest could detect the particular exercise the person was trying to perform and provide feedback this could encourage a patient controlled rehabilitation mindset.

There is also the concept regarding socialization among people with disabilities and with able-bodied individuals. It is often not feasible for the injured patient to grasp a Playstation guitar controller to play Guitar Hero for example. As such the individuals of lower functionality are left out of some of the socially engaging behaviors of their able-bodied counterparts. A technology that could be attached to an existing game system and use a sip and puff or other assistive device as an input and play alongside a traditional playing device could even the playing field of limitations and be brought within the individual’s home.

**Game Modification:**

This iteration of the Astrowheelie attempts to take into consideration the functional ability levels of the players. This will allow calibration toward either an increasing level of difficulty for players that find Astrowheelie too easy, or a decreasing level of difficulty for those who have trouble simply manipulating their wheelchairs, let alone a gaming environment. Astrowheelie is set up with nine levels of difficulty, level one being the lowest and level nine being the highest. The variation between the levels consists of three variables: ship speed, asteroid speed, and point scoring distribution. This will attenuate the level of difficulty for the player.

**Quantitative Metrics:**

Data from the first user study consists primarily of qualitative data. In an effort to get more quantitative data for the second user study the pre and post questionnaires are substituted for two quantitative upper body functionality surveys. The Disabilities of the Arm, Shoulder and Hand, also known as the DASH questionnaire asks the user to respond to a series of questions regarding ability to complete a task. It uses scales from one to five which range from no difficulty to unable to complete a task. Tasks on the DASH questionnaire include changing a light bulb and making a bed.

A DASH disability / symptom score varies between 0 and 100 and can assess in assisting ability levels between participants. Those with lower Dash scores tend to have more upper body functionality. From this data, researchers can look for possible connections between difficulty levels, amount of exercise, and DASH scores. These activities represent functional activities of daily living (ADL’s) that can help determine the strong and weak points of the participant’s upper body. This data can also apply to working capabilities that can help people with disabilities have an understanding of how functional they are in completing a job. The DASH questionnaire is cited in literature relating to the functionality of the upper body.

The Upper Extremity Functional Index is a functional scale that assesses the degree in which the lifestyle of the individual has changed since their injury. This could be significant in drawing correlations between Astrowheelie as an effective supporting therapy tool versus being used primarily for entertainment purposes. With the combination of these two questionnaires, the Astrowheelie team will be able to discover fine details that distinguish participant’s ability level. This in turn can provide future directionality toward the specific target populations that future research projects can address. This tool is currently in use most often during work related injury assessments.

To make a quantitative judgment on the fitness reliability of the Astrowheelie interface, it is necessary to calculate individual energy expenditure. The most efficient way for doing this calculation would be to use a Volumetric Oxygen (VO2) machine, similar to those used in athletic training environments. However due to lack of access to a VO2 machine the researchers are calculating energy expenditure using the amount of linear motion of the participants, the weight of themselves and their wheelchairs together, and the time spent playing the game.

**Holster / Lap tray / Wii Mote Modification:**

The research team decides to make three changes to the physical design of the interface. First, the Wii remotes have a tendency to move within the holsters. To accommodate, new pouches of nylon were created to grasp the Wii remote more securely, especially during quick movements. Second, the researchers changed the orientation of the Wii remote pouch to be perpendicular to the strap holding it onto the wheel. This made the System more stable to reduce noise in the data. Finally, to gain more quantitative data regarding linear motion a third Wii remote sits on the front of the lap tray which is strapped around the participant to record the change in position of the entire chair over time.

**User Testing:**

After the success of the first user study in October, the Astrowheelie team decides to collaborate with researchers from the Shepherd Center once again. The focus this time centers on gathering quantitative measurement and the attenuation of the interface to the ability level of the participant. Shepherd Center continues to assist the team by giving access to a resource pool of individuals that use manual wheelchairs. Nine participants with various levels of spinal cord injury decide to volunteer for the study. The Georgia Tech Institutional Review Board (IRB) approves the entire structure of the user study before work actually gets underway.
Major changes for this study are the usage of the two quantitative questionnaires, the addition of difficulty levels, weighing of the participants, and the additional Wii remote with improved system design setup. Participants still have the Wii remotes attached for their tires, and still play for a period of 15 minutes. One key difference is that instead of comparing the Astroids game with a Pacman game, the researchers will be comparing the control condition of the Astroids game (without the adjustable levels) and the experimental condition (with the most challenging of the adjustable levels). Once finished playing the different levels of the game, the patient uses the NASA Task Load index, which includes areas such as mental and physical load to compare the workload efforts of the two difficulty settings. The research team makes sure that the individual does not cause any harm to themselves or others when trying to navigate the interface.

**DISCUSSION:**

After compiling our data and analyzing trends we discovered several trends among the responses that we received from our participants.

As one could reasonably expect, the participants who traveled more distance during the test burned more calories. The ratio of change in calories burned to distance traveled in difficulty levels five and nine were very similar: 0.36155 cal/m and 0.36385 cal/m respectively. However, the ratio of change in calories burned to distance was different when the participants used difficulty level one: 0.29692 cal/m which represents a significant decrease in the rate of caloric consumption. This could be attributed to the fact that in level one everything moves more slowly so the participants would not need to accelerate themselves as much as in other levels. Though it is not a linear relationship, the rate of caloric consumption does increase as the difficulty level increases.

Despite the lower rate of caloric consumption during testing of difficulty level one, participants burned more calories in total while testing this level. Table 1 shows that participants burned an average of about 13 calories more in level one than in either of the other two levels. It also shows that the average calorie consumption is roughly equal in levels five and nine. Similarly, the average distance traveled in level one was dramatically higher than in levels five or nine. This could imply that the factors that distinguish between the levels (ship speed, asteroid speed, point accumulation) should increase exponentially rather than linearly as the difficulty level increases.

When comparing the calories burned at levels five and nine with the reported work load index for each participant a surprising pattern arises. When participants burned more calories they generated a lower work load index. This undermines the purpose of the system which was to give users a physically challenging but mentally stimulating workout. Any future versions of the system should focus on making the physical component more challenging.

A final observation comes from comparing each participants upper extremity functionality with their reported work loads while testing difficulty levels five and nine. The Dash score was the measure of functionality used here and higher Dash scores imply that a participant has less functionality while lower Dash scores imply that they have high functionality. For difficulty level five there was an extremely weak positive correlation between the participants’ Dash scores and work load indices. This would suggest that those participants with little functionality found this level marginally more challenging than those participants with high functionality. However, when comparing these data values collected while testing level nine no correlation exists between functionality and work load at all. As shown in Table 1, the average workload for level nine was almost 20 points higher than that of level five. Therefore there must be another factor that should be explored that serves as the primary affector of the differences in work load from level to level.

**Table 1. Summary of Data Collected**

<table>
<thead>
<tr>
<th>Difficulty Level</th>
<th>Average Calories Burned (cal)</th>
<th>Average Distance Traveled (m)</th>
<th>Average Speed (m/s)</th>
<th>Average Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Easy)</td>
<td>36.621</td>
<td>122.706</td>
<td>0.25630</td>
<td></td>
</tr>
<tr>
<td>5 (Norm)</td>
<td>23.259</td>
<td>62.744</td>
<td>0.32119</td>
<td>46.370</td>
</tr>
<tr>
<td>9 (Hard)</td>
<td>23.580</td>
<td>61.525</td>
<td>0.27872</td>
<td>65.630</td>
</tr>
</tbody>
</table>

**FUTURE WORK:**

Future work on this project can focus around the issues of discussion at the Shepherd Center meeting. Wearable exercise training devices, adaptable sip and puff games for lower functioning patients and social interactivity tools via video game input (Guitar Hero, Rock Band) are a few of the possible directions for this type of work. The room for expansion on this project is massive simply because with each patient comes a new set of customized needs. With financial support some of these products may even be able to enter the home and allow for rehabilitation wherever the patient may be located.

**CONCLUSIONS:**

From the knowledge gained from organizing a user study, it can be determined that although the Astrowheelie interface is not a substitute for traditional forms of therapy, it can go a long way toward increasing the entertainment value of the healing process. Furthermore, there is a need for further research into technological developments to assist the disabled and finding ways to adapt that technology to life beyond the rehabilitation center.
ACKNOWLEDGEMENTS:
We would like to thank Stephen Cuzzort and Dr. Thad Starner for their consistent support and availability throughout the course of our project. We would also like to thank the Shepherd Center, specifically Dr. Michael Jones and John Morris for helping us organize the study.

REFERENCES:


