Published in final edited form as:

Am J Phys Med Rehabil. 2011 December ; 90(12): 992–998. doi:10.1097/PHM.0b013e318228ca9f.

Tuning Algorithms for Control Interfaces for Users with Upper Limb Impairments

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Abstract

Objective—Approximately 40% of Americans with disabilities cannot operate wheeled mobility devices and computers adequately due to diminished upper-limb motor control, sensory limitations, and cognitive impairments. We developed tuning software that can customize control interfaces for individuals with upper limb impairments. This study compared differences in each parameter among different diagnostic groups.

Design—Subjects ranged from 18 to 80 years. Athetoid Cerebral Palsy (ACP), Spastic Cerebral Palsy (SCP), Multiple Sclerosis (MS), Upper Limb Spasticity (ULS) and Control groups were used. We used a validated tuning software protocol to customize an isometric joystick prior to a virtual tracing or driving task. Tuning parameters were then compared across groups.

Results—Seventy-five subjects were included. Gain, the parameter responsible for force to output ratios, in each directional axis (leftward gain: $p=0.018$, rightward gain: $p=0.003$, reverse gain: $p=0.007$, forward gain: $p=0.014$) was significant across diagnostic groups. Post-hoc analyses showed that the control group required smaller leftward gain than SCP, MS and ULS groups and smaller gain in all other directions compared to SCP.

Conclusions—Gain may be a useful parameter for tuning by clinicians and efforts aimed at gain customization may aid the development of commercially available tuning software packages.

Keywords

Assistive Technology; Isometric Joystick; Rehabilitation; Movement Disorders; Wheelchairs

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Disclosures:

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

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Four million Americans with disabilities who live in community settings use control interfaces to operate wheeled mobility devices, and millions more use them to access computers.¹ Some of the common control interfaces used today include head switches, voice recognition systems, oversized trackball mice, and joysticks. The conventional movement sensing joystick (MSJ) has a stick that can be manually manipulated in a variety of directions. An isometric joystick (IJ) developed by the Human Engineering Research Laboratories (HERL), on the other hand, is a novel device with a static stick that responds to directional forces exerted on it²⁻³. (see figure 1) Similar devices have been used in the airplane industry and are currently utilized in modern laptop computers. The variable compliance joystick (VCJ) also developed at HERL can simulate the properties of both the MSJ or IJ.⁴

Movement sensing joysticks have mechanical properties and very basic programming capabilities that can be used to compensate for unintentional user movements including small amplitude tremor²⁻³. However, other impairments like spasticity, large amplitude tremor, or choreoathetosis may have a large impact on the ability to control devices like wheelchairs or computers and may preclude many users from independently operating them. Fehr et al. showed that up to 40% of people who use control interfaces cannot use them adequately due to diminished upper-limb motor control, sensory limitations, and cognitive impairments. It was concluded that half of these individuals could be aided by improved control systems.⁵ Another study by Riley and Rosen showed that customization of a joystick to an individual led to better performance in computerized tracking tasks.⁶ While it may not be surprising that performance with a customized device is superior to performance with an uncustomized one, the reality is that advanced tuning is not an option on commercially available interfaces. Before this can become a reality, it is important to identify the specific parameters and settings that are useful in personal customization of interfaces, which is the aim of this study.

HERL has developed advanced tuning software that can be used to customize control interfaces for individuals with upper limb impairments and movement disorders^{2,7}. This tuning software allows customization of several different parameters. Directional axes can be adjusted for individuals who operate the device at biased angles. Gain can be optimized to control the amount of force required to produce output. Optimization of gain is possible along x and y axes defined by the IJ's left/right and forward/reverse plane respectively. Minimum thresholds (dead zones) can be set that direct the system to ignore forces from small amplitude tremor. Maximum thresholds can also be set that limit the amount of force that can produce device output. The tuning software has been used in published^{4, 8-21} and in-progress studies, and results have shown that customization provides superior performance in wheelchair driving and computer access tasks compared to standard, uncustomized interfaces.

This tuning software has been used in studies by individuals with Athetoid Cerebral Palsy (ACP), Spastic Cerebral Palsy (SCP)⁸, Traumatic Brain Injury (TBI)⁹, Multiple Sclerosis (MS)^{4, 10-11}, Parkinson's disease¹², as well as unimpaired control subjects. However, to date, no research has been done to identify which customization parameters are important for individual diagnostic groups or those with upper limb impairments in general. Comparison of parameters across groups could help in generating default parameter profiles for each population. We have previously discussed how consumers and clinicians could benefit from having a variety of default profiles available to them in order to appropriately customize a control interface.⁴ Rather than start with factory settings, clinicians and

consumers could instead use diagnostic profiles as a reasonable starting point from which customization would then occur. Multiple parameter profiles could also be useful for individuals who have variations in their condition such as with flares and remissions or variations of ability that occurs during the day due to fatigue. People with MS, for example, could switch profiles during use to accommodate for times of fatigue or disease flares.

Hypotheses

Individuals with Multiple Sclerosis (MS) will require larger dead zones, more bias of axes, and higher gain compared to Spastic Cerebral Palsy (SCP) and control subjects. Subjects with MS will require smaller dead zones, lower bias axis adjustments and lower gain than those with Athetoid Cerebral Palsy (ACP).

Rationale

Individuals with no impairments or with spasticity are likely to require smaller adjustments than those with MS who often present with tremor, weakness and fatigue in addition to spasticity. People with ACP, on the other hand, may require even larger parameter adjustments due to the involuntary movement disorder.

METHODS

We collected tuning parameter data on dead zone, bias axis angle, and gain from several studies conducted at HERL. All studies used were approved by the Institutional Review Boards of the VA Pittsburgh Healthcare System and/or the University of Pittsburgh. Prior to participation in the research studies, the HERL IJ was tuned using a validated protocol which eliminated output of unintended resting movements, corrected for directional axis bias, optimized gain, and adjusted the maximum force recognized by the joystick² (see figures 2–4). This tuning process generated an electronic file with final parameters selected for each subject. These parameters were then used for analysis in this study.

Participants in each study also completed a self-report background questionnaire. The questionnaire included demographic, mobility device use and clinical history questions.

The studies included individuals with ACP, SCP, MS, Upper Limb Spasticity (ULS), and Control subjects with no upper limb impairment. No subjects were excluded. Subjects from the ACP group were collected from an unpublished, in progress study in which subjects used an IJ to move a cursor to acquire circular targets that appeared on a computer screen. Outcome variables included Trial time and accuracy of target acquisition.

Individuals with SCP and the control population were collected from a study which included subjects aged 12–80 with upper limb spasticity paired with aged matched controls with no upper limb impairment.⁸ Participants used either an IJ or MSJ to negotiate a simulated wheelchair icon through 2D mazes with a variety of 90-degree turns on a computer screen. Outcome variables included Reaction time, Trial time: time in seconds from beginning to end of a trial, Total distance traveled and Frequency of boundary collisions.

Subjects with MS or ULS were acquired from three studies. Subjects ranged in age from 18–80. The first study included subjects with ULS or rigidity.¹⁰ Participants traced three different shapes on a computer screen using a conventional MSJ and a tuned IJ in a randomized design. Outcome variables included Trial time, Offset: the average deviation of sample points from the center of the path in pixels, Error: the average deviation of the absolute value distance of the sample points from the center of the path in pixels and Variability: the standard deviation in distances of the sample points from the mean distance of sample points. In the second study subjects with pathological tremor performed driving

tasks using a simulated wheelchair icon that negotiated right and left hand turns.¹¹ The task was randomized for the use of a conventional MSJ or tuned IJ during each trial. Outcome variables included Trial time, Frequency of boundary collisions and Error. The third study included individuals with a diagnosis of MS. Subjects performed both computer simulated and real time indoor driving tasks using a tuned IJ or a VCJ.⁴ Tasks included left and right turns, straight forward driving and Docking: a sharp right turn immediately followed by a sharp left turn. Randomization according to joystick type and the use of an algorithm to correct for fatigue was used. Outcome variables included Trial time, Error and Frequency of boundary collisions.

Statistical analyses were performed using SPSS 17.0. Significance levels were set at 0.05 a priori. The presence of spasticity in the arm used for joystick manipulation was a common feature across all groups except the control group so subjects were placed into groups based on their primary diagnosis for analysis. Groups were compared with respect to age and Barthel Index score using ANOVA and gender, race, mobility device status, and tremor using Chi-Square analysis or exact statistics. Tremor data was not collected for the SCP group. Using ANCOVA significant variables were then evaluated for their effect on the outcome of each tuning parameter variable. Those with a significant effect were then used as fixed factors or covariates in the subsequent analysis using the tuning parameter variables. Groups were compared with respect to x-axis dead zone, y-axis dead zone, and -x-axis gain using Univariate Analysis and absolute bias axis angle, +x-axis gain, -y-axis gain, and +y-axis gain using ANOVA. Logarithmic transformation was used to normalize dead zone and gain, and inverse transformation was used to normalize absolute bias axis angle. Where significant interactions were found Bonferroni's correction and Tukey's-b test were used for post hoc analysis.

RESULTS

Seventy-five individuals (mean age=43.6+/-14.7 years, mean Barthel index score=58.3+/-33.3, 41.3% females) were included in this study. Sixty-four (85.3%) were Caucasian, eight (10.7%) African American, one (1.3%) Asian American and one (1.3%) Hispanic. Seventeen subjects (22.7%) were veterans. The most common mobility aid used in all groups except the control was a power wheelchair (57.3%). Eight subjects (10.7%) had a history of tremor

Table 1 shows statistics for demographic variables in each group. Diagnostic groups included ACP (n=10), SCP (n=30), MS (n=12), ULS (n=8), and Control (n=15). Age (p=0.004) and Barthel Index score (p<0.0001) were found to be significantly different among the diagnostic groups and were used as covariates in the univariate and ANOVA analyses. Other demographic variables found to differ significantly included mobility device used (p<0.0001), and presence of tremor (p=0.002). After ANCOVA analyses mobility device used and presence of tremor were not found to account for significant variation with respect to each tuning parameter variable. As a result both demographic variables were excluded as covariates in subsequent analyses.

Table 2 shows statistics for tuning parameter variables across groups. Out of the tuning parameter variables, gain in each directional axis (-x-axis (leftward) gain: p=0.018, +x-axis (rightward) gain: p=0.003, -y-axis (reverse) gain: p=0.007, +y-axis (forward) gain: p=0.014) was found to be significantly different among groups. After post hoc analysis, -x-axis gain was found to be significantly lower in the Control group when compared to SCP, MS and ULS groups. With respect to all other directional axes for gain, control subjects had a significantly lower gain compared to individuals in the SCP group.

DISCUSSION

One explanation for why many of the parameters did not stratify across diagnostic groups as expected is that these parameters are best customized at the personal level. Indeed, Riley and Rosen⁶, in their study on customization of joysticks for 6 individuals with tremor, found few consistencies in the various combinations of settings used. However, until now, little work has been done in this area since that study was published in 1987. More work is needed to develop a comprehensive, algorithmic approach to tuning a control interface for each individual. However, this study begins the process by suggesting that we target gain first for those with upper limb impairments, especially when conditions like spasticity are present.

Gain appeared to be an important parameter in joystick customization when those with impairments were compared to control subjects. However, gain did not stratify as expected within those with impairments. This finding demonstrates the need for customization of force parameters to compensate for those with many types of motor impairment. Our results also suggest that adjustment of gain may be specific for motor impairment due to spasticity which was commonly found across groups. Another important finding was the beneficial effect of customizing gain in the x-axis, or left/right direction, rather than the forward/reverse direction for those with disabilities. This suggests that motor impairments may have an effect on the use of control interfaces, depending on direction of applied force. These findings may be clinically useful once advanced customization of devices becomes more widely available.

Prioritizing customization of parameters like gain may help clinicians focus on interventions that will improve interface control. Improvements in interface control may then lead to the development of commercially available tuning software packages for those with conditions such as spasticity. Default tuning software packages could improve access to mobility devices and computers. This should have a lasting effect on mobility and quality of life for many individuals with disabilities.

One limitation of this study was that only the IJ was used. More work is needed to evaluate advanced programming techniques that can be applied to other types of control interfaces. Future studies should also examine the effect of customization on performance. We currently have a study in progress that will compare performance on a simulated driving task utilizing either a customized IJ or a standard MSJ. Performance data may aid in the further development of the IJ and availability of the device in a commercial setting.

CONCLUSION

In summary, gain was found to differ significantly between control and disability groups in customization of the IJ. Individuals with no upper limb impairment required less gain in the -x (leftward) axis compared to the SCP, ULS, and MS groups and less gain in all other axes compared to the SCP group. Highlighting gain as a priority in joystick customization may help improve interface control. Future work should study the effect of parameter customization on performance to help continue the development of the IJ.

Acknowledgments

Funding for work in this manuscript was provided by the Rehabilitation Medicine Scientist Training Program NIH: K12 HD001097-09, the VA Center of Excellence for Wheelchairs and Associated Rehabilitation Engineering (B3142C), VA Merit Review (B3287R) and the University of Pittsburgh School of Medicine Dean's Summer Research Stipend. The data was collected at the Human Engineering Research Laboratories which is a joint venture between the VA Pittsburgh Healthcare System and the University of Pittsburgh. The contents of this paper do not represent the views of the Department of Veterans Affairs or the United States Government.

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Figure 1.
The Human Engineering Research Laboratories Isometric Joystick.

Figure 2.

Shown is a dead zone adjustment representative of what the investigator or clinician would see during joystick customization. Data points represent small amplitude tremor generated by the study participant. The dead zone adjustment allows the controller to ignore any movement that falls within its boundaries.

Figure 3. Depicted is the bias axis angle correction. Study participants were asked to push an isometric joystick in the four cardinal directions and their output was displayed as shown above. Due to the software's angle bias adjustment the user's directional force axes, which are slightly biased clockwise, will be interpreted as normal.

Figure 4. Template selection. In our study all templates were elliptical as shown above. Elliptical templates limit output along the x-axes (left and right directions) while allowing gain optimization along the y-axes (forward and reverse directions). Gain optimization adjusts the amount of force required to produce a certain output.

Table 1

Comparison of Diagnostic Groups With Respect To Demographic Variables

	Athetoid CP	Spastic CP	MS	Upper Limb Spasticity	Control	P-value (Statistical Test)
N	10	30	12	8	15	
Demographic Information						
No. Female (%)	2 (20)	16 (53.3)	5 (41.7)	1 (12.5)	7 (46.7)	0.131 (Chi-Square)
Mean Age	45+/-9.8	40+/-15.3	56+/-8.3	51+/-9.4	37+/-16.2	0.004 (ANOVA)
Mean Barthel Index Score	23+/-16.8	45+/-25.4	81+/-11.8	43+/-29.3	100+/-0.0	<0.0001 (ANOVA)

Table 2

Comparison of Diagnostic Groups With Respect To Gain

	Athetoid CP	Spastic CP	MS	Upper Limb Spasticity	Control	P-value (ANOVA)
Mean -x-axis gain	2.2+/-1.0	2.6+/-1.3	2.6+/-1.5	2.4+/-0.6	1.5+/-0.5	0.018
Mean x-axis gain	2.2+/-1.0	2.6+/-1.3	2.3+/-1.7	2.4+/-0.6	1.5+/-0.5	0.003
Mean -y-axis gain	1.7+/-0.5	2.5+/-1.5	1.9+/-1.1	2.3+/-0.5	1.5+/-0.5	0.007
Mean y-axis gain	1.7+/-0.5	2.5+/-1.5	2.1+/-1.5	2.3+/-0.5	1.5+/-0.5	0.014