USABILITY OF MOVEMENT-TO-MUSIC TECHNOLOGY FOR CHILDREN WITH PHYSICAL DISABILITIES

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ABSTRACT

We present results of a usability evaluation of an optical, non-contact interface to electronic music for children with physical disabilities. Usability data were collected via questionnaire and retrospective video review. Empirical usability data were organized within the International Organization for Standardization (ISO) usability framework and were analyzed with data aggregation and inferential statistics. The technology was found to be significantly more usable among children with disabilities than among their able-bodied peers ($p<0.05$).

INTRODUCTION

Many children with severe physical disabilities are not able to effectively cause changes in their environments. This inability to exert control over the environment leads to grave developmental consequences including, increased dependence (Glickman,1995), limited intrinsic motivation and withdrawal (Missiuna,1991) and augmented risk of developing learned helplessness (VanTatenhove, 1987).

Efforts to augment environmental control among children with severe physical disabilities have led to the creation of numerous contact devices and accompanying software. Examples include Kaoss Pad (*www.korg.co.uk*), a sound effects controller with a touch-sensitive pad, Quintet *(www.quintet.ie*) and MIDImate, switch-based devices facilitating music access, and Super Switch Ensemble (*www.switchintime.com*), software that accepts both switches and adapted keyboards for improvisational music playing. Contact devices offer haptic feedback but are limited by the number of control sites that a child can motorically and cognitively master.

Non-contact alternatives have proven successful in rehabilitation settings. The SoundBeam *(www.soundbeam.co.uk)*, an instrument which produces music when ultrasonic beams are interrupted, has been used in the treatment of children with severe physical disabilities (Swingler, 1998) and children with multiple learning disabilities (Ellis, 1996). MIDIcreator *(www.midicreator.com)* allows music to be created by detecting movement through ultrasound or electric field sensing and is integral to the Drake Music Project for individuals with disabilities (Drake and Grant, 1987). An optical detection system, the Very Nervous System *(http://www.interlog.com/~drokeby*) has also been implemented for adults with severe physical limitations. While removing the demand for reliable physical control sites, existing non-contact devices are prohibitively expensive, not adaptive to individual abilities, have significant hardware requirements and often, demand time-consuming set-up.

In light of the above, we have developed an economical computer-based system specifically for children with physical disabilities, with the goal of enhancing interaction with the environment. Mindful of children's primary occupation of play and the excessive muscle tone and limited range of movement, characteristic of disabilities such as spastic cerebral palsy, we elected to focus on the creation of music through a non-contact, optical interface. Cognizant of the high rate of abandonment of assistive devices when consumers are excluded from the early stages of design (Riemer-Reiss, 2000), we proceeded with formal usability evaluation with the target users, i.e., children with physical disabilities.

SYSTEM

The movement-to-music system can be considered an alternate access pathway or interface to music. By simply moving within the camera's field of view, the child can produce musical sounds. The system consists of a multimedia capable PC computer (Pentium III 900MHz), a universal serial bus (USB) charge-coupled device (CCD) camera and a custom software program developed in Visual C++. Through the camera, the computer captures images of the child's movements. These images are analyzed by the software (motion detection and tracking), which in turn, sends the appropriate General MIDI (standard format for electronic music) messages in real-time to the computer's sound system, producing audible music. The video image of the child is continuously displayed on a large television screen. The system is portrayed in Figure 1.

Three different movement to music translation schemes were implemented. The simplest was a direct cause and effect scheme where every detected movement initiated music. A pre-sequenced MIDI tune could be played out in this manner. In a second translation method, the left and right-most points of movement with respect to the midline were tracked. The 2-dimensional coordinates

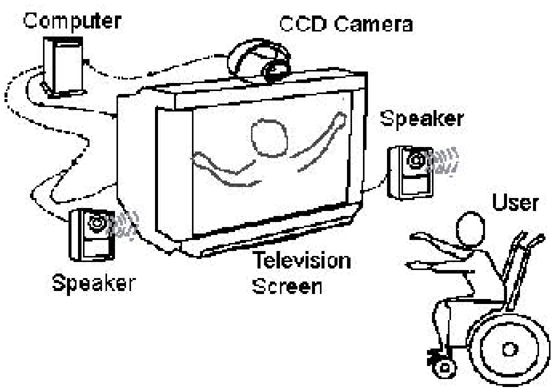

Figure 1. The movement-to-music system

were translated into MIDI messages which, in turn, triggered music algorithms within an object-oriented MIDI sequencer. This had the effect of “composing” harmonious musical events in real-time when movements extended beyond thresholds on either side of the midline. The third translation scheme involved the detection of movement in designated regions around the child. Each region was assigned specific musical properties such as timbre, volume and pitch and response properties such as dwell-times for activation and deactivation. In this latter scheme, the targeted regions were also displayed visually as coloured shapes or bitmaps of instruments, superimposed upon the video image of the child. This paper describes results from the evaluation of the first two translation schemes.

SAMPLE AND USABILITY TEST

Seven able-bodied children (age 5.3±0.8) and five children with spastic cerebral palsy (age 6.3±0.94) participated in the usability evaluations, which were carried out in accordance with the ethical guidelines laid out by the authors’ institutions. Usability evaluations were conducted over two to four sessions, each approximately 20-30 minutes in duration. Within a given usability test, the child was accompanied by an occupational therapist and a music therapist or a music technology rehabilitation specialist. Initially, the child was prompted to perform simple tasks intended to illustrate the concept of cause and effect, including imitation of the therapist. Subsequently, both structured and free play tasks with the movement-to-music system were performed. A cued instrumental task, which required the child to produce a specific sound according to the lyrics of a song, was also included in the evaluation.

DATA COLLECTION

Empirical usability data were collected via a custom post-evaluation questionnaire intended to tap into the child's subjective perceptions of efficiency and satisfaction with the system. Two occupational therapists external to the project participated in retrospective video review of all participants, filling out detailed usability checklists. This exercise involved the extraction of various times and measurements. Usability criteria from both the questionnaire and video review are summarized in Table 1. The numbers in parentheses indicate the admissible range of values for the particular measurement. For example, instruction time can be any positive real number ($\Re^+$) in seconds while enjoyment is a real number between 1 and 10. The usability data were organized under the three dimensions of effectiveness, efficiency and satisfaction, as prescribed by ISO 9241-11, the international standard on usability.

ANALYTICAL METHOD

Data were analyzed according to a recently proposed analytical methodology for ISO-compatible empirical usability data (Chau et al., 2002). The key steps include: data transformation and data summarization along each usability dimension, computation of a usability index

Table 1. Usability criteria

Effectiveness	**Efficiency**	**Satisfaction**
Direction of movement (0,1,2,3,4)	Instruction time ($\Re^+$)	Average time per instrument combination ($\Re^+$)
Left elbow range-of-motion (0-150°)	Understanding time ($\Re^+$)	Attention level (1-10)
Right elbow range-of-motion (0-150°)	Fatigue during session (0,1)	Enjoyment level (1-10)
Shoulder range-of-motion (0-180°)	Overall fatigue (1-10)	Song enjoyment (1-10)
No. of times system not respond ({0,1,2,…})	Amount of prompting (1-10)	Willingness to return (1-10)
No. of different instrument combinations ({1,2,…})	Fatigue after session (1-10)	Response to system (1-10)
		Session time ($\Re^+$)

distribution and statistical comparisons against expected usability via inferential statistics. In this particular example, due to non-gaussian distribution of the usability scores along individual dimensions, a nonparametric ranksum test was invoked.

RESULTS AND DISCUSSION

The main results of the usability evaluation are summarized in Table 2. All scores can range from 0, meaning not usable, to 1, implying highest usability. Surprisingly, overall usability was significantly higher for children with cerebral palsy ($p<0.05$). Upon examination of individual dimensional scores, we see that effectiveness scores are significantly lower in the able-bodied population. This is in part due to the fact that the able-bodied children consistently moved outside of the camera's range of view, such that the system could not respond to movement. Furthermore, the completeness of exploration as indicated by various criteria within the effectiveness dimension was greater in children with cerebral palsy. We hypothesize that this may be due to the novelty of being able to effect, voluntary control over the physical environment.

No statistical differences were detected in the efficiency dimension. This suggests that the movement-to-music system is equally learnable by both groups of children and the effort to interact with the environment is approximately equivalent. Satisfaction scores also did not exhibit statistical differences, but we caution that variability in this dimension was relatively high in both groups. In the cerebral palsy group, only 1 child scored more than one standard deviation below the mean. Omitting this child from the comparison, the satisfaction dimension becomes significantly different between able-bodied and cerebral palsy groups ($p<0.05$) with a mean score of 0.77 ± 0.04. This agrees more closely with our qualitative observations where general interest and participation among the cerebral palsy group seemed higher.

Table 2. Usability scores

	Able-bodied	Cerebral Palsy
Effectiveness	0.58±0.03	0.76±0.03*
Efficiency	0.74±0.13	0.74±0.04
Satisfaction	0.62±0.07	0.73±0.10
Overall usability	0.65±0.06	0.80±0.02*

* Statistically significant ($p<0.05$)

CONCLUSION

Through a systematic usability evaluation, we have found that a non-contact, optical interface can be usable by young children with cerebral palsy for increasing interactions with their environments. Data collection and analysis were conducted under an ISO-compliant framework. The conclusions of the study are limited by the relatively small study sample. Generalization to other children populations with different disabilities would require additional, independent usability evaluations.

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