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An evaluation of the Wii Nunchuk as an alternative assistive device for people with intellectual and physical disabilities using switch controlled software

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ABSTRACT

Many people with intellectual disabilities also have physical difficulties which prevent them from using standard computer control devices. Custom made alternative devices for those with special needs can be expensive and the low unit turnover makes the prospect unattractive to potential manufacturers. One solution is to explore the potential of devices used in contemporary gaming technology, such as the Nintendo Wii. The Wii Nunchuk has the potential to replace joystick functions with the advantages of not being surface bound and easier for some individuals to grasp. This study evaluated the feasibility of using the Nunchuk by comparing its performance as a switch with the participant's usual switch. Twenty three volunteers aged between 17 and 21 with intellectual and physical disabilities completed a Single Switch Performance Test using the new device and their familiar device. For most functions of the switch, there was no significant difference between the participants' performance using the Nunchuck and their familiar device. Additional analysis found that some participants' performance did improve whilst using the Nunchuck, but this was not significantly related to physical or cognitive ability. Those whose performance was better with the Nunchuk were more likely to hold it in the conventional way than were those who had better performance with their familiar device. This merits it being offered as a possible alternative to currently available switches for those with physical difficulties affecting their grip.

1. Introduction

There is a growing body of work to indicate the value of computer based activities for people with intellectual disabilities. The role of non immersive virtual environments (VE) and multimedia has been described by Standen and Brown (2005, 2006). Virtual environments have been shown to be effective in facilitating the acquisition of living skills for example shopping (Standen, Cromby, & Brown, 1998) and navigating new environments and preparing, in children with severe intellectual disabilities for the potentially distressing experience of giving evidence in court (Laczny, Brown, Francik, & Cooke, 2001). In virtual environments, their three-dimensional nature allows the creation of ecologically valid settings to promote activities like choice making (Standen & Ip, 2002) which people with intellectual disabilities have limited opportunity to practice. Finally, these computer packages can provide an engaging activity for people who are frequently under occupied and denied real world opportunities (Standen, Lannen, & Brown, 2002).

The educational role of computer based activities has been enhanced with the recognition of the value of learning through playing computer or video games (Futurelab, 2009). Computer games have begun to acquire a positive reputation and the term "serious games" has emerged (see Griffiths, 2004; Underwood, 2008). Green and Bavelier (2003) found that playing action video games can give a person the ability to monitor more objects in their visual field and do so faster than a person who does not play such games. In their most recent study, Green and Bavelier (2007) found a causative relationship between action video game playing and increased spatial resolution of visual processing. Similarly, Standen, Karsandas, Anderton, Battersby, and Brown (2009) found performance benefits for

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people with intellectual disabilities. Standen, Rees, and Brown (2009) investigated whether computer games may give people with intellectual disabilities the opportunity to practice the underlying components of decision making, a skill in which they can experience difficulties. After repeated sessions playing a Tetris like game, the intervention group showed a significant improvement in two paper based tests of decision making. The improvement observed in the control group failed to reach significance.

However there is a danger that the potential of serious games will not be exploited because people with intellectual disabilities have problems using the standard computer control devices. This is particularly so for the navigation of three dimensional software (Standen, Brown, Anderton, & Battersby, 2006). There are a variety of interfaces commercially available for navigating three dimensional non immersive environments but these have been described as "mostly adequate…rather obstrusive and require some amount of training to use" (Bing Kang, 1998). The problems for people with intellectual disabilities in using these devices have been reported by Standen et al. (2006). The two main reasons for this are the level of cognitive ability of the users and the motor difficulties they experience.

The difficulties caused by level of cognitive ability were highlighted in a study (Standen, Brown, Proctor, & Horan, 2002) that tried to identify what strategies tutors employ in teaching people with intellectual disabilities to use virtual environments designed to teach independence skills. Much of the time spent by the tutor in the learner's early sessions was on providing assistance with the input devices. Users experienced problems in remembering what tasks were accomplished by each device and in moving from one device to the other as many used the same (dominant) hand for both devices.

Many people with intellectual disabilities have fine motor difficulties as they suffer from conditions where damage has been caused to the central nervous system, such as cerebral palsy, multiple sclerosis, muscular dystrophy and dyspraxia. They therefore find the devices difficult to control and those that suffer from tremor have difficulty in making accurate movements with the device. The study by Standen et al. (2006) also found difficulties with devices that were surface dependent i.e. those that had to be positioned on a surface in order to be used as are most computer mice. This was especially so for the joystick to which users frequently applied too much force so that the base moved away from them. Surface dependent devices also present challenges for those who use a wheelchair and have difficulties positioning their chair close enough to a table or desk so that they can operate the control device. The results from Standen et al. (2006) confirmed those reported in earlier studies (Brown, Kerr, & Crosier, 1997; Trewin & Pain, 1999) and they cautioned that with problems like these, users can become frustrated and demotivated and fail to benefit from the advantages of using VE.

One solution to the problem of interfaces is to develop "natural interfaces that are intuitively simple and unobstrusive to the user" (Bing Kang, 1998). These are interfaces that have the capability to capture human gestures or biodata and translate it into code to replace standard interfaces. Bing Kang (1998) described an approach that used the orientation of the user's face to move and orient the VE. Coyle, Farrell, White, and Stewart (1998) have developed a non contact head controlled mouse emulator for use by quadriplegic operators to control VE; whilst Bates and Istance (2004) are developing a reliable system for eye based VE interaction. More recently, Hochberg et al. (2006) implanted a 96 microelectrode array in the primary motor cortex which allowed a patient with tetraplegia to control the position of the cursor on a computer screen. These systems are best suited to replace a single function of the mouse either the right or left click or the control of the arrow, thus limiting their usefulness in interactive educational VE. Additionally they are often difficult to calibrate and can be tiring for disabled users. Their utility will ultimately depend on how affordable they will be to a target population who also experience multiple disadvantages due to the added impact of low resources and income.

Another solution is to modify the software for example to abandon the three dimensionality of the software thus simplifying the task for the user so that they can control it with a simple switch. The advantages of this approach are that even the most disabled users can utilise switch technology (eg Lancioni O'Reilly, Singh, Sigafoos, Oliva, & Severini, 2008) and switches can be made to respond to a wide range of physical data. Specialised assistive switches can be tailored to a range of disabling conditions. So for someone whose easiest movement is a sideways swing of the upper arm but has no fine motor ability, a switch could be activated by swiping a protruding stick or wand. For someone with tetraplegia a switch can be positioned in their head support that responds to pressure from their head.

While there are a wide variety of switches available for those with use of their upper limb, most of them must be placed on a surface in order to work. Bearing in mind the problems identified by Standen et al. (2006), in an earlier study (Brown, Battersby, Standen, & Anderton, 2005) we utilised a user sensitive inclusive design methodology to design a wireless switch for use with a virtual learning environment (VLE) that did not require three-dimensional navigation or to be placed on a surface but could be grasped by the user and squeezed to close the switch. The switch based device was required to provide control (scanning and selection) of the online VLE and embedded learning materials by a group of 30 students with a wide and heterogeneous range of physical and cognitive abilities. Using a repeated measures design, the switch was compared with three switches currently in use at the college. Unfortunately the wireless switch was less effective than the three other switches in terms of help needed to use it, performance and user ratings. The conclusion was that further cycles in the design process are needed after the quantitative evaluation.

Custom made alternative devices for those with special needs can be expensive and the low unit turnover makes the prospect unattractive to potential manufacturers. An alternative low cost solution is to exploit and modify contemporary gaming technologies for use as control devices. Recently, Battersby (2008) demonstrated the possibility of using the Nintendo Wii Remote (Wiimote) as a platform for the development of assistive technology by interfacing it to a contemporary personal computer (Battersby, 2008). It has been used successfully as a virtual cane for the blind (Evett, Brown, Battersby, Ridley, & Smith, 2008) and offers potential advantages to users with limited budgets because it is "mainstream, easily available and relatively cheap" (Battersby, 2008). The Wiimote comes with a Nunchuk (see Fig. 1) which consists of a basic motion sensor (a 3 axes accelerometer) and an analogue control stick alongside a trigger button which acts as a switch. Thus it has the potential to be used as a surface free mouse and/or joystick. It is simple to move and easily operable by the thumb and forefinger and from the analysis of user requirements in the previous study (Brown et al., 2005) could be easier to use than a standard game controller. An additional advantage is that data from the contained accelerometers could be used to provide tremor compensation which would be a distinct advantage for such a user group, many of whom experience tremor as a result of cerebral palsy or other neurological problems acquired at birth.

As a first step in evaluating the utility of the Nunchuk for people with intellectual disabilities, the study set out to compare its performance when used as a switch with performance achieved with participants' currently used assistive switch device.

Fig. 1. The Wii Nunchuk.

2. Method

2.1. Design

A within subjects design compared performance data on computer-based tasks when using the Nunchuk and each participant's familiar device.

2.2. Participants

Twenty three volunteers aged between 17 and 21 with a mean age of 19.17 years, were recruited from students attending a specialist college for people with intellectual and physical disabilities. Potential participants were identified by a lecturer from the college who is on the research team and the Occupational Therapist at the college. Inclusion criteria were:

- ability to use a switch that could be interfaced with a computer
- adequate visual ability to see a computer screen
- sufficient hearing to hear audio feedback from the tests

The characteristics of the participants are shown in Table 1. Cognitive ability was assessed using the British Picture Vocabulary Test (BPVS; Dunn, Dunn, Whetton, & Burley, 1997). BPVS scores ranged from 14 to 135 (which equates to reading ages ranging from less than 2 years–16 years) with a mean of 74 (which equates to a reading age of 7 years and 3 months), SD = 32.32. Subtests of the Quick Neurological Screening Test (QNST; Mutti, Martin, Sterling, & Spalding, 1998) examined eye tracking and the physical ability of the upper limbs. Scores were recorded in three categories: a score of 7 or less was categorised as in the normal range ($n = 2$; 9.5%) a score of 8–25 was classed as a moderate discrepancy ($n = 8$; 38.1%) and over 26 was categorised as a severe discrepancy ($n = 11$; 52.4%). The researcher was unable to collect data from two participants on these measures either because the participant would not cooperate or the researcher could not successfully communicate with them.

2.3. Software

The software used was the Single Switch Performance Test (SSPT; Liffick,). This test was in use at the college to help staff select the most appropriate device for each student. It tests three different functions of a switch:

- The Activation Test required the participant to click the switch as soon as the screen changed colour.
- The Release Test required the participant to press and hold the switch down whilst the screen was one colour and release the switch as soon as possible when the screen changed to another colour. Maximum hold time for the Release Test was set at 3 and 5 s. Activation and Release Tests generated data on the mean, fastest and slowest response times in seconds.
- The Repetition Test required the participant to press the switch five times in succession as quickly as possible and generated data on time taken to test completion in seconds.

Lower scores indicate shorter reaction times i.e. faster switch press or release times.

Table 1
Participants listed in order in which they were recruited showing their age, sex, diagnoses, ability scores and familiar device.

Participant no.	Age	Sex	Disability	BPVS Raw score	QNST Raw score	Familiar device
001	21	F	Hypertonic quadriplegia	62	14	Mouse
002	20	F	Cerebral palsy	77	4	Mouse
003	18	M	Cerebral palsy	53	36	Mouse
004	19	M	Cerebral palsy	72	48	Rollerball
005	19	M	Cerebral palsy	135	13	Mouse
006	19	F	CP	–	–	Rollerball
007	20	F	Spina bifida	87	4	Mouse
008	19	F	Cerebral palsy	41	–	Mouse
009	20	M	Cerebral palsy	–	–	Rollerball
010	19	M	Ataxia myoclonus some hearing difficulties	48	20	Rollerball
011	18	F	Cerebral palsy	107	26	Mouse
012	19	F	Friedrich's ataxia	112	41	Mouse
013	20	F	Cerebral palsy	98	16	Mouse
014	19	F	Cerebral Palsy	94	30	Mouse
015	19	M	Cerebral Palsy	69	29	Rollerball
016	19	M	Cerebral Palsy	85	55	Rollerball
017	19	M	Muscular dystrophy	103	56	Keyboard
018	18	M	Cerebral Palsy	86	50	Wobblestick
019	20	M	Cerebral palsy	94	18	Rollerball
021	17	M	Cerebral palsy ataxia	22	18	Mouse
022	20	M	Cerebral palsy	17	62	Rollerball
023	21	F	Cerebral palsy hypertonia global developmental delay	14	13	Rollerball
024	21	M	Epilepsy communication impairment	81	11	Mouse

2.4. Control devices

Each participant used the Nunchuk with its joystick function removed and their usual (familiar) device. These were:

- Rollerball $n = 9$ (see Fig. 2). This is a mouse replacement which can move the cursor but also has a button in the left hand upper corner that acts as a switch.
- Mouse $n = 12$. A standard two button mouse was used at the college
- Big Keys keyboard $n = 1$ the switch function is provided by the spacebar
- Wobblestick $n = 1$ (see Fig. 3) this activates a switch through a swiping action or any body movement and then return to its original position when released.

2.5. Outcome measures

The primary outcome measure was the participants' performance on the SSPT. The researcher also noted the following additional outcomes: number of erroneous clicks or releases; problems participants had using the Nunchuk; how participants held the Nunchuk.

2.6. Procedure

Permission to carry out the study was obtained from the local Medical School Ethics Committee. Consent was gained from the carer or parent as nearly all participants had insufficient cognitive ability to read the volunteer information form. Their college lecturer was responsible for establishing whether, throughout their participation, the volunteer was happy to continue their involvement in the project. The researcher requested assent at each stage of the participant's involvement.

Fig. 2. Rollerball.

Fig. 3. Wobblestick.

Participants were ranked according to their ability scores and these ranks were used to group participants into matched pairs. One member of each pair was randomly assigned by coin toss to one of two groups with the remaining member assigned to the other. The two groups differed in the order that they used the two devices in the testing.

Each participant had two test sessions, each lasting between 15 and 25 min. Prior to testing, participants completed the SSPT once using the Nunchuk, to familiarize them with the SSPT and the new device, which may have looked and felt different to their familiar device. In the following two sessions, the participant used the Nunchuk in one session and their familiar device in the other.

The participants, if able, completed three trials of all three components of the SSPT, in order to generate a better sample of their performance. Some participants were not able to complete all three components. If more than ten sequential erroneous clicks occurred, the component was abandoned. During the sessions, the researcher sat alongside to help when needed. If the college timetable allowed, test sessions were scheduled to occur within the same week and conducted either in a quiet corner of the participant's classroom or in a lecturer's office. A photograph was taken to demonstrate how each participant held the Nunchuk.

2.7. Analysis

Participant demographic details, ability test scores and SSPT results (in seconds) were analyzed using SPSS 15. BPVS and QNST raw scores were normally distributed and analyzed using parametric tests.

Each participant's reaction times from their three trials of each component of the SSPT were averaged. Most SSPT results were not normally distributed and thus analyzed using non-parametric analyses. The Mann Whitney U test was used to compare male and female reaction times. The Wilcoxon Test was used to determine whether there were any significant differences between the median reaction times generated using each device in each component of the SSPT. A sign test was used to compare the number of erroneous clicks or releases made by participants using each device in the activation and release tests. The association between ability scores correlated with SSPT results was measured using Spearman's rho.

In a further analysis, unpaired t-tests compared the median ability scores for those with and without better performance using the Nunchuk and a Fisher test was used to compare types of grip used by those with and without better performance using the Nunchuk.

3. Results

Unpaired t-tests showed that there were no significant differences between the two groups in age and ability scores and a Fisher test showed that there were no significant differences between the two groups in level at the college or choice of familiar device. Although a Fisher test showed a significant difference between numbers of males and females in each group (Fisher Exact probability = 0.026) there were no significant differences between male and female reaction times so it is unlikely that the uneven gender distribution had any effect on results.

Table 2
Median reaction times in seconds for the activation test using the Nunchuk and the familiar device.

	Device					
	Nunchuk ($n = 23$)			familiar ($n = 23$)		
	Median	Lower quartile	Upper quartile	Median	Lower quartile	Upper quartile
Mean activation time	0.70	0.45	1.01	0.73	0.50	1.43
Fastest activation time	0.24	0.17	0.45	0.23	0.26	0.50
Slowest activation time	1.15	0.89	2.32	1.37	0.72	3.75

Table 3
Median reaction times in seconds for the release test using the Nunchuk and the familiar device. *significant difference where $z = 2.045$, $p < 0.05$.

		Device					
		Nunchuk $N = 23$			Familiar $N = 23$		
		Median	Lower quartile	Upper quartile	Median	Lower quartile	Upper quartile
3 s	Mean release time	0.74	0.47	1.33	0.56	0.45	0.95
	Fastest release time	0.28	0.21	0.40	0.34	0.23	0.39
	Slowest release time	1.26	0.76	2.57	0.89	0.73	2.16
5 s	Mean release time*	0.81	0.57	1.08	0.55	0.48	1.12
	Fastest release time	0.44	0.33	0.63	0.38	0.30	0.63
	Slowest release time	1.28	0.93	2.34	1.05	0.69	1.94

Table 4
Median time in seconds for repetition test completion using the Nunchuk and the familiar device.

	Device					
	Nunchuk ($n = 23$)			Familiar ($n = 23$)		
	Median	Lower quartile	Upper quartile	Median	Lower quartile	Upper quartile
Repetition time	3.35	1.73	5.15	2.93	1.57	6.31

3.1. Single switch performance test (SSPT) results

Results from the three component tests of the SSPT are shown in Table 2 to 4. Some participants could not successfully complete all components of the test, particularly the release test. This was either because they did not appear to understand the principle of the test or could not apply prolonged pressure the switch. There were no significant differences between participants' median reaction times using the Nunchuk and the familiar device for all switch functions. The only exception is mean release time (5 s) where participants' reaction times are significantly faster with the familiar device (See Table 3).

When the participants who did not complete three trials in the specified component were excluded ($N = 3$), there were no differences between the devices in the median number of erroneous clicks or releases sustained for both the release and the repetition tests. In the activation test, there were significantly (Sign test exact probability 0.012) more errors with their familiar device than with the Nunchuk and 80% of participants incurred no erroneous clicks in the activation test using the Nunchuk, compared to 47% using their familiar device. However, in both release tests, more participants incurred four or more erroneous releases using the Nunchuk than with the familiar device (see Table 5)

To increase reliability, both the researcher and a colleague assigned "type of grip" to each photograph and their observations were compared giving 100% agreement.

Some participants performed better using their familiar device than with the Nunchuk. However, others demonstrated faster reaction times with the Nunchuk than their familiar device. Group analysis hides the variation between individuals. As a result, the sample was split according to whether they had faster reaction times with the Nunchuk or with their familiar device in each component of the SSPT. This showed that in both the activation and the repetition subtest, 11 participants performed better with the Nunchuk and 12 participants performed better with their familiar device. There were no significant differences between these two groups in either BPVS scores or QNST scores. However, an examination of the way participants chose to hold the Nunchuk indicated that this was related to whether they obtained a better performance with it than with their familiar device. Photographs of the way participants held the Nunchuk were independently categorised by two raters into one of three categories: standard ($n = 11$; Fig. 4), backward/arched ($n = 5$; Fig. 5) or requiring assistance with use ($n = 7$; Fig. 6).

In the activation test and repetition test, 55% and 64% of participants who improved using the Nunchuk were using standard grip respectively, when proportions of participants using the standard grip were compared between the two groups, the difference between them was not significant.

Finally, problems experienced by participants during testing are displayed in Table 6. The most common problem was that some participants (30%) were unable to hold the Nunchuk unassisted. Eleven participants required assistance with their familiar device but this consisted of ensuring it remained in the best position for use.

4. Discussion

This study found no overall differences between participants' performance with the Nunchuk and their familiar device for the functions tested in the Single Switch Performance Test (SSPT). The only exception was in the release test with maximum hold of 5 s, where participants

Table 5
Percentage of participants with zero or four or more errors when using the Nunchuk and their familiar device.

	Device			
	Nunchuk		Familiar	
	No errors (%)	Four or more errors (%)	No errors (%)	Four or more errors (%)
Activation test	80	9	47	22
Release test (3 s)	20	40	25	50
Release test (5 s)	10	40	33	33

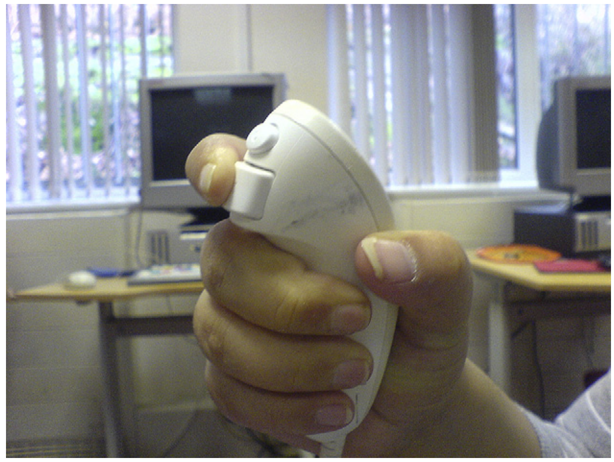

Fig. 4. Standard grip.

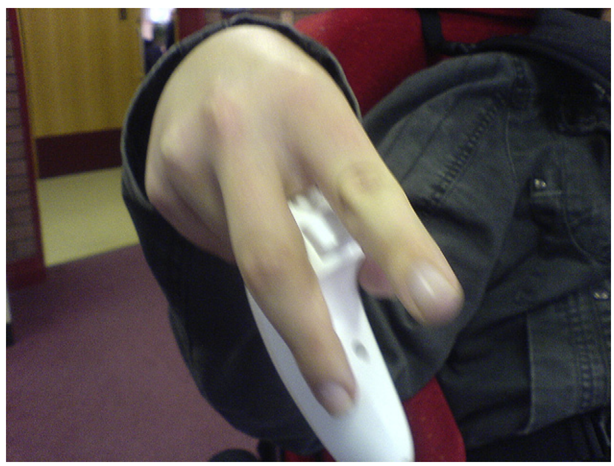

Fig. 5. Backward or arched grip.

performed significantly better with their familiar device than with the Nunchuk. So it could be concluded that the switch function of the Wii Nunchuk performs just as well as people's familiar devices. However, group analysis disguised the fact that almost half of the participants demonstrated better performance using the Nunchuk. Those that did were no different in chronological age, reading age or upper limb ability. However there is some suggestion that being able to hold the Nunchuk in the way it was designed is related to being able to achieve better performance with it. People with intellectual disabilities present with a range of motor disabilities (Wuang, Wang, Huang, & Su, 2008)

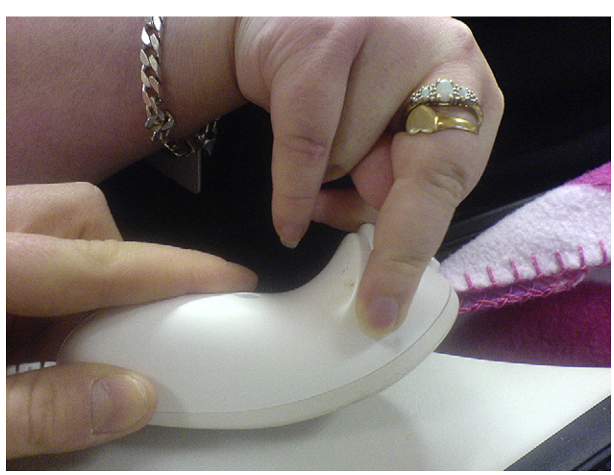

Fig. 6. Requiring assistance.

Table 6
Problems experienced by participants when operating the Nunchuk.

Problem using the Nunchuk	Frequency	(%)
Needed assistance to hold	7	(30)
Difficulty applying adequate pressure to switch	5	(22)
Pressing “C” button instead of “Z”	2	(9)
Fingers slipping off of button	3	(13)
Unable to apply prolonged pressure to the switch	6	(26)

and these findings merit offering the Nunchuk switch to users as an optional device but at present, there would be no method of identifying those who would benefit from its use and users would be required to try the SSPT first.

The aim of the study was to collect information to decide whether the Wii Nunchuk might be a useful control device for some students with intellectual and physical disabilities. This group is extremely heterogeneous in terms of their level of cognitive ability and the presence, type and severity of accompanying physical disability and representative of the population that are in need of more appropriate control devices. Some volunteers could have been omitted to reduce the variability of the sample but not only would this have reduced the generalisability of the sample, it may also have reduced our chances of identifying that some users achieved a better performance with the Nunchuk.

Testing took place in the participants' usual learning setting so performance in the study would be subject to the same environmental influences and distractions that prevail in the situation for which the device is intended. However, one considerable difference between the study and the everyday learning situation of the participants was the type of software on which the devices were being tested. While the Single Switch Performance Test is straightforward, has minimal learning effects, is easy to administer and involves the range of functions required of a switch, the software differs sufficiently from the educational software being produced for such a target group. Firstly, testing took only a short amount of time and students at the college typically were expected to have much longer sessions using the educational software available in the classroom. In contrast, unlike the SSPT, classroom educational software put little if no emphasis on making a response as fast as possible. Any further evaluation of the Nunchuk would have to involve performance on the software for which its use is intended.

The problems experienced by participants in using the Nunchuk suggest that it could still benefit from some modifications in its casing. For example 26% of participants were unable to apply prolonged pressure to the Nunchuk switch a problem that might be resolved with different positioning or sensitivity of the trigger switch. An increase in response time has been noted with wireless devices however the size of delay is small when compared to the reaction times of the users. In spite of any delay in response the Nunchuk allowed almost half of the participants in this study to gain faster reaction times than they did with their usual devices. Wireless devices are becoming more and more popular in assistive technology primarily because being surface free and lacking connecting cables makes them much easier to use especially for wheelchair users.

Despite the limitations discussed, this study was able to demonstrate the efficacy of the switch function of the Wii Nunchuk for some people with intellectual and upper limb motor disabilities. This suggests further investigations that use a larger sample and more appropriate software. Future studies could investigate whether the type of grip a user employs can predict whether or not a person will have better performance with the Nunchuk or even whether encouraging users to hold the Nunchuk a certain way improves its performance. Finally, evaluation of its navigation function should be conducted in order to evaluate its full potential as a control device for people with intellectual and physical disabilities.

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