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A case study of product usability of a pelvic device used by children with neuromotor impairments

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Abstract

On assistive technology targeted for people with activity limitations and participation, usability issues becomes an essential tool to ensure that the product has the appropriate ergonomics characteristics, in other words, ensure that it fits the specific user's needs. The aim of this study was to analyze the usability of an adaptive seating device for children with neuromotor impairments, by using kinematic indicators of the reaching movement. The study sample consisted of 13 children with associated neurologic conditions. The tests were developed by using a wooden bench height adjustable, integrated with the adaptive seating device under study, and a system to capture three-dimensional image, called Qualisys Track Manager. The following reaching kinematics variables were measured: maximum reaching velocity, movement duration, index of curvature, and unit movements. It was found that the use of the adaptive seating device had a positive impact on upper limb function in children with neuromotor impairments. It was also noticed an improvement in the reaching movement kinematics, which was statistical significant for the index of curvature and unit movements. As main conclusions, it is possible to point out some positive effects that the product under study seems to have on users' movements, such as the improved movement quality of the upper limb, which could mean a better postural adjustments and higher trunk postural control. By identifying new measures of usability in terms of effectiveness and efficiency for the analyzed device, the results obtained may serve also as performance indicators, providing new data that may help to improve the product and eventually modifying it, in order to turn it more compatible with the needs of the considered target population.

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1. Introduction

One aspect of a product evaluation can be the usability test, which is designed to evaluate the product under controlled conditions, simulating the interaction and the user experience quality [1,2]. The product usability assessment can be performed by measuring the user's performance through their level of effectiveness, efficiency and satisfaction [3]. However, before we select a usability test, we should always be aware of the specificity and the target product features, as well as the profile of the users who will use the product [4]. Assistive technologies are increasingly utilized to perform activities, improve functions and increase the biomechanical performance of the user [5]. They are designed to promote the users' independence, increase their self-esteem and skills in daily life activities, in order to improve interactions with the environment and integration into society [6,7]. Of the many assistive technology stands out adapted seats for sitting position, which can facilitate postural control, improve posture and the upper limb function, so as to allow children with postural instability to be engaged in activities at home, such as playing on the floor, eating on dining table with family members and perform personal hygiene activities. Studies have also reported increases in the amount and quality of the activities of these children, particularly by conducting more independently and safer activities, as well as the interaction between all members of the family [8,9,10,11,12,13]. The adaptive seating device tested for usability purposes in this study is called Hip Grip pelvic stabilizer, and it was developed by the company Bodypoint. This pelvic stabilization device can be adapted to the anthropometric characteristics of each user and it was designed to be applied in other support products, including a bench or a wheelchair (Figure 1), to help children and adults, with motor disabilities, maintain stability while allowing functional pelvic movements [14]. It has a joint and a spring, which gives the equipment a relationship between stability and mobility. Hip Grip gives tactile information of pelvic girdle limits and with its proper adjustment, it influences the anterior pelvic tilt, which thereby enables a higher lower trunk extension, enhancing sitting posture. According to some authors, there is a higher stabilization of the pelvis in a position with slight anterior tilt, which is a strategy that indicates increased trunk and lower limbs muscles activity [15,16,17,9,10]. This type of positioning places the center of gravity slightly in front of the ischial tuberosities, and the feet transmit more than 25% of the body weight to the floor [18].



Fig. 1. Hip Grip pelvic stabilizer applied in a bench and in a wheelchair (Bodypoint image).

Although Bodypoint indicate some beneficial effects of using Hip Grip, especially in terms of a greater capacity to reach, there is no known data regarding its influence on upper limb movement quality. Reaching is considered as an essential component for movement and to perform activities of daily routine [19]. Children with postural control problems, including cerebral palsy, have slower movement patterns, less efficient movement and less coordination when compared with typically developing children. They take more time to perform movement, have a longer reaction time, a longer and non linear path and larger number of unit movements, verifying that additional difficulties arise when developing more demanding tasks, particularly in reaching and grasping [20,21,22, 23]. It is considered to be an efficient movement that one which moves directly to the target without the occurrence of strange or unusual movements [19]. Kinematic analysis is a possible measure of upper limb performance used in studies with these children [20,22,23] and consists of describing the movement observed in function of time and space, providing information about the linear and angular displacements of the joints, velocities and accelerations of body segments.

The aim of this study was to analyze the usability of the Hip Grip pelvic stabilizer, which is commercially available for people with physical limitations, particularly children. By using a kinematic analysis, this work had the purpose to develop quantitative usability measures (maximum reaching velocity (MRV), movement duration (MD), index of curvature (IC), and unit movements (UM)) in order to evaluate the influence of this adaptive seating device

in the upper limb reaching movement.

2. Methods and materials

2.1. Participants

The study sample consisted of 13 children (5 female; 8 male), selected for convenience, aged 6 to 13 years old, with neuromotor impairments, resulting from a confirmed diagnosis of central nervous system damage. According to the Gross Motor Function Classification System (GMFCS) [24], 10 children could walk without assistive devices (level I and II, $n=7$ and $n=3$, respectively) and 3 walked with help of assistive mobility devices (level III). The inclusion criteria defined were: ability to sit independently on a bench, mobility in the upper limbs to do the reach movement and cognitive ability to understand and follow simple verbal commands [25,20,26,22,27]. Exclusion criteria included any musculoskeletal problems in the trunk and/or upper limbs, [28] and any orthopaedic surgery or botulinum toxin injection in the upper limbs or lower limbs during the preceding 6 months [23]. The research protocol was approved by the University of Minho and the High Institute for Allied Health Technologies of Porto with ethical considerations. Parents signed consent forms to participate and the children gave their oral permission.

2.2. Instruments

Data collection was performed in a laboratory context, at the Activity and Human Movement Study Center - High Institute for Allied Health Technologies of Porto. For kinematic data acquisition, four cameras Qualisys Motion Capture System (sampling frequency of 100 Hz) were used. Qualisys Track Manager (QTM) Software (Qualisys, Sweden) was used for data analysis. For each data collection it was also used a hydraulic plinth and a height adjustable wooden bench, where the hip-grip device was integrated.

2.3. Procedures

The evaluation was performed in a single moment. Anthropometric data were collected from all participants, including weight (kg), height (m), the upper limb length (reach forward) (cm), the thigh and leg length (cm) and the height elbow (cm) [22,21]. Each child was assessed in sitting without trunk support. Seat height was adjustable by measuring the distance between knee joint and the ground [29]. They were seated with $2/3$ of the thigh's length in contact with the seat, which was determined by the distance between the greater trochanter and knee joint. Feet were kept on the floor or in a stool and children's usual shoes were maintained during data collection, in order to recreate as much as possible the daily routine conditions. Plinth's height was adjusted to each child's elbows height [28]. All the participants wore the same black sweater and the remaining clothing and footwear used were also dark to improve the image capture procedures. Children had opportunity to do 2-3 practice trials before data collection was initiated [30]. They were instructed, after a verbal cue, to reach and grasp a 0.33 L plastic water bottle, bring it to the mouth, and return to starting position at a natural self-paced speed, recreating as much as possible the daily living activity of drinking (Figure 2). The water bottle was placed on the sagittal plane and there was no restriction in time and speed to reach the target [25,26]. The forward reaching movement was selected because it is a functional and significant task in the daily routine of children [31]. Subjects started the task with approximately 0° of flexion/extension/rotation at the shoulder, approximately 90° of flexion at the elbow with forearm in pronation and the palm of the hand resting on thigh [28]. For the upper limb that was not in test, children were instructed to keep the hand in contact with the hydraulic plinth.

The task was requested for two distances of the set target: one corresponded to the anatomical reaching distance of the upper limb (100%), using the measured distance from the midpoint of the shoulder and the head of the second metacarpal, with the elbow extended; and the other distance other corresponding to 120% of the first [22,23] as shown in Figure 2b. These distances were performed sequentially but randomly. All the verbal commands were given similarly and by the same researcher [31]. Both limbs were assessed, starting with the dominant hand, which was defined as the preferred hand to write or draw [20,26]. Three valid repetitions of the task were recorded,

separated by five seconds rest period[30]. For each limb's assessment, eight reflective markers were placed in the following landmarks: 1 at the sternum; 1 at the acromion; 2 at the elbow (medial and lateral epicondyle); 2 at the wrist (ulna and radio styloid process); 2 in hand (distal phalanx of the thumb and index finger) [29]. The 9th marker was placed into the cork of the bottle (Figure 1). The markers were captured by the cameras, allowed the movement trajectory evaluation. All the procedures were performed with and without the hip-grip device in a randomly order to avoid the influence of learning by repetition [32].

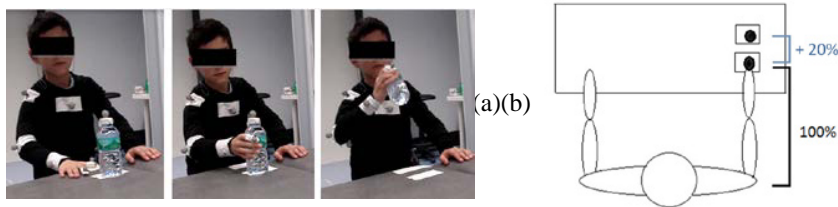


Fig. 2.(a) Forward reaching task; (b) Forward functional reach at 100% and 120%.

2.4. Data analysis

At the end of all collections there were 12 trials for each upper-limb, 24 for each child. Although the task consisted of reaching, grasping and bringing to the mouth the bottle of water, only the reach-to-grasp phase of the 120% distance was analyzed. Kinematic data from 312 trials was digitally low-pass filtered using a second order Butterworth filter with a cut-off frequency of 7 Hz, and analyzed in terms: maximum reaching velocity (MRV), movement duration (MD), index of curvature (IC), and unit movements (UM).

Some trials were excluded for presenting poor quality, particularly those which exhibited many failure/capture errors, and/or atypical motion path. Movement onset was defined as the time at which index finger tangential velocity exceed 5% of its maximal value, while movement offset was defined as the time correspondent to the frame which presented the lowest velocity in the contact time with the bottle[20,28,33]. The IC was obtained from the ratio between index finger's real distance (real length of the reaching path) and the optimum distance (the length of the straight line between starting position and the target). If the result is 1, it represents an ideal straight path, whereas $IC > 1$ represents an abnormal or atypical curved path [19]. UM represents acceleration and deceleration cycles in the velocity profile of the index finger market [20,19]. It reflects the number of times that child corrects hand movements. UM were obtained by direct observation of the velocity graph. It was considering a UM when the acceleration and the deceleration was greater than 20%. The smaller number of UM will guarantee a more harmonious forward reaching movement[22,23]. After these procedures, an average was estimated of the 4 variables extracted, with and without Hip Grip for both upper-limbs.

2.5. Statistics

Descriptive statistics were used to calculate the average, standard deviation and the minimum and maximum values of the 4 variables under study. The program used for statistical treatment was the Statistical Package for Social Sciences (SPSS). To compare the results with and without the Hip Grip it was applied the non-parametric test for independent samples and paired Wilcoxon signed-rank, with a 0.05 significance level. The independent variable was the integration of Hip Grip in the bench and the dependent variables were the measured parameters: MRV, MD, IC and UM.

3. Results and Discussion

The statistical test Wilcoxon signed-rank was applied to the average differences, with Hip Grip – without Hip Grip. It is expected that for the variables MD, IC and UM the results be negative, thus revealing a more efficient gesture. In other words, a gesture is more efficient if it is done in a quicker way, with a smaller IC and UM. To the MRV the reasoning is reversed, since it is expected that the use of Hip Grip increase the MRV and in this case,

positive values mean an improvement. However, it should be noted that positive values at MRV only have this meaning if the previous variables decrease. The 4 variables were studied in 3 different situations: the two upper limbs together (N=26; 13 cases); dominant and contralateral upper limb individually (N = 13; 13 cases); GMFCS severity level (level I, II and III). Due to limitations purposes, only results with statistical significance will be presented and discussed in this section.

Variables studied for the upper limbs together

Table 1 presents the mean values, standard deviation, maximum and minimum of four variables under study for a sample size N = 26 (13 cases). Table 2 presents the results of the statistical test.

Table 1 –Descriptive statistics for the analyzed variables, with (W) and without (WO) Hip Grip.

	MRV		MD		IC		UM	
	W	WO	W	WO	W	WO	W	WO
Average	651,26	641,93	1,17	1,16	1,88	1,77	4,12	3,67
SD	172,13	153,34	0,37	0,41	0,40	0,55	1,73	1,71
Max.	981,07	900,23	1,90	2,02	2,87	3,39	7,67	8,00
Min.	348,45	269,11	0,56	0,47	1,32	1,25	2,00	1,50

Table 2 - Wilcoxon test results for the 4 variables.

	MRV With – MRV Without	MD With – MD Without	IC With – IC Without	UM With – UM Without
Z	-0,292	-0,165	-1,994	-2,133
Asymp. Sig. (2-tailed)	0,770	0,869	0,046	0,033

The analysis of the values obtained shows that the use of Hip Grip revealed a statistically significant change in the IC parameter ($Z = -1.994$, $p = 0.046$). Once the average with and without Hip Grip is respectively 1.77 and 1.88, and the difference between these values is significant, it is suggested that the use of the device contribute to a better quality of the motion trajectory. The use of pelvic device also showed a statistically significant change in the parameter UM ($Z = -2.133$, $p = 0.033$). In fact, the average of this indicator was 3.67 with Hip Grip and 4.12 without Hip Grip, which can also demonstrate that the use of the device resulted in a more harmonious movement.

Regarding the decrease of the MRV, when analyzed in isolation situation, it is possible to observe a decrease in the movement efficiency. However, in an analysis with other variables it seems to point to an increase in efficiency. In fact, the decrease in speed, combined with less IC an MU, may be associated with a better movement control, since children with neuromotor problems often do faster gestures as a compensatory strategy in response to the difficulties in modulating the activity of specific postural tasks, such as reaching movement [34].

Variables studied for the dominant and contralateral upper limb individually

Table 3 presents the values of the four variables studied, considering only cases in which the movement has been performed with the dominant upper limb (N = 13). Table 4 presents the results of the corresponding statistical test.

Table 3 –Descriptive statistics of the analyzed variables, with (W) and without (WO) Hip Grip for the dominant upper limb.

	MRV		MD		IC		UM	
	W	WO	W	WO	W	WO	W	WO
Average	649,12	612,39	1,15	1,05	1,81	1,65	3,97	3,35
SD	224,46	167,81	0,44	0,41	0,46	0,55	1,91	1,67
Max.	981,07	844,07	1,90	1,79	2,87	3,20	7,67	7,00
Min.	348,45	269,11	0,56	0,47	1,32	1,25	2,00	1,50

Table 4 - Wilcoxon test results for the 4 variables of the dominant upper limb.

	MRV With – MRV Without	MD With – MD Without	IC With – IC Without	UM With – UM Without
Z	-1,153	-1,713	-1,433	-2,518
Asymp. Sig. (2-tailed)	0,249	0,087	0,152	0,012

According to the obtained data, there are statistically significant differences only in the parameter UM ($Z = -2.518$ and $P = 0.012$). In fact the average value using the Hip Grip is 3.35 and without Hip Grip is 3.97. However,

the average values for IC and MD also decreased with the use of the Hip Grip, although with no statistical significance, which can be explained by the small size of the sample. MRV also decreased with the Hip Grip, keeping up the explanation that it is a motor control strategy for movement. In short, when considering the use of the pelvic device for the dominant upper limb, it is apparent that the movement is more harmonious, but only with a single statistical evidence variable.

Variables studied according to the GMFCS severity level

Table 5 presents the values of the four variables under study, for the seven children with GMFCS level I, representing N = 14. Table 6 presents the results of the statistical test.

Table 5 –Descriptive statistics of the analyzed variables with (W) and without (WO) Hip Grip for GMFCS level I.

	MRV		MD		IC		UM	
	W	WO	W	WO	W	WO	W	WO
Average	624,12	586,95	1,17	1,23	1,78	1,62	3,94	3,61
SD	180,60	160,04	0,35	0,38	0,34	0,32	1,53	1,72
Max.	981,07	869,95	1,78	2,02	2,42	2,41	7,00	8,00
Min.	366,47	269,11	0,70	0,66	1,32	1,30	2,00	2,00

Table 6 - Wilcoxon test results for the 4 variables of GMFCS level I.

	MRV With – MRV Without	MD With – MD Without	IC With – IC Without	UM With – UM Without
Z	-1,036	-0,847	-2,605	-1,258
Asymp. Sig. (2-tailed)	0,300	0,397	0,009	0,208

Considering the cases of GMFCS level I, only statistically significant differences were observed for the IC parameter ($Z = -2.605$, and $P = 0.009$), with an average of 1.62 with Hip Grip and 1.78 without Hip Grip. It is noted that values of UM variable also decreased with the use of Hip Grip, but were not statistically significant, and this result can be explained by the small sample size. Although the MD in this group was higher, the MRV remains low with the use of Hip Grip, which it continues to show the same motor strategy previously described. Therefore, the behavior trajectory in children with severity level I seems to lead to a higher quality of movement with use of Hip Grip, but only with evidence of a single variable.

Table 7 presents the values of the four variables under study, for the three cases with GMFCS level II, representing N = 6. Table 8 shows the results of the statistical test.

Table 7 – Descriptive statistics of the analyzed variables, with (W) and without (WO) Hip Grip for GMFCS level II.

	MRV		MD		IC		UM	
	W	WO	W	WO	W	WO	W	WO
Average	578,00	618,27	0,86	0,82	1,82	1,56	3,11	2,64
SD	142,15	61,37	0,25	0,27	0,27	0,35	0,81	1,41
Max.	738,47	694,44	1,18	1,18	2,14	2,25	4,00	5,33
Min.	348,45	535,18	0,56	0,47	1,45	1,25	2,33	1,50

Table 6 - Wilcoxon test results for the 4 variables of GMFCS level II.

	MRV With – MRV Without	MD With – MD Without	IC With – IC Without	UM With – UM Without
Z	-0,524	-0,943	-1,992	-1,156
Asymp. Sig. (2-tailed)	0,600	0,345	0,046	0,248

Considering the cases of GMFCS level II, statistically significant differences exist in the IC parameter ($Z = -1.992$, and $P = 0.046$), showing an average of 1.56 with Hip Grip and 1.82 without Hip Grip. However, by checking the average values of table 7, it is concluded that the remaining parameters are consistent with what was expected. With the use of Hip Grip the MD, IC and UM decreased and the MRV increased, which is concluded that there was a better performance and more efficient reaching movement, but only with statistical significance in the IC. The fact that these values were not statistically significant can be explained because it is a very small sample, only three children and six cases in total.

As a summary, the results obtained during this study show that the motion trajectories are non-linear, so that it can confirm that children with central nervous system injuries present inefficient movement patterns. By studying the variables MRV, MD, IC and UM, it was found that the use of Hip Grip pelvic stabilization have a positive impact on the upper limb function showing more efficient movement patterns, which could mean better postural adjustments and higher trunk postural control. It was also possible to highlight the importance of the anterior pelvic tilt, which indicates more trunk muscles activity and thereby enhance sitting posture, essential for tasks involving reaching movement. Based on 3D QTM registration system, it was found more appropriate kinematic reaching movement with statistical relevance in IC and the UM, when these variables are analyzed using a sample size $N = 26$. It was also found that, when analyzed individually dominant upper limb as well as children of GMFCS level I and II, the use of Hip Grip showed statistical evidence but only with the support of one variable. These results show the influence of environmental factors in the realization of global motor functions [35] and are consistent with other studies conducted with assistive technologies to the sitting position, which relate to assist trunk postural control, upper limb function and the development of activity of daily routine [8,9,10,12,13].

The usability analysis of this pelvic device focused on users and was tested in a laboratory environment, in order to be able to evaluate the equipment for a target population under controlled conditions, collecting information about the quality of users experience with Hip Grip, while they were observed carrying out a task which is regarded as one of the major functional activities of human - those involving reach movements [23]. The technique used to carry out this usability test had an objective character, since it was based on a quantitative analysis of 4 kinematic indicators, using a 3D image capture system that allowed the movement characterization, as well as to obtain some conclusions with statistical significance on upper limb trajectory quality.

Despite the importance of the data obtained, it is also important to acknowledge some limitations of this study. One important limitation of the usability evaluation was the component related to users' satisfaction, which was not possible to assess from the majority of children that were included in the sample. The main reason for this situation is explained by the insufficient contact with the equipment, as well as the impossibility to create other opportunities to enhance the children's familiarization with Hip Grip. This fact has limited the collection of children's sensations or experience with and without the Hip Grip. In addition, children's answers at this respect might be influenced by social desirability.

4. Conclusions

This work adds data on the development of a usability test for an assistive technology. It was possible to understand some effects that adaptive seating device can have on postural control, specifically in upper limb performance among children with neuromotor impairments, having identified new usability measures in terms of effectiveness and efficiency for the Hip Grip pelvic stabilizer. The results can serve as performance indicators of this population, making available to the developers of Hip Grip new information on its use, which could contribute to an improvement of the product and possibly modify it, in order to make it more compatible with the needs of the target population. It was also possible to verify the relevance of adapted seats to the sitting position, which seems to have a positive influence on trunk postural control and upper limb function, which is essential for the development of daily routine activities.

Further developments of this work may include the development of a longitudinal study. Since adaptive seating device influence the conditions that allow children to have better life quality experiences, the developed research should take into account the specific contexts of children's lives. In other words, it is proposed an initial assessment, followed by a period of time in contact with the device at home or at school and finally a second assessment. By developing such a study, it will be possible to assess the impact of adapted seats in the child functional capacities, complemented with data that can be also transmitted by their families.

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