INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
7 & 8 SEPTEMBER 2017, OSLO AND AKERSHUS UNIVERSITY COLLEGE OF APPLIED SCIENCES, NORWAY

HANDLE DIAMETER AND THE INFLUENCE ON THE ERGONOMICS OF CRUTCHES

Guilherme da Silva BERTOLACCINi[1], Melissa Marin VASQUEZ[1], Ana Carolina BIANCHI[1], Frode Eika SANDES[2,3], Luis Carlos PASCHOARELLI[1] and Fausto Orsi MEDOLA[1]
[1]Graduate Programme in Design, UNESP - Univ. Estadual Paulista, Bauru, Brazil
[2]Department of Computer Science, Faculty of Technology, Art and Design, Oslo
[3]Akershus University College of Applied Sciences, Norway

ABSTRACT
The research in the field of ergonomics can contribute to the design process of Assistive Technologies using objective and subjective data measurements. The auxiliary crutches are assistive devices commonly used in the process of rehabilitation after lower-extremity injuries. However, for many subjects, walking with crutches in not an easy and comfortable task, as the loads on the upper limbs are substantial and expose the users to potentially harmful long-term effects. In this way, the objective of this study was, first, to report the evaluation of the user-crutch interface by using an objective measurement of the subjects' muscular activity and exertion perception, and to discuss how objective data measured from the subjects can contribute for the design of the interface. Eleven able-bodied subjects participated. The test protocol consisted of 3 trials of walking with crutches, each one with a different hand diameter, namely 20 mm, 32 mm and 40 mm. Surface electromyography of forearms muscles was collected, and perceived exertion was measured using the Borg's Scale. The mean of maximum EMG values showed that the highest values activity happened in the extensor *digitorum* muscle using the largest handles. However, the smallest handles increase electromyography activity in the *flexor digitorum superficialis* muscle. Statistically significant difference was found between the smaller and the larger handle diameter. The analysis of exertion perception did not show statistical difference in any of the situations investigated. Handle diameter was shown to be a factor affecting the biomechanics of the walking with crutches. In addition, ergonomic evaluation can provide objective measurements that, ultimately, may be applied in the improvement of user-product interface.

Keywords: Axillary crutches, Walking, Electromyography, Exertion perception, Handle design.

1 INTRODUCTION

One of the main characteristics of the research in the field of the ergonomic design is the multidisciplinarity. The ergonomics can contribute to the design process by providing a wide view of many aspects related to the user-device interface, such as physical interactions, cognitive, emotional and perceptual aspects. Thus, studies addressing objective and subjective represent a positive research strategy for the analysis of the interaction between user and the object.

From an ergonomic perspective, usability is one of the most important characteristics related to the user-device interaction during the process of usage. It refers to safe, efficient and satisfactory use. In the field of the Assistive Technologies (AT), independence and social participation are important outcomes that complement the traditional ergonomics variables of the user-device analysis. Additionally, ergonomics can contribute to the improvement of assistive technologies by providing parameters to optimize the comfort, efficiency and satisfaction of the interface. Alternative designs of hand rims have been proposed to make manual wheelchair propulsion easier and more comfortable [1], [2].

Auxiliary crutches, also known as regular crutches or standard crutches, provide support for the human body designed with the purpose of assisting patients with lower limbs impairments in balance and mobility, requiring additional support during displacement with the use of arms and hands for support

and propulsion. In addition, crutches increase the load on the upper limbs, relieving body weight supported by the legs. [3].
One of the main objectives of the rehabilitation of a lower limb injury is to recover the normal gait. In this way, the use of crutches is required in many situations and gait and energy expenditure have been studied [4], [5], as well as the biomechanical loads in the upper limbs [6], [7], and handle forces.
Because walking with crutches requires a higher energy expenditure and strength in the arm and shoulder, it is usually difficult to be used by elderly people. Additionally, the incorrect support in the armpit can result in high pressure, discomfort, pain and nerve compression. When walking with crutches, the user relies on the upper limbs (mainly the handles) to support the body weight during a significant part of the gait cycle. In this context, the relation between the loads on the upper limbs and handle design become a relevant aspect of the ergonomics of user-crutch interaction.
In this way, the objective of this study was two-fold: first, to report the evaluation of the user-crutch interface by using an objective measurement of the subjects' muscular activity and exertion perception; and to discuss how objective data measured from the subjects can contribute for the design of the interface. It is important to verify how the design can influence the biomechanics and perceptive aspects of subjects, as well as, promote perspectives of analysis that can help to develop projects in a wider and more complex context, in terms of design to help the community.

2 MATERIAL AND METHODS

To investigate how the interface design influences muscular activity, we tested three handles of different diameters, and measured muscular activity during walking with crutches. A sample of eleven non-disabled subjects, all male (average age of 22.3+2.1 years, average height of 1.75 ± 0.06 meters, average weight of 77.12± 14.78 Kilograms), were recruited at São Paulo State University (UNESP, Bauru, Brazil) and voluntarily participated in this study. Participants met the following inclusion criteria: (1) minimum age of 18 years; (2) had no upper limbs pain, injuries or disorders that could influence the activity of walking with crutches. Prior to data collection, participants read and signed an informed consent form that had been submitted and approved by the Ethics Committee on the Faculty of Architecture, Arts and Communication - UNESP (Process. N. 800.500).
For the data collection, a pair of crutches were used with three different handle diameters, namely 20 mm, 32 mm and 40 mm (see Figure 1).

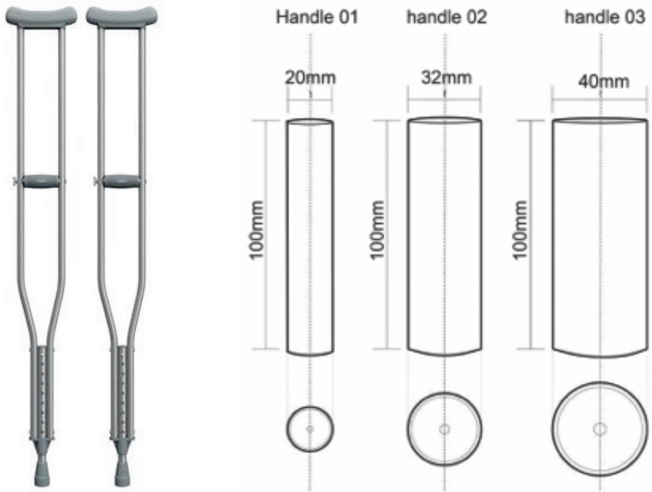

Figure 1. Crutches used and handles characteristics

These handles were tested with the user walking with auxiliary crutches following a straight line (five steps). The protocol was repeated three times for each handle, and the sequence of the handles was randomized.
During the tests, surface electromyography (sEMG) data were collected, to measure the electrical activity of two forearm muscles: *extensor digitorum* and the *flexor digitorum superficialis* muscle. The sEMG is a biomechanical measurement technique widely used in ergonomics research, and refers to the measurement of the electric signal from muscles during contraction. Electromyography (EMG)

signals are considered most useful as electrophysiological parameters to understanding the human body's behaviours.

For this study a wireless surface electromyography (EMG) system (CAPTIV system, TEA Ergo, Nancy France), and triode surface electrodes T3402M (Thought Technology, Montreal, Canada) (Figure 2) were used and placed in the respective positions for each muscles in accordance to the SENIAM project (www.seniam.org) and palpatory anatomy in both subject's forearms.

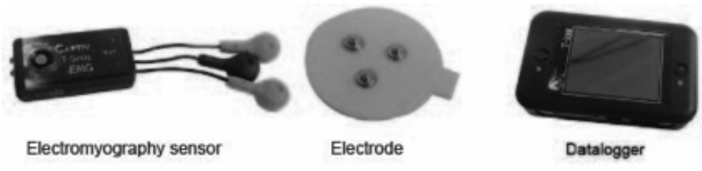

Figure 2. Surface electromyography system

The electrodes for the *flexor digitorum superficialis* muscles were placed between úmerus (origin) and medium falange bases of the fingers (insertion) in the muscular belly (see Figure 3). The electrodes respective for the *extensor digitorum* were placed between the lateral epicondyle of the úmerus (origin) and medial and distal phalanges (insertion) in the muscular belly (see Figure 3).

Figure 3. extentor digitoum and flexor digitorum superficialis muscles

The EMG signal was sampled at 2,048 Hz, with 128 Hz root mean square (RMS) calculation, and analyzed with the CAPTIV L-7000 software (TEA Ergo, Nance, France). The mean values of all the subjects for the bilateral EMG measurements of both muscles were obtained. The Shapiro-Wilk test was performed to check the distribution of the data. In order to verify statistical difference in paired data, the nonparametric Wilcoxon test was applied, since the data did not have a normal distribution. Significance was determined by $p \leq 0.05$. All statistical analyses were performed using the software STATISTICA v8 (StatSoft, EUA).

After the test, subjects rated their perceived effort in the CR10 Borg's Scale (BORG, 1982). This test was developed by Gunnar Borg in the work "Perception scale exertion (PSE)", with the objective to classify and measure the intensity of a specific effort related to physical activities. The test consisted in a protocol that does not involve equipment or complex evaluation processes. This tool allows the assessment of the perception of effort in a given activity with the use of verbal anchors in a scale (see Figure 4).

0	Absolutely nothing
0,3	
0,5	Extremely weak
1	Very weak
1,5	
2	Weak
2,5	
3	Moderate
4	
5	Strong
6	
7	Very strong
8	
9	
10	Extremely strong
11	
...	
•	Absolute maximum

Figure 4. Borg's Scale

The mean of all subjects scores (responses) was obtained and the Shapiro-Wilk test was performed to verify the distribution of the data. In addition, parametric and non-parametric tests were performed to compare the means of perceived exertion among the different handles**.** All statistical analyses were performed using the software STATISTICA v8 (StatSoft, EUA).

3 RESULTS

The mean of the maximum EMG values showed that the highest activity was found in the *extensor digitorum* muscle using the largest handles (444.76 mV for left forearm 401.47 mV for right forearm). However the smallest handles increased EMG activity in the flexor *digitorum superficialis* muscle (415,32 mV for right forearm and 416,51 mV for left forearm). The statistical analysis demonstrated that the mean of maximum EMG in left *flexor digitorum* muscles had significant difference ($p < .03$) between the smallest (416.51 mV) and largest (225.58 mV) handles. In addition, the mean of maximum EMG values in right *flexor digitorum superficialis* muscles had statistical difference ($p < .01$) between the handles number two (544.27 mV) and number three (379.07 mV), as shown in Figure 5.

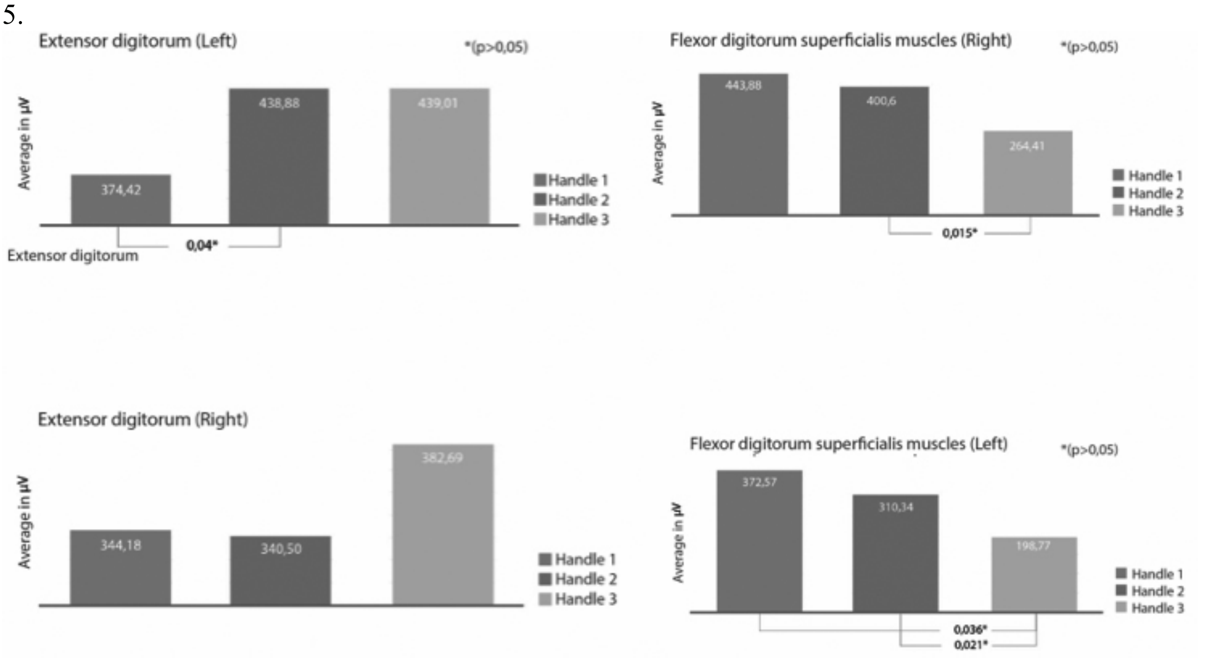

Figure 5. Mean of EMG values

Borg's scale demonstrated a exertion perception between 3,86 and 3,18 in a scale of 11 levels, in which 0 represents absence of physical exertion and 11 the highest physical exertion already made during life. No statistical difference was observed in any of the situations analyzed (see Figure 6).

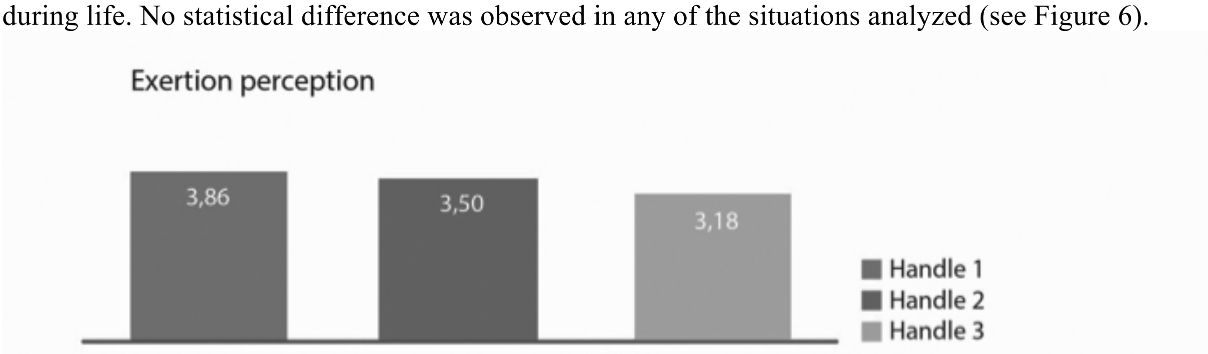

Figure 6. Mean of perceived exertion in the handles

The 20 mm handle (no. 1) exhibited the highest exertion perception, and the 40 mm handle (no. 3) exhibited the lowest exertion perception, which corroborates with the EMG results.

4 DISCUSSION

Walking with crutches comprises the repetitive application of hand grip on the handlebars and sustained body weight with the upper limbs. This combination, in long-term, exposes the users to the risk of upper limb injuries. In this way, handle design is a key factor in the user-crutch interaction, as it represents the main contact interface during the process of usage. This study addressed the influence of different diameters of crutch handles on the forearms activity and subjects' exertion perception during gait. This knowledge can be an important evaluation parameter in the ergonomic design process, and other studies showed that objective data measured from subjects can benefit the design of the interface of packages, assistive devices and handles [8], [9], [10].

In general, the results of EMG and perceived exertion showed that handle diameter can influence the load on the upper limbs, specifically on the forearms. Additionally, it showed that the use of the smallest handle diameter was related to higher perception of effort and increased activity of the fingers' flexor muscle. A possible explanation of this is that the smallest diameter (20 mm) does not provide enough support for a stable coupling and firm grip. The results of EMG showed that higher activity of the flexors muscles was related to lower activity in the extensor muscle, showing the characteristic of antagonism between these muscles.

The results of Borg's scale demonstrated that the use of different handle diameters could influence the perceived exertion during walking with crutches. The handles with the smallest diameter seem to demonstrate highest effort of the users, probably because the diameter (20 mm) is insufficient to provide proper support to the entire hand's surface, thus requiring the users' additional effort to hold it firmly.

This study has several limitations. First, the wrist posture was not controlled, and different wrist positions could influence the activity of the forearm muscles. Additionally, crutch gait kinematics were not verified for each subject and handles, that could also influence the qualitative and quantitative results.

This study showed that combining measurements of objective and subjective data from the subjects is a positive strategy to investigate the interface between product and user. This data can provide parameters that, ultimately, may contribute for the improvement of the ergonomics of the design of a product. Additionally, other measurements can be of interest, especially when it comes to manual interfaces, such as the distribution of contact forces on hands' surface [9], [11].

The optimal size of handles, in general, depends on the functionality [10]. According to Sandvik (1997) [12], the handles should have correct shapes and sizes for specific functions, to distribute the pressures in the hand's surface and transmit the force with less effort. From an ergonomic point of view, more important than the size of the handle is the anatomical shape for a better distribution of pressure and contact area with the entire surface of the hand. Previous studies have provided some insights on the benefits of an anatomical shape in manual operated devices [9].

5 CONCLUSION

This study presented an example of how ergonomic evaluation can provide objective measurements that, ultimately, may be applied in the improvement of user-product interface. Here, we addressed a single but relevant factor of the interface of manually operated objects, that is, the diameter of crutches handles. In general, the diameter of handles influenced both the perceptive and physiological aspects of the subjects walking with crutches. Also, a larger diameter of handle was shown to be a positive factor, as it decreased muscular effort and perceived exertion. In this way, the use of perceived and biomechanical parameters to evaluate product ergonomics can be a successful experience to make design decisions based on objective evidences.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge CAPES (Coordination for the Improvement of Higher Level Personnel) and CNPq (National Council for Scientific and Technological Development, Process Nº 458740/2013-6), for the financial support.

REFERENCES

[1] Dieruf, K. and Ewer, L. and Boninger, D. The natural-fit handrim: factors related to improvement in symptoms and function in wheelchair users. *J. Spinal Cord Med.* 2008, 31, pp.578-766.

[2] Richter, W.M. and Rodriguez, R. and Woods, K.R. and Karpinski, A.P. and Axelson, P.W. Reduced finger and wrist flexor activity during propulsion with a new flexible hand rim. *Arch. Phys. Med. Rehabil.* 2006, 87, pp.1643-1647.

[3] Lighthall, H. L. and Gutierrez, D. D. and Newsam, C. J. and Gronley, J. K. and Mulroy, S. J. and Perry, J. A comparison of shoulder joint forces during ambulation with crutches versus a walker in persons with incomplete spinal cord injury. *Arch Phys Med Rehabil*, 2006, 87, pp.63-70.

[4] Moran, J. and Murphy, A. and Murphy, D. and Austin, A. and Moran, D. and Cronin, C. and Guinan, E. and Hussey, J. The energy expenditure of non-weight bearing crutch walking on the level and ascending stairs. *Gait & Posture.* 2015, 42(1), pp.23-26.

[5] Lephart, K. and Utsey, C. and Wild, D.L. and Fisher, S.R. Estimating energy expenditure for different assistive devices in the school setting. *Pediatr. Phys. Ther.* 2014, 26(3), pp.254-9.

[6] Sala, D.A. and Leva, L.M. and Kummer, F.J. and Grant A.D.; Crutch handle design: effect on palmar loads during ambulation. *Arch. Phys. Med. Rehabil.* 1998, 79(11), pp.1473-6.

[7] Opila, K.A. and Nicol, A.C. and Paul, J.P. Upper limb loadings of gait with crutches. *J. Biomech. Eng.* 1987, 109(4), pp.285-90.

[8] Bonfim, G. and Medola, F. and Paschoarelli, L. *Usability in the Development of Pachaging Design: Complementing the Subjective Evaluation. In: Soares M., Falcão C., Ahram T. (eds) Advances in Ergonomics Modeling, Usability & Special Populations.* Advances in Intelligent Systems and Computing, vol 486. Springer Cham.

[9] Medola F.O. and Silva, D.C. and Fortulan, C.A. and Elui, V.M.C. and Paschoarelli, L.C. The influence of handrim design on the contact forces on hands' surface: A preliminary study. *International Journal of Industrial Ergonomics.* 2014, 44, pp.851-856.

[10] Ayoub, M.M. and Lo Presti, P. The Determination of an Optimum Size Cylindrical Handle by Use of Electromyography. *Ergonomics,* 2007, 14(4), pp.509-518.

[11] Muralidhar, A. and Bishu, R.R. and Hallbeck, M.S. The development and evaluation of and ergonomic glove. *Appl. Ergon.* 1999, 30, pp.55-563.

[12] Sandvik. Sandvik's 11 point programme: the scientific way to develop better hand tools. *West midlands: Sandvik.*