EFFECT OF ASSISTIVE DEVICES ON HAND AND ARM POSTURE DURING ACTIVITIES OF DAILY LIVING

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HIGHLIGHTS

- Assistive devices affect upper limb postures in activities of daily living
- Assistive devices reduce the use of precision grasps in the right hand by 31.9%
- Assistive devices increase palm contact by 26% and 29.1% in right and left hands
- Some devices increase shoulder flexion, elbow pronation and wrist deviation
- Results may help in selecting assistive devices depending on patient's dysfunctions

ABSTRACT

Assistive devices (ADs) are products designed to overcome the grip strength and mobility difficulties produced by ageing and different pathologies. Nevertheless, little is known about the postural effect of such devices. This work aims to quantify this effect on the entire upper limb. Ten healthy right-handed subjects performed 13 activities of daily living (ADL) with normal products and 22 ADs and both arm (shoulder, elbow and wrist) and hand (grasp types and contacts) postures were analysed. ADs were found to affect upper limb postures in ADL, reducing the use of precision grasps in the right hand by 31.9% and increasing palm contact by 26% and 29.1% in right and left hands, respectively. Nevertheless, they were also found to increase shoulder flexion, elbow pronation and wrist deviation, which may be a drawback in some pathologies. Results may help in the selection of a suitable AD for enhancing ADL performance depending on the patient's limitations due to a particular pathology.

KEYWORDS

Assistive device, activities of daily living, upper limb posture, grasp classification.

1. INTRODUCTION

Ageing and different pathologies reduce hand mobility and grip strength, hindering the normal performance of activities of daily living (ADL) (Brand and Hollister, 1999), therefore affecting personal independence. There are different commercial adaptive products or assistive devices (ADs) aimed at making it easier to carry out some ADLs in these situations by overcoming the difficulty of grasping and manipulation arising from the use of standard products. Therapists are responsible for indicating the most suitable product for each patient, and have to choose from among different available ADs designed to carry out the same task. However, this selection is not an easy decision, since there are no tools to evaluate the potential impact of each product on the improvement of patients' quality of life or any information about the side effects resulting from its use. Therefore, therapists must make decisions based on their own clinical experience, which leads to a call to cater for training needs regarding appropriate product assessment (Long et al., 2007). A detailed objective study about the effect of their use could be essential to determine recommendations and precautions when using ADs.

Some studies have presented reviews of ADs available on the market for different fields, such as feeding (Holt and Holt, 2011), personal care (Harman and Craigie, 2011; Hepherd, 2011) or mobility (Stowe et al., 2010), but they only offer qualitative descriptions of the products and the difficulties presumably overcome. The use of ADs during the performance of ADL has been studied mainly from data collected through user surveys or group discussions (Hemmingsson et al., 2009; Hoffmann and McKenna, 2004; Kraskowsky and Finlayson, 2001; Mann et al., 1993; Skymne et al., 2012; Wielandt et al., 2006; Yeung et al., 2016). These studies were focused mainly on identifying the reasons for rejection. Rejection was found to depend on factors such as equipment suitability (pre-prescription home visits), perception of the product, anxiety, adequate training or the conviction that the AD was not needed (Hoffmann and McKenna, 2004; Kraskowsky and Finlayson, 2001; Skymne et al., 2012; Wielandt et al., 2006). Furthermore, the problems arising from using ADs were found to be related to the type of impairment (Mann et al., 1993) and the number of ADs used was seen to depend on the severity of the impairment. In children with disabilities, the studies have also dealt with the use of ADs in schools or education (Hemmingsson et al., 2009), stressing the need for both verbal information and practical experience. Despite all these useful conclusions, however, the results remain qualitative.

Only a few studies have attempted to quantify the effect of the use of ADs on the hand and upper limb posture (Ma et al., 2009, 2008; McDonald et al., 2016; Van and Steenbergen, 2007). Some of these experimental studies were carried out on healthy subjects performing some ADL (McDonald et al., 2016), and others on subjects with pathologies such as Parkinson (Ma et al., 2009, 2008) or cerebral palsy (Van and Steenbergen, 2007). Although these studies have analysed the effect on hand posture (McDonald et al., 2016), arm posture (Ma et al., 2009; Van and Steenbergen, 2007) and hand-arm posture (Ma et al., 2008), the ADL considered was only the task of eating with a spoon (Ma et al., 2009, 2008; McDonald et al., 2016; Van and Steenbergen, 2007). Important conclusions were drawn from these works, such as the importance of the effect of the diameter of the handle of the product on the speed and smoothness of the hand movement (Ma et al., 2008). Kinematics was also found to affect the perceived comfort, the products handled with greater speed and smoothness being rated better (Ma et al., 2008). However, the hand kinematics analysis was very limited, only taking into consideration the range of motion of interphalangeal and metacarpophalangeal joints (McDonald et al., 2016) or the number of fingers involved in the grasp (Ma et al., 2008).

Registration of all hand joint angles simultaneously without affecting the normal use of products is challenging. To get round this, many studies in the field of ergonomics and safety at work are based on direct observation of the posture (David, 2005). In this line, several methods are widely used, such as the Ovako Working Posture Analysis System (OWAS) to evaluate the overall body posture (Karhu et al., 1977) or the Rapid Upper Limb Assessment (RULA) to assess the upper limb postures (McAtamney and Nigel Corlett, 1993). Some recent studies that have used video recording and posture classification to describe the posture of hands (Hwang et al., 2010; Vergara et al., 2014; Wang et al., 2014) have employed grasp taxonomies to classify hand posture in more detail and may complement posture classification methods.

The aim of this work is to analyse the effect of ADs on hand and arm postures, on the basis of the relationship reported in the literature between kinematics and comfort. To do so, the postures employed by healthy subjects when using ADs during the performance of a variety of ADL are compared to those utilised when performing the same ADL with standard products. Due to the wide variety of ADs available in the aspect of mobility, self-care and domestic life, and the importance of these fields for personal independence, it was considered appropriate to compare the hand and arm postures during the performance of representative ADLs from these fields. This comparison may help to understand ADs users' rejection and contribute to a better assessment of ADs depending on the pathologies or impairments that their use is intended to supplement. In addition, the study of these postural effects may be useful during the design of new products focused on specific pathologies.

2. MATERIAL AND METHODS

Ten healthy right-handed subjects (5 male, 5 female; age 35.1 ± 13.8 years) volunteered to participate in the experiment, approved by the university ethics committee. The subjects were previously informed about the characteristics of the experiment and gave their written consent.

2.1. Selection of tasks and material

After studying the different types of ADs for grasping that are commercially available (such as personal care, dressing, eating or drinking), 22 products were chosen as being representative. Then, in accordance with the ADs that were chosen, 13 ADL associated with their use were selected from the World Health Organization's International Classification of Functioning, Disability and Health (ICF). All the specific tasks selected are listed in Table 1. Each of these tasks was carried out with the normal products and with one, two, three or four ADs (Figure 1), except task 11 (brushing hair), in which half of the subjects used a normal and an adapted comb, while the other half used a normal and an adapted brush.

ID	TASK	PRODUCTS
1	Opening cans	1 NP, 1 AD
2	Unscrewing a bottle top	1 NP, 2 ADs
3	Pouring from a bottle	1 NP, 1 AD
4	Pouring from a carton	1 NP, 1 AD
5	Drinking from a glass	1 NP, 1 AD
6	Eating with a spoon	1 NP, 4 ADs
7	Eating with a fork	1 NP, 4 ADs
8	Carrying a dish	1 NP, 1 AD
9	Using a tap	1 NP, 1 AD
10	Brushing teeth	1 NP, 1 AD
11a	Brushing hair (comb)	1 NP, 1 AD
11b	Brushing hair (brush)	1 NP, 1 AD
12	Sliding a zip up/down	1 NP, 2 ADs
13	Buttoning/unbuttoning a shirt	1 NP, 2 ADs

Table 1: ADL performed in the experiment and products used during their performance (NP: normal product, AD: assistive device).

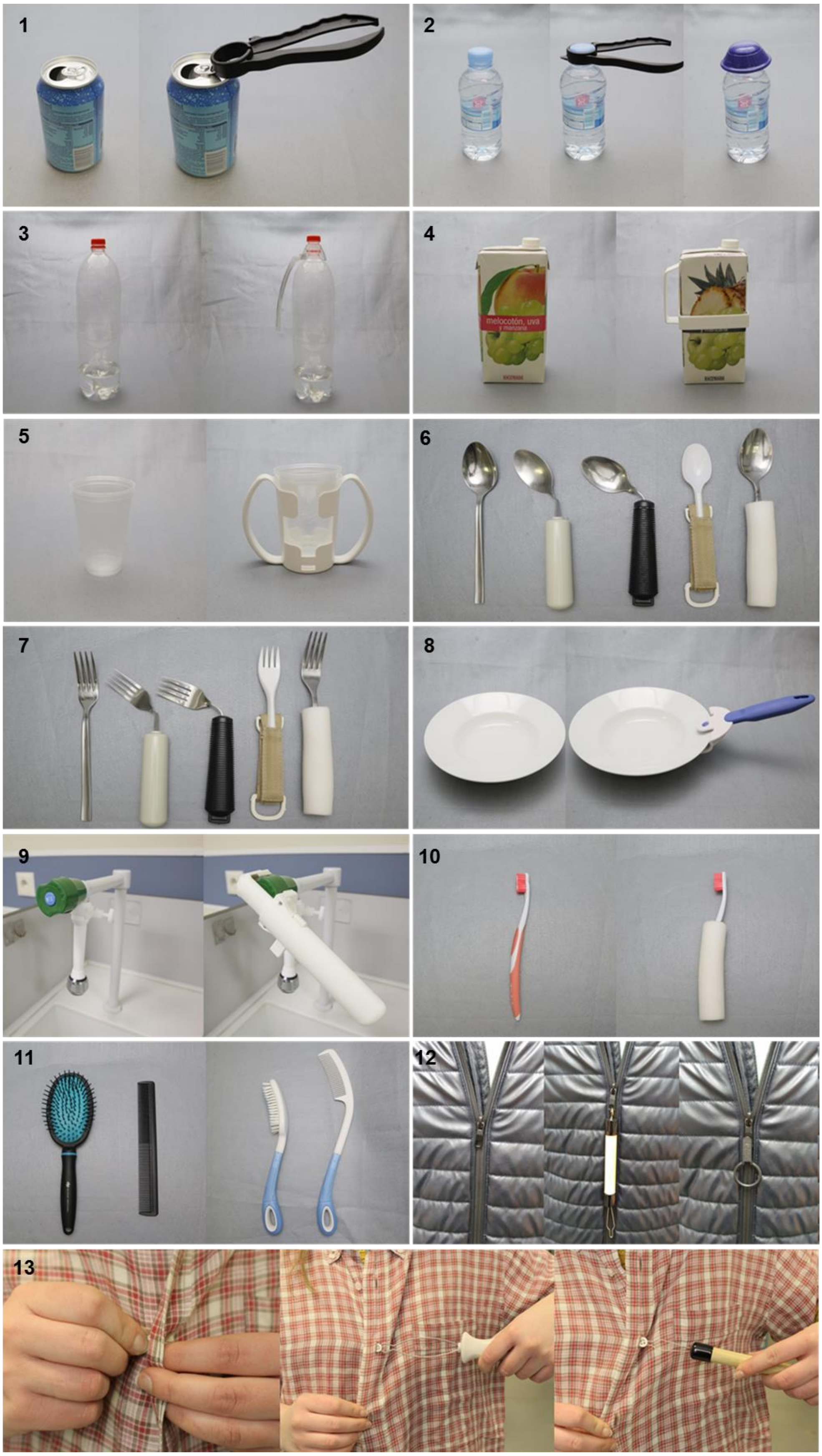

Figure 1: Products used during the performance of the ADL considered in the experiment.

Three scenarios were prepared (Figure 2). The objects were arranged in the same position for all the subjects, and the initial and final postures of each subject were controlled to ensure they were the same.

Figure 2: Scenarios prepared for the experiment. (Scenario 1: A chair with the objects to perform the dressing tasks. Scenario 2: A table with the objects to perform the eating/drinking tasks. Scenario 3: A sink and a table with the objects to perform the self-care tasks).

2.2. Experiment

Before actually carrying out the tasks, subjects were given instructions on the use of the products and on how to perform the tasks. The subjects were recorded on video while performing the selected ADLs with the normal products and the ADs. The subjects performed the tasks with the hand they preferred, and with both hands when needed. Several of them, even being right-handed, performed some tasks with their left hand (using the tap, for example). Furthermore, because of the way the buttons were set out on the shirt, the AD was held with the left hand in the task of buttoning and unbuttoning a shirt. The order of the tasks and scenarios to be performed by each subject was randomised, and subjects were not given any extra time to get used to the ADs.

2.3. Data analysis

The video recordings were analysed in order to separate the tasks into elementary grasp actions (EGAs), defined as those in which the hand maintained a specific type of grasp. For each EGA, the type of grasp for both hands, the parts of both hands in contact with the object, the posture of both arms and the duration of the EGA in seconds were identified by visual analyses. These analyses were performed by a single trained observer throughout all the experiments in order to avoid inter-observer data variation. The postures of the shoulder, elbow and wrist were identified qualitatively following a classification based on that proposed in the RULA method (McAtamney and Nigel Corlett, 1993). Shoulder flexion/extension (F/E) was classified as neutral, slightly flexed or highly flexed, and shoulder abduction/adduction (AB/AD) as neutral, abducted or adducted. Regarding the elbow postures, F/E was classified as neutral, flexed or extended, and pronation/supination (P/S) as neutral, pronated or supinated. Finally, wrist F/E was classified as neutral, flexed or extended, and wrist AB/AD as neutral, abducted or adducted. For arm postures on the borderline, the closest-to-neutral zone was always considered, as the most favourable case. The hand posture analysis was performed using a seven-grasp type taxonomy (Figure 3), previously used by the authors to study the frequency of use of grasps during ADL (Vergara et al., 2014). This taxonomy also classifies those grasp types into power or precision grasps, as specified in Figure 3. Regarding the analysis of the hand parts in contact with the object during the grasp, six hand zones (the palm, the thumb and each of the four fingers) were taken into consideration. In the cases in which the identification of the arm posture or contacts was not possible by observation, these data were considered as missing or not available (NA).

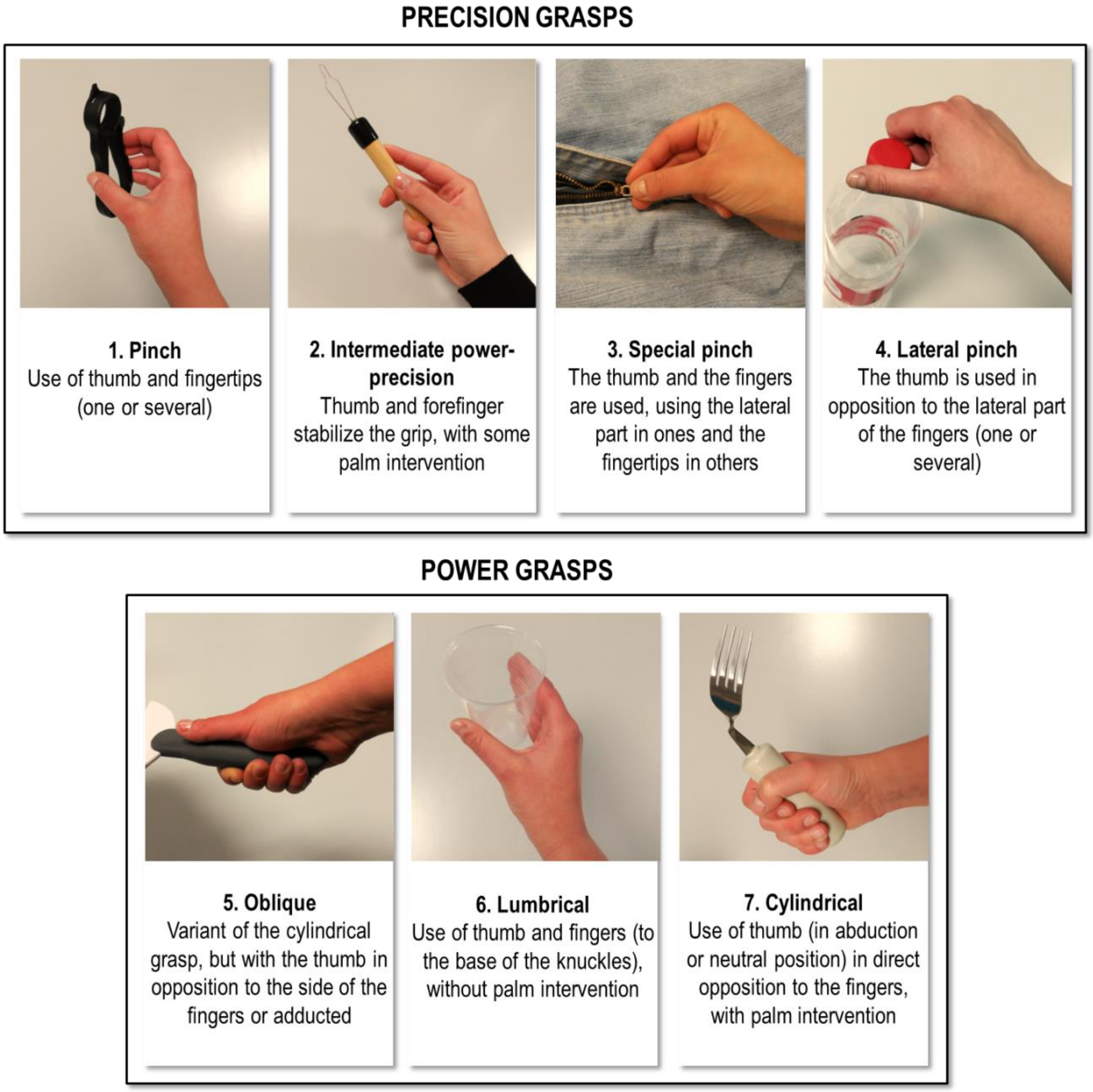

Figure 3: Grasp classification.

Firstly, in order to have an overview of the recorded data, the time required to accomplish each task (per subject and product) and the overall time spent using each hand for each task and product were computed (in seconds). Then, to check for statistical differences in the time required to accomplish the tasks with normal products and with ADs, a repeated measures ANOVA was performed, using the type of product (normal and the different ADs for each task) as the withinsubjects factor. The descriptive analysis of these data showed that the time of accomplishment of the tasks was quite different between subjects and tasks. Therefore, in order to ensure that all the tasks, products and subjects were weighted to the same extent in all the subsequent analyses, the original durations of the EGAs (in seconds) were normalised with the duration of their corresponding record. In this way, each record (each task performed by each subject with each product) had a duration of 100 equivalent seconds. The percentages of time spent using the different types of grasp per hand, contacts of the hand with the objects and arm postures were obtained from the equivalent durations, and descriptive statistics were used to identify differences between the use of ADs and normal products. Different contingency tables for percentages of time of use were computed and the associated chi-square test was applied to identify whether the differences observed between standard products and ADs were statistically significant. The contingency tables of percentage of time were: type of grasps × product (two 7×2 tables, one per hand); hand contact zones × product (twelve 2×2 tables, six per hand) and neutral postures of the wrist, elbow and shoulder × product (six 2×2 tables, one per hand and arm joint). In the case of each 7×2 table for type of grasps, the post-hoc analysis was performed by computing seven new 2×2 tables, one per grasp and applying the Bonferroni correction to the bilateral asymptotic significance level in order to compensate for the number of grasp types analysed at the same time. After that, chi-square tests were also computed in the same way for grasp types and arm postures but separating for each AD in comparison with its corresponding standard product.

3. RESULTS

The total amount of time spent using the right and left hands during the experiments was 46 min 51 s and 23 min 35 s, respectively. The amount of time that only the right hand (without using the left) was used was 23 min 57 s, while the left hand alone was used for only 42 s, mainly for reaching objects or in the zipping tasks. Table 2 details the amount of time used by each hand to perform each task.

	TIME (s)			
	NP		**ADs***	
TASK	R	L	R	L
Opening cans	38	38	106	97

Unscrewing a bottle top	33	33	152 *	135 *
Pouring from a bottle	39	22	42	19
Pouring from a carton	43	12	45	11
Drinking from a glass	49	-	48	23
Eating with a spoon	67	-	308 *	-
Eating with a fork	67	-	315 *	-
Carrying a dish	59	59	92	14
Using a tap	28	14	45	6
Brushing teeth	91	-	86	-
Brushing hair (comb)	38	2	35	1
Brushing hair (brush)	25	-	29	-
Sliding a zip up/down	35	38	107 *	102 *
Buttoning/unbuttoning a shirt	100	100	689 *	689 *
TOTAL	**712**	**318**	**2099**	**1097**

Table 2: Total amount of time that each hand (R: right hand, L: left hand) was used to perform the different tasks during all the experiment when performed by all the subjects with normal products (NP) and ADs. *Note that the time for these tasks corresponds to all of the ADs jointly.

Figure 4 shows the box-and-whiskers plot of the time required to accomplish each task when performed with normal products and with ADs. Significant differences (bilateral asymptotic sig. ≤ 0.05) were found after an ANOVA for the tasks of opening cans (1), unscrewing a bottle top (2), eating with a spoon (6) (only for the adapted spoon A2), carrying a dish (8), sliding a zip up and down (12) (only for the adapter A1) and buttoning/unbuttoning a shirt (13). It can be observed that the time of accomplishment in all of these tasks with differences was far higher when performed with ADs. This can be attributable to the lack of experience of the subjects with ADs, owing to the fact that all of them were healthy.

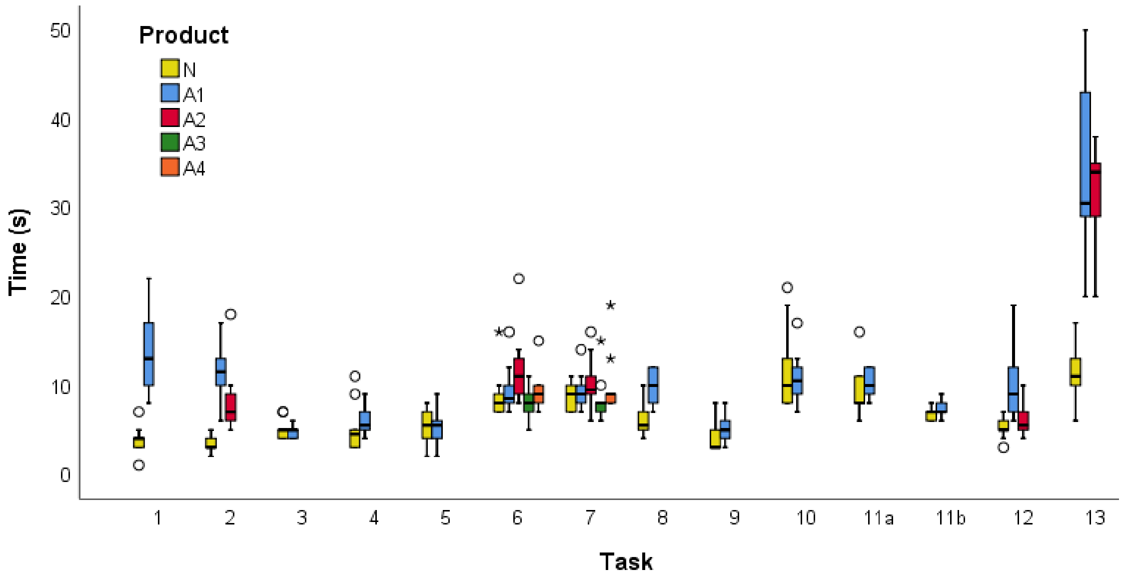

Figure 4: Time of accomplishment of the tasks.

Table 3 shows the percentages of time of use of each type of grasp separated for normal products and ADs (obtained from equivalent durations). Significant differences were found after the chi-square test, with a bilateral asymptotic sig. ≤ 0.0071 (after applying the Bonferroni correction) for all the grasp types, except for the special pinch one with the right hand, where the differences obtained were far lower than for the rest. It can be observed that the time of performance of precision grasps (pinch and lateral pinch) decreased when using the ADs, while an increase was found for power grasps such as cylindrical or oblique.

		Right hand (%)		Left hand (%)	
		N	**ADs**	**N**	**ADs**
Power grasps	**Cylindrical**	<u>**20.7**</u>	<u>**25.5**</u>	<u>**33.5**</u>	<u>**44.5**</u>
	Lumbrical	<u>**6.4**</u>	<u>**3.5**</u>	<u>**13.2**</u>	<u>**7.1**</u>
	Oblique	<u>**10.5**</u>	<u>**36.6**</u>	<u>**2.8**</u>	<u>**6.2**</u>
Precision grasps	**Special pinch**	10.8	10.3	<u>**13.8**</u>	<u>**4.4**</u>
	Intermediate	<u>**10.6**</u>	<u>**5.7**</u>	<u>**5.0**</u>	<u>**18.0**</u>
	Lateral	<u>**18.0**</u>	<u>**3.6**</u>	<u>**6.6**</u>	<u>**2.1**</u>
	Pinch	<u>**22.0**</u>	<u>**9.9**</u>	<u>**22.0**</u>	<u>**14.1**</u>

Table 3: Percentage of equivalent time of use of each type of grasp for each hand when using normal products (N) and assistive devices (ADs). Significant differences are underlined.

Table 4 shows the statistically significant differences found in the time of use of each grasp type per hand in each task and AD used after applying the Bonferroni correction. It can be observed that significant differences were found for almost every grasp type and object, and also that there was an increase in oblique and cylindrical grasps while using ADs and a decrease in the lateral and pinch ones.

	CYL		SPE		INT		LAT		LUM		OBL		PIN	
TASK	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Opening cans	+	=	=	=	+	+	=	=	+	=	+	=	-	-
Unscrewing a bottle top (A1)	+	+	-	=	=	=	-	-	+	=	+	=	=	=
Unscrewing a bottle top (A2)	=	=	+	=	=	=	-	=	+	+	=	=	+	=
Pouring from a bottle	-	+	=	=	=	=	=	=	=	=	+	=	=	=
Pouring from a carton	-	=	=	=	=	=	=	=	-	=	+	=	=	=
Drinking from a glass	=	=	=	=	=	=	=	=	-	=	+	=	=	=
Eating with a spoon (A1)	+		=		=		-		=		+		=	
Eating with a spoon (A2)	+		=		=		-		+		+		=	
Eating with a spoon (A3)	+		-		-		-		=		=		-	
Eating with a spoon (A4)	+		=		+		-		+		+		=	
Eating with a fork (A1)	+		-		-		-		+		+		=	
Eating with a fork (A2)	+		-		=		-		=		=		=	
Eating with a fork (A3)	+		-		-		-		=		-		-	

Eating with a fork (A4)	+		=		-		-		=		+		=	
Carrying a dish	+	=	-	=	-	-	=	=	-	-	+	=	-	+
Using a tap	+	+	=	=	-	-	-	-	=	=	+	=	=	=
Brushing teeth	+		=		-		=		=		+		=	
Brushing hair (comb)	=	=	-	=	=	=	=	=	=	=	-	=	+	=
Brushing hair (brush)	+		=		-		=		=		+		=	
Sliding a zip up/down (A1)	=	=	+	=	=	+	-	-	+	=	+	=	-	=
Sliding a zip up/down (A2)	=	=	-	=	+	=	-	-	=	=	=	=	-	+
Buttoning/unbuttoning a shirt (A1)	=	+	+	-	=	+	=	=	=	=	=	+	-	-
Buttoning/ unbuttoning a shirt (A2)	=	+	+	-	=	+	=	=	=	=	=	=	-	-

Table 4: Statistically significant differences in time of use of each grasp type and task while using normal products (NP) and ADs for both right (R) and left (L) hands. Sign criteria: (+) for higher values while using ADs; (-) for lower values while using ADs; (=) when no differences were found. Empty cells for the left hand when only the right hand was used.

Table 5 shows the contact rates (obtained from the equivalent durations) for each hand while using normal products and ADs. Significant differences (bilateral asymptotic sig. ≤ 0.05, underlined values) were found for all the parts except for the left index finger. An increase in the contact of the palms, the middle fingers, ring fingers and little fingers can be observed while using ADs, as well as a decrease in the contact of the thumbs and the right index finger.

Contacting part	**Right hand**		**Left hand**	
	NP CR (%)	ADs CR (%)	NP CR (%)	ADs CR (%)
Palm	**42.6**	**68.6**	**42.7**	**71.8**
Thumb	**99.7**	**96.7**	**98.3**	**96.6**
Index finger	**98.8**	**97.0**	98.3	98.1
Middle finger	**85.2**	**93.4**	**88.5**	**93.2**
Ring finger	**57.4**	**80.2**	**70.0**	**86.1**
Little finger	**46.9**	**71.3**	**56.3**	**83.8**

Table 5: Palm and fingers contact rates (CR) with normal products (NP) and ADs for both hands. Significant differences are underlined.

Table 6 shows the rates of neutrality of the postures of shoulders, elbows and wrists (and all possible combinations of these joints) while using the normal products and ADs (obtained from the equivalent durations). Significant differences (bilateral asymptotic sig. ≤ 0.05, underlined values) were found in the postures of all the joints and their combinations. A more detailed analysis is presented in Table 7, where the rates of neutrality of the postures using the different products for each task are compared, and the statistically significant differences are marked. It can be observed that significant differences (bilateral asymptotic sig. ≤ 0.05) were found for almost all the tasks and products.

Arm segment	Right arm		Left arm	
	NP NR (%)	ADs NR (%)	NP NR (%)	ADs NR (%)
Shoulder	72.5	70.6	84.8	87.6
Elbow	30.0	22.0	59.0	54.6
Wrist	77.9	74.9	87.3	81.7
Shoulder and elbow	26.0	20.2	52.7	49.0
Shoulder and wrist	59.9	57.5	75.4	71.1
Elbow and wrist	25.8	19.7	53.2	45.4
Shoulder, elbow and wrist	23.0	18.5	46.9	40.2

Table 6: Shoulder, elbow and wrist rates of neutrality (NR) while using normal products (NP) and ADs. Significant differences are underlined.

TASK	SHOULDER R	SHOULDER L	ELBOW R	ELBOW L	WRIST R	WRIST L
Opening cans	**SF**	+	**S, P, F**	=	**AB, E, AD**	+
Unscrewing a bottle top (A1)	+	+	**P**	+	**AB, AD**	=
Unscrewing a bottle top (A2)	+	=	+	+	=	=
Pouring from a bottle	=	**AB**	=	=	+	=
Pouring from a carton	=	**AB**	=	=	**E, AD**	=
Drinking from a glass	**SF**	=	=	=	+	=
Eating with a spoon (A1)	+		**P, S**		=	
Eating with a spoon (A2)	+		**F, P, S**		=	
Eating with a spoon (A3)	=		**S, P**		**AD, F**	
Eating with a spoon (A4)	=		**P, S**		**F, AD**	
Eating with a fork (A1)	**SF**		**P, F**		=	
Eating with a fork (A2)	**SF**		**P**		=	
Eating with a fork (A3)	**SF**		=		**AD, F, E**	
Eating with a fork (A4)	**SF**		**P**		=	
Carrying a dish	**SF**	=	**P, S, E**	**E**	+	+
Using a tap	=	+	=	=	=	=
Brushing teeth	=		=		**E**	
Brushing hair (comb)	=	=	**P,S,E**	=	=	=
Brushing hair (brush)	=		**F,S**		=	
Sliding a zip up/down (A1)	=	=	=	=	**AD**	=
Sliding a zip up/down (A2)	=	=	=	+	=	+
Buttoning/unbuttoning a shirt (A1)	=	=	**S**	=	**F**	**F, AD, AB**
Buttoning/ unbuttoning a shirt (A2)	=	=	=	**F**	**F**	**F, AD, AB**

Table 7: Significant differences in rates of neutrality while using the normal products (NP) and ADs for each task for shoulder, elbow and wrist postures. (=) indicates that no significant differences were found and (+) indicates that postures were more neutral while using ADs. When postures were less neutral, the postures that increase are indicated in each cell, ordered from a higher to a lower rate of increase. Empty cells for the left hand when only the right hand was used. Posture abbreviations: SF (slightly flexed), F (flexed), E (extended), AB (abducted), AD (adducted), P (pronated), S (supinated).

4. DISCUSSION

In general terms, the results from the analysis of grasp types show that precision grasps are less frequent than power grasps when using ADs, as expected due to the presence of thicker handles. This is coherent with the results obtained from the study of the contacts of the palm and fingers. While the thumb and index fingers (commonly used in precision grasps) decreased their rate of contact while using ADs, the palm and the rest of the fingers (used in power grasps) increased it. Furthermore, the results obtained from the video analysis show less neutral postures of the arm in the tasks with fewer precision grasps and more power ones (see tasks of unscrewing the bottle top (A1), eating with spoons (A3, A4), eating with fork (A1-A4) or brushing one's hair with a brush). These results may be explained by the use of less neutral arm postures to compensate for the lack of precision of the power grasps. These results are also in accordance with Landsmeer (1962), who stated that in power grasps all the movements of the object have to be generated by the arm joints, while in precision handling the hand is able to perform the entire movement, without requiring any movement of the arm.

From the analysis of grasp types it can be observed that even though differences were obtained for almost all the products, not all these differences implied a decrease in precision grasps. The products used in the tasks of unscrewing a bottle top, eating with a spoon, using the tap, brushing teeth and brushing one’s hair with a brush were the ones that presented a decrease in precision grasps and an increase in power ones. The differences in other tasks arose, however, because of the substitution of the grasp by another of the same type (power or precision), such as the task of pouring from a carton (which presented a higher rate of oblique grasps and a lower rate of cylindrical and lumbrical ones) and the task of drinking (which presented a higher rate of oblique grasps and lower rate of lumbrical ones). Nevertheless, the rest of the tasks presented differences both in power and in precision grasp types. In some cases, an increase in precision grasps was found but always accompanied by an increase in another type of power grasp. In sum, no AD increased the rate of precision grasps significantly (which is coherent with the first global analysis of grasp types, where a general increase in power grasps was obtained). Yet, results show that some products are more suitable than others for people with reduced hand mobility, as some of them still require the use of precision grasps, which may be difficult for them to perform. Precision grasps require an independent movement of the joints and a placement of the fingertips so that the object can be held correctly (which involves an opposition and rotation of the thumb) (Landsmeer, 1962). These required movements are unfeasible for many pathologies, such as osteoarthritis, where the joints that are most affected by the pathology are the distal interphalangeal joints and the base of the thumb (Chaisson et al., 1997), generally resulting in a reduction in both joint mobility and grip strength (Kjeken et al., 2005).

In a detailed study of the results from the arm posture analysis, a less neutral posture was observed in all the joints and combination of several joints when using ADs. On analysing the effect of the products used in each task, it can be seen that only the bottle opener A2, the tap AD and the zip adapter A2 produced a more neutral posture for all the arm joints. Other products produced combined effects, such as the bottle handling AD, which produced a more neutral posture for the right wrist and a less neutral posture for the left shoulder. Other products that also gave rise to combined effects were the can opener AD, the bottle opener A1, the glass adapter, the spoons (A1 and A2) and the dish adapter. Nevertheless, the tasks of pouring from a carton, eating with a spoon (A3 and A4), eating with a fork, brushing one's teeth, brushing one's hair (comb and brush), sliding a zip with A1 and buttoning and unbuttoning a shirt presented less neutral postures for some of the arm joints and, in some cases, for two joints at the same time (e.g. the A3 and A4 spoons produced less neutral postures for the right elbow and wrist). In general terms, they produced more flexed postures of the right shoulder, more extreme postures of pronation/supination of the right elbow, a more flexed posture of the left wrist and more extreme postures of abduction/adduction and flexion of the right wrist. These effects may hinder manipulation in patients in whom these joints are affected, and therefore special care should be taken when prescribing ADs in these cases. These results are in line with those from previous studies that showed that the problems arising when using some ADs depended on the type of impairment (Mann et al., 1993).

The ADs considered implement different changes in the design of the original products. Some of the ADs used in the eating tasks have thicker bent handles (A1, A2, A4), which were observed to provide less neutral postures for the shoulder and elbow in the case of the forks and for the elbow and wrist in the case of spoons. Nevertheless, the A3 adapter (when using the fork), with a thicker but not bent handle, was the only AD fork that presented less neutral postures for the wrist. Therefore, as a thicker handle requires the use of a power grasp, it generates a lack of precision that has to be offset with wider ranges of motion in the rest of the arm joints. Moreover, bending the handle seems to solve this effect at wrist level, at least when using the forks.

Some ADs that implement thicker handles or just additional ones, such as buttoning and unbuttoning ADs, have questionable effects on arm posture, since they generate less neutral postures for the wrist. The same problem appears in the task of opening a bottle with the opener A1, which required a wider range of movement of the elbow and wrist while performing the task, while the opener A2 (with no handle added) did not produce this effect. This same opener A1 was also used in the task of opening a can and, even using it in a different way, it produced the same effect on the right elbow, wrist and shoulder. In the task of carrying a dish, a similar effect on the shoulder and elbow was observed. Less neutral postures were also found during the task of pouring from a carton, drinking from a glass, brushing one's teeth, brushing one's hair (with the comb and the brush), using the A1 zip adapter and buttoning and unbuttoning a shirt. The conclusion here may be that thicker handles or extra handles added to the device in order to help carry out the task reduce the precision of the grasp, which could give rise to side effects to be studied in further work. These results highlight the importance of distinguishing between ADs compensating for a lack of grip strength and those compensating for a loss of dexterity, as considered in a previous study (Shipham, 2003). As pointed out in that work, ADs that compensate for loss of grip strength are most commonly used in pathologies such as rheumatoid arthritis. Nevertheless, these patients (commonly elderly adults) may also present reduced mobility in the entire upper limb, such as osteoarthritis patients (Kjeken et al., 2005). According to the results of this work, care should be taken not to prescribe an AD that requires less neutral postures of the arm joints when compensating for the lack of grip strength. In these cases, the prescription may not be based on the pathology, but on the patient's specific diagnosis and reported limitations. It is important to take this aspect into account, because in pathologies such as osteoarthritis opener ADs are very common (Santos et al., 2018) and, as the results show, there may be different designs available which can thus produce different effects on the entire upper limb.

Before ending, it is important to remark on the limitations of the study. On the one hand, the number of subjects participating in the experiment was low (5 males, 5 females), and they did not suffer from any impairment or pathology. However, they were selected so as to have different (normally distributed) hand sizes in order to obtain representative data of a healthy adult population. Furthermore, as regards the variety of activities and ADs considered, the sample size was large enough (130 for normal products and 220 for ADs) to obtain overall results for ADs. On the other hand, the visual method used to identify the arm posture may have introduced some uncertainty for postures on the borderline, but in these cases a conservative solution was adopted (closest-to-neutral zone was assumed). Furthermore, in order to avoid systematic bias, a single trained observer performed the entire analysis. In future work it would be interesting to recruit a higher number of subjects with different pathologies in order to quantify the effect of the same products depending on the impairment.

Taking into account all the results reported, it can be concluded that not all the products may be suitable for all pathologies. Some products were found to require less neutral postures, and perhaps a redesign is needed if they are intended to assist patients with pathologies affecting upper limb mobility. In this sense, a pathology-oriented design of ADs, focused on the effects of each product on certain joints, could be interesting. This pathology-oriented design would be a significant aid for therapists in the process of selecting ADs. Furthermore, it would be a way to ensure that patients' quality of life is being improved by using the AD, which is, ultimately, their main purpose.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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REFERENCES

Brand, P.W., Hollister, A.M., 1999. Clinical Mechanics of the Hand. Mosby Publishing, St. Louis.

Chaisson, C.E., Zhang, Y., McAlindon, T.E., Hannan, M.T., Aliabadi, P., Naimark, A., Levy, D., Felson, D.T., 1997. Radiographic hand osteoarthritis: incidence, patterns, and influence of pre-existing disease in a population based sample. J. Rheumatol. 24, 1337–43.

David, G.C., 2005. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occup. Med. (Chic. Ill). 55, 190–199. https://doi.org/10.1093/occmed/kqi082

Harman, D., Craigie, S., 2011. Gerotechnology series: Toileting aids. Eur. Geriatr. Med. 2, 314–318. https://doi.org/10.1016/j.eurger.2011.01.017

Hemmingsson, H., Lidstrom, H., Nygard, L., 2009. Use of Assistive Technology Devices in Mainstream Schools: Students' Perspective. Am. J. Occup. Ther. 63, 463–472. https://doi.org/10.5014/ajot.63.4.463

Hepherd, R., 2011. Aids for bathing and showering. Eur. Geriatr. Med. 2, 190–193. https://doi.org/10.1016/j.eurger.2011.02.006

Hoffmann, T., McKenna, K., 2004. A Survey of Assistive Equipment Use by Older People following Hospital Discharge. Br. J. Occup. Ther. 67, 75–82. https://doi.org/10.1177/030802260406700204

Holt, R.C., Holt, R.J., 2011. Gerotechnology: Kitchen aids. Eur. Geriatr. Med. 2, 256–262. https://doi.org/10.1016/j.eurger.2011.01.019

Hwang, J., Kong, Y.-K., Jung, M.-C., 2010. Posture evaluations of tethering and loose-housing systems in dairy farms. Appl. Ergon. 42, 1–8. https://doi.org/10.1016/j.apergo.2010.03.008

Karhu, O., Kansi, P., Kuorinka, I., 1977. Correcting working postures in industry: A practical method for analysis. Appl. Ergon. 8, 199–201. https://doi.org/10.1016/0003-6870(77)90164-8

Kjeken, I., Dagfinrud, H., Slatkowsky-Christensen, B., Mowinckel, P., Uhlig, T., Kvien, T.K., Finset, A., 2005. Activity limitations and participation restrictions in women with hand osteoarthritis: Patients' descriptions and associations between dimensions of functioning. Ann. Rheum. Dis. 64, 1633–1638. https://doi.org/10.1136/ard.2004.034900

Kraskowsky, L.H., Finlayson, M., 2001. Factors Affecting Older Adults' Use of Adaptive Equipment: Review of the Literature. Am. J. Occup. Ther. 55, 303–310. https://doi.org/10.5014/ajot.55.3.303

Landsmeer, J.M.F., 1962. Power Grip and Precision Handling. Ann. Rheum. Dis. 21, 164–170. https://doi.org/10.1136/ard.21.2.164

Long, T.M., Woolverton, M., Perry, D.F., Thomas, M.J., 2007. Training Needs of Pediatric Occupational Therapists in Assistive Technology. Am. J. Occup. Ther. 61, 345–354. https://doi.org/10.5014/ajot.61.3.345

Ma, H.-I., Hwang, W.-J., Chen-Sea, M.-J., Sheu, C.-F., 2008. Handle size as a task constraint in spoon-use movement in patients with Parkinson's disease. Clin. Rehabil. 22, 520–528. https://doi.org/10.1177/0269215507086181

Ma, H.-I., Hwang, W.-J., Tsai, P.-L., Hsu, Y.-W., 2009. The effect of eating utensil weight on functional arm movement in people with Parkinson's disease: a controlled clinical trial. Clin. Rehabil. 23, 1086–1092. https://doi.org/10.1177/0269215509342334

Mann, W.C., Hurren, D., Tomita, M., 1993. Comparison of Assistive Device Use and Needs of Home-Based Older Persons With Different Impairments. Am. J. Occup. Ther. 47, 980–987. https://doi.org/10.5014/ajot.47.11.980

McAtamney, L., Nigel Corlett, E., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. 24, 91–99. https://doi.org/10.1016/0003-6870(93)90080-S

McDonald, S.S., Levine, D., Richards, J., Aguilar, L., 2016. Effectiveness of adaptive silverware on range of motion of the hand. PeerJ 4, e1667. https://doi.org/10.7717/peerj.1667

Santos, P. da S., Martins, N.I.M., Leite, V.M.M., Sanguinetti, D.C. de M., Paixão, L.K.P.A., Marques, C.D.L., Amaral, D.S., 2018. Use of assistive devices by individuals with hands osteoarthritis. Cad. Bras. Ter. Ocup. 26, 145–152. https://doi.org/10.4322/2526-8910.ctoAO0999

Shipham, I., 2003. Rheumatoid arthritis: hand function, activities of daily living, grip strength and essential assistive devices. Curationis 26, 98–106. https://doi.org/10.4102/curationis.v26i3.857

Skymne, C., Dahlin-Ivanoff, S., Claesson, L., Eklund, K., 2012. Getting used to assistive devices: Ambivalent experiences by frail elderly persons. Scand. J. Occup. Ther. 19, 194–203. https://doi.org/10.3109/11038128.2011.569757

Stowe, S., Hopes, J., Mulley, G., 2010. Gerotechnology series: 2. Walking aids. Eur. Geriatr. Med. 1, 122–127. https://doi.org/10.1016/j.eurger.2010.02.003

Van, D., Steenbergen, B., 2007. The use of ergonomic spoons by people with cerebral palsy: effects on food spilling and movement kinematics. Dev. Med. Child Neurol. 48, 888–891. https://doi.org/10.1111/j.1469-8749.2006.01940a.x

Vergara, M., Sancho-Bru, J.L., Gracia-Ibáñez, V., Pérez-González, A., 2014. An introductory study of common grasps used by adults during performance of activities of daily living. J. Hand Ther. https://doi.org/10.1016/j.jht.2014.04.002

Wang, H., Hwang, J., Lee, K.-S., Kwag, J.-S., Jang, J.-S., Jung, M.-C., 2014. Upper Body and Finger Posture Evaluations at an Electric Iron Assembly Plant. Hum. Factors Ergon. Manuf. Serv. Ind. 24, 161–171. https://doi.org/10.1002/hfm.20362

Wielandt, T., Mckenna, K., Tooth, L., Strong, J., 2006. Factors that predict the post-discharge use of recommended assistive technology (AT). Disabil. Rehabil. Assist. Technol. 1, 29–40. https://doi.org/10.1080/09638280500167159

Yeung, K.T., Lin, C.H., Teng, Y.L., Chen, F.F., Lou, S.Z., Chen, C.L., 2016. Use of and selfperceived need for Assistive devices in individuals with disabilities in Taiwan. PLoS One 11, 1–13. https://doi.org/10.1371/journal.pone.0152707