Development and validation of a clinically applicable arm use monitor for people after stroke

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J. Rehabil. Med. **2018**; *50: 705-712*

ABSTRACT

Objective: Developing and validating a clinically applicable and easy-to-use accelerometry-based device to measure arm use in people after stroke, i.e., the Activ8 arm use monitor (Activ8-AUM).

Design: Development and validation study.

Patients: Included were 25 people after stroke at different stages of rehabilitation.

Methods: The Activ8-AUM consists of three single-sensor Activ8s: one on the unaffected thigh and one on each wrist. Arm use was calculated by combining movement intensity of the arms with data from body postures and movements from the leg sensor. Data were divided into two sets: one for determining situation-specific movement intensity thresholds for arm use, and the other to validate the Activ8-AUM using video recordings.

Results: Overall agreement between the Activ8-AUM and video recordings was 75%, sensitivity was 73% and specificity was 77%. The agreement between the different categories of arm use ranged from 93-42% for the affected arm and from 82-24% for the unaffected arm.

Conclusion: By combining the movement intensity threshold with body postures and movements, good agreement was reached between the Activ8-AUM and video. This result, together with the easy-to-use configuration, makes the Activ8-AUM a promising device to measure arm use in people after stroke.

BACKGROUND

After stroke, about 75% of the survivors suffer from impairments of the arm, such as paralysis[1]. These impairments often result in limitations in daily life activities, greater dependency, and restrictions in social participation[2]. Limitations in daily life activities can be due to reduced performance of the arm which, in turn, can be the result of decreased capacity. However, the reduced performance can also be a result of other factors, leading to a discrepancy between what people can do (capacity) and what they actually do (performance), and in a weak or absent relationship between capacity and performance[3-5]. This so-called non-use of the affected arm is an important topic in stroke rehabilitation[6]. Therefore, besides measuring arm capacity with existing clinical measures, arm use needs to be measured too. Objectively measured arm use can be used to evaluate the effect of rehabilitation, and also during rehabilitation for coaching and feedback to stimulate arm use and personalize treatment.

Accelerometry has been introduced as an objective method to measure arm use in people after stroke[7-11]. This technique is at the moment the only one which objectively measures long periods of time to be able to measure behavior in daily life. Wrist-worn accelerometers measure arm movement and can provide a measure of arm use. However, use of accelerometry to measure arm use has specific challenges, particularly regarding sensitivity and specificity: e.g., to what extent does the device accurately determine periods of arm use when measuring arm movements. Some types of arm use (e.g., holding a cup of coffee) are associated with as little movement as possible. In addition, not all movements are necessarily related to arm use, e.g., arm movements measured during walking and during other whole body movements are functionally different from arm movements during sitting or standing. This latter issue, in which arm use is generally overestimated, has been recognized in other studies. For example, Uswatte et al.[12] used the ratio of the affected and unaffected arm, assuming that movements during walking and whole body movements affect both arms equally ; this notion has also been applied by others[10,11,13]. However, being able to remove arm movements due to walking would be a more reliable method to overcome this source of overestimating arm use. Therefore, our group developed and validated a device (the Vitaport ULAM[14]) which combines the movement intensity of the arms with data on body postures and movements (hereafter called 'postures/movements'). This additional information allows to detect walking and, based on this information, separate arm movement during walking from arm use. Rand & Eng[15,16] also used such a configuration to eliminate activity counts of arm swing while walking.

However, our previously developed Vitaport ULAM is an expensive multi-sensor system; moreover, because it is not user-friendly for patients to wear, and for therapists to analyze the data, it is not practical for use in daily life. To overcome these issues, but to still objectively measure arm use combined with postures/movements in daily life, a new clinically applicable and easy-to-use arm use monitor is required. In a previous study, we showed that measuring postures/movements in people after stroke with the Activ8 Physical Activity Monitor (Activ8) resulted in an accuracy of > 95% for the 'upright position' and of > 90% for 'lying/sitting and bicycling'[1]. The Activ8 is a simple one-sensor and low-cost accelerometer that is suitable for use in daily life[17]. For the present study we used the functionality of the existing Activ8, placed on the front of the unaffected thigh, and combined that with two additional Activ8s, one on each arm; this new configuration was called the 'Activ8 arm use monitor' (Activ8-AUM). The aims of the present study were to develop an algorithm to detect arm use using the Activ8-AUM, and to assess the validity of this new device and algorithm to detect arm use in people after stroke.

METHODS

Participants

In the present study we included people after stroke suffering from mobility problems in the arm, the leg or both and aged between 18 and 75 years. People after stroke were excluded when mobility problems were not caused by the stroke, or when they had insufficient communication skills or cognitive function to understand instructions. To guarantee safe participation, people after stroke with a functional ambulation category score <3[18] were also excluded. Between October 2015 and February 2016, eligible people after stroke were recruited via their physiotherapist or were approached by letter via their treating physician. For screening, the clinical expertise of the individual's physical therapist or physician was used. All participants provided written informed consent. The study was approved by the Medical Ethics Committee of Erasmus MC University Medical Center Rotterdam (MEC 2015-211). We were able to included 25 people after stroke: 22 males and 3 females, mean age of 56 (SD 12) years. These participants had a mean post stroke time of 15 (SD 14) months; 10 participants suffered from a hemorrhage stroke, and 11 were affected on the right side. Arm function was measured with the Frenchay Arm Test (scores 0-5, with higher scores indicating better function)[19]: 14 participants had a score of 0 or 1, 1 participant had a score of 2, and 10 participants had a score of 4 or 5.

Classification of arm use

For this study, the theoretical starting point was the framework for arm use as defined by Schasfoort et al.[20]. According to this framework, arm use is defined as 'active movement

[1] Fanchamps et al. The Accuracy of the Detection of Body Postures and Movements Using a Physical Activity Monitor in People after a Stroke

of parts of the arm, holding objects or leaning' (Figure 5.1). This framework also shows that arm use is conceptually not the same as arm movement, and reveals the challenges and limitations of measuring arm use with accelerometry. For example, arm use can occur without much movement (e.g., when holding a cup of coffee; Figure 5.1, class 1). On the other hand, arm movement is not necessarily related to arm use, e.g., arm movements that are primarily the result of whole-body movements, such as changing sitting posture (Figure 5.1, class 4). In the framework of Schasfoort et al.[20], arm movement during walking is considered to be secondary use. In the present study, we focus only on primary use, assuming that this occurs only during sitting or standing. Therefore, analyzing arm data during walking was beyond the scope of this study.

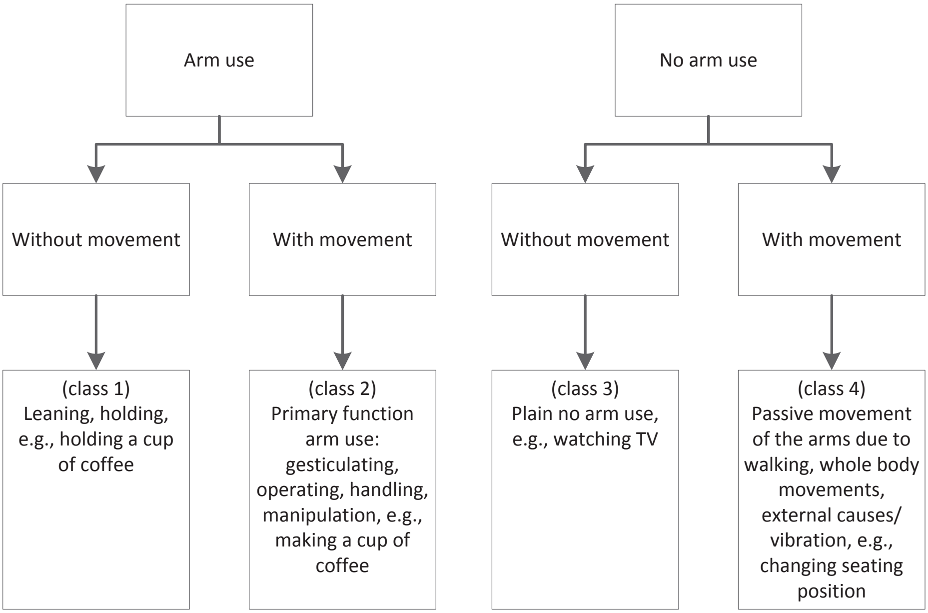

Figure 5.1 Different classes of arm use showing the relation between use and movement.

Measurement protocol

We designed a measurement protocol (Table 5.1) that included activities mainly encompassing one of the first three classes of Figure 5.1. Although no activities with class 4 as a major part of the activity were included, this class was expected to occur during other activities. Measurements were performed at a rehabilitation clinic or at the participant's home. Each specific activity lasted approximately 80 s; however, especially at the participant's home and during complex activities with arm task, the duration of some activities could be shorter (e.g., if the activity was completed) or longer (e.g., kitchen activities). The total protocol lasted maximally 1 h (including rests between activities).

Table 5.1 Activities of daily life included in the measurement protocol.

Activities including arm use, but without arm movement (class 1)	Activities including arm use, and with arm movement (class 2)	Activities including no arm use, and without arm movement (class 3)	Activities including no arm use, but with arm movement (class 4)
Sitting with a static arm task ‡	Sitting with a dynamic arm task ‡	Lying without an arm task	No tasks included
Standing with a static arm task ‡	Standing with a dynamic arm task ‡	Sitting without an arm task *	
	Personal care activities	Standing without an arm task *	
	Vacuuming		
	Hanging laundry		
	Packing a bag		
	Kitchen activities		
	Throwing a ball		

** these activities were performed twice; ‡ these activities were performed combined with multiple functional upper limb tasks (e.g., holding/reading a paper, writing, eating, and getting dressed).*

During lying, sitting, and standing without arm task, participants were instructed to be as still and as comfortable as possible. During all other activities, they were instructed to perform the activity at a comfortable, self-selected pace and using their own movement strategy. Any activities that appeared to be too difficult for an individual were excluded from the protocol. For safety reasons, participants stated their own physical limits and supervision was available during all measurements. However, to ensure that activities were performed as 'normally' as possible (to reflect everyday life), the supervision was kept as unobtrusive as possible.

Activ8 arm use monitor (Activ8-AUM)

The Activ8-AUM consists of three Activ8s (2M Engineering, Valkenswaard, The Netherlands)[17]: one Activ8 on the front of the unaffected thigh, and the others on each wrist (Figure 5.2). All sensors are easy to attach: those on the wrists are worn dorsally (like a watch) and attached with a wristband. The one on the leg is attached (with skin tape while sitting) to the front of the leg approximately halfway between hip and knee. The concept of the Activ8-AUM is similar to that of the Vitaport ULAM used by Schasfoort et al.[14], which has sensors on the wrists, chest and legs, and combines the movement intensity of the arms with data on postures/movements to calculate arm use.

The Activ8 contains a triaxial piezoelectric crystal accelerometer and was originally designed as a one-sensor device to wear on the leg or in a trouser pocket. It measures postures/movements (lying/sitting, standing, walking, cycling, running, and non-wear) as well as their movement intensity (expressed in the arbitrary unit movement counts).

Figure 5.2 Placement of the three Activ8s of the Activ8-AUM device.

Detection of postures/movements is based on the angular position of the sensor and the movement intensity, whereas movement intensity is based on the variability around the mean of the raw acceleration signal. Raw acceleration signals are measured at 12.5 Hz and converted to postures/movements with a resolution of 1.6 Hz. Data were stored with the smallest possible epoch of 5 s, resulting in eight samples for the postures/movements per epoch. For each epoch the movement counts are calculated per detected postures/movements. The internal clock used a 32kHz watch crystal (20ppm), resulting in a max clock drift of 2 s per 24 h. To be able to measure arm use, two additional Activ8s were used (one on each wrist). In the analyses, only the movement intensity data from these two sensors were used. For this, the movement counts of the detected postures/movements were summed per wrist sensor to one value for each 5-s epoch per arm, representing the total movement intensity of that arm during those 5 s. Therefore, the smallest unit in which the data could be analyzed was an entire epoch of 5s.

Video recording as reference method

A handheld digital video camera was used to record all activities; this served as the reference method. Each second of the video was classified based on the classes described in Figure 5.1: 1) arm use without movement, 2) arm use with movement, 3) no arm use without movement, and 4) no arm use with movement. To do this, criteria for the different classes were developed, extensively discussed and tested. Arm use was defined as voluntary, purposeful activity of the arm, related to active movement of the arm, or holding objects or leaning. Movement was defined as at least an observable movement of the wrist with a minimal duration of 1 s; this meant that a minor finger movement or a movement lasting only a fraction of one second was not assigned as movement. These two definitions were combined to classify the four classes mentioned above. If a classification showed to be ambiguous, a second researcher was asked to analyze this part of the measurement. In cases of no agreement a third observer was involved. Both arms were scored separately, because the classification of both arms was not necessarily the same during 1 s. Thereafter, the 1-s four-class classification was converted to a 5-s two-class classification to be comparable to the 5-s dichotomous output of the Activ8-AUM, i.e., arm use and no arm use. First, class 1 and 2 of the 1-s classification were recoded to arm use and class 3 and 4 were recoded to no arm use. Then, the majority of the samples within an epoch determined the classification for the entire epoch, either as arm use or no arm use.

Data analysis

As mentioned, the Activ8-AUM combines the movement intensity of the arms with data on postures/movements from the leg sensor. The Activ8-AUM is based on the assumptions that 1) arm use only occurs during sitting and standing, and 2) that arm use is associated with a movement intensity above a certain level. The second assumption requires defining an optimal movement intensity threshold. To do this, half of the data were selected as a development dataset, and the other half was used to validate the Activ8-AUM. The detection of postures/movements and calculation of the movement counts was done with the standard Activ8 software. These data were the input for an in-house MATLAB program detecting arm use.

Development of the Activ8-AUM

First, the data on postures/movements from the leg sensor were combined and time-synchronized with the data on movement intensity of the arm sensors and with the video data. Synchronization of the sensors was based on the time stamps within the data files using the 'synchronize' function of Matlab. The second step was selecting epochs of lying/sitting and standing, based on the postures/movements data from the leg sensor. An epoch was selected as lying/sitting when at least 5/8 samples within the 5-s epoch were determined as lying/sitting. The same holds for standing, when at least 5/8 samples had to be determined as standing for an epoch to be selected as standing. To fulfill the second assumption of the Activ8-AUM mentioned before, in the development dataset four movement intensity thresholds were determined: for the situation (A) unaffected arm during lying/sitting; (B) affected arm during lying/sitting; (C) unaffected arm during standing; (D) affected arm during standing. Although the protocol was carefully composed, such an imposed protocol probably has a different ratio of arm use and no arm use than the ratio in daily life. This different ratio might affect the optimal movement intensity threshold. Therefore, our data were adjusted to create a ratio comparable to that earlier established in the daily life of people after stroke[6]. To establish the optimal movement intensity threshold for each of the four situations mentioned above (A-D), thresholds were systematically changed between 1 and 40 movement counts, in steps of 1. Within each of the four situation, arm use was determined based on all possible thresholds (0/1, no arm use/arm use) and was compared to the two-class classification of arm use according to the video data. To determine the accuracy of each threshold per situation, the Youden's index[21] was calculated.

$$\text{Youden's index} = \text{sensitivity} + \text{specificity} - 100$$

In this, sensitivity was defined as:

$$\frac{\textit{number of samples the Activ8-AUM correctly determined as arm use}}{\textit{number of total samples of arm use}} \times 100\%$$

and specificity was defined as:

$$\frac{\textit{number of samples the Activ8-AUM correctly determined as no arm use}}{\textit{number of total samples of arm use}} \times 100\%$$

Per situation mentioned above (A-D), the movement intensity threshold with the highest Youden's index was chosen to be the value for the movement intensity above which an epoch is classified as arm use.

$$\frac{\textit{number of samples correctly determined as arm use} + \textit{correctly determined as no arm use}}{\textit{total number of sample}} \times 100\%$$

Validation of the Activ8-AUM

To validate the Activ8-AUM we applied the optimal movement intensity thresholds, determined in the development dataset, to the validation dataset. Again, arm use according to the Activ8-AUM was compared to arm use according to the video data (both dichotomous measures: arm use/no arm use). Then, sensitivity, specificity, and agreement were calculated overall and for different groupings of the data: per limb, per class of Figure 5.1, and per activity of the protocol. Agreement was defined as:

$$\frac{\textit{number of samples correctly determined as arm use} + \textit{correctly determined as no arm use}}{\textit{total number of sample}} \times 100\%$$

When calculating the outcomes per activity of the protocol, there was no arm use expected in activities without arm task, like only arm use was expected in activities with arm task. However, since the video recordings were used as golden standard, it might be possible that some arm use appeared in tasks without arm task and sometimes no arm use was performed in activities with arm tasks. Therefore, both sensitivity and specificity were calculated per task, provided that arm use or no arm use sufficiently appeared, i.e. at least more than 60 s (=12 5-s epochs).

RESULTS

Participants

Six participants (relatively early after their stroke onset) who were unable to perform all the activities in a first session, agreed to participate in an additional session later on during rehabilitation; for these participants, both sessions were used for the analysis. The total group of 31 measurements was divided into two datasets; a development dataset with 16 measurements and a validation dataset with 15 measurements.

Development of the Activ8-AUM

Figure 5.3 presents the movement counts for different activities of the development dataset. For both the affected and unaffected arm, the median movement counts of activities without arm task were low compared to those with arm task, indicating that a threshold could be set for discriminating between these two. However, the interquartile range was relatively large for all activities, indicating that the intensity of arm use and no arm use differed between and within participants, and that an overlap in movement counts existed between arm use and no arm use. For the affected arm, median movement counts were smaller than for the unaffected arm, with the largest difference during standing.

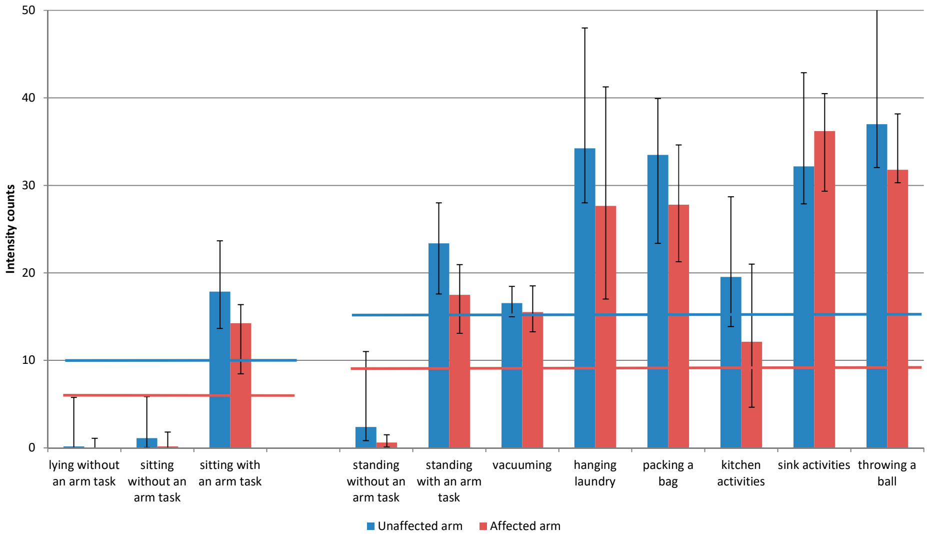

Figure 5.3 Median movement counts (25th to 75th percentile) per activity for the unaffected and affected arm.

The first three activities are subcategories of lying/sitting, the remainder are subcategories of standing. Horizontal lines indicate the movement intensity thresholds above which an epoch is classified as arm use (black for the unaffected and grey for the affected arm). The 75th percentile for throwing a ball with the unaffected arm was 94 counts.

The overlap in movement counts between arm use and no arm use showed that it was not possible to define a threshold with 100% accuracy for detecting arm use. Based on the highest Youden's index, four movement intensity thresholds defining arm use were determined: for both standing and lying/sitting activities, separately for the affected and unaffected arm (Figure 5.3: see horizontal lines). Table 5.2 shows that, after applying those thresholds in the development dataset, the sensitivity, specificity, and agreement between the Activ8-AUM data and the video data were all 74% or higher.

Validation of the Activ8-AUM

Table 5.3 shows the number of epochs, the sensitivity, specificity, and agreement between the Activ8-AUM and the video of the validation dataset for the different groupings of data. Table 5.2 directly compares these variables in the development and validation dataset. The validation dataset contained 2802 5-s epochs for the unaffected arm and 2557 5-s epochs for the affected arm, which corresponds to ≥ 3.5 h of measurement. Overall, detecting arm use had a sensitivity of 73% and a specificity of 77%. In case arm use was not correctly determined it was determined as no arm use. When evaluating the validity per class of Figure 5.1, or per activities of the protocol, the accuracy was consistent but with some important exceptions. 'Arm use without movement' (class 1) was frequently detected incorrectly, especially in the unaffected arm (sensitivity unaffected arm: 24%; affected arm 42%). An example of this is holding onto the table during standing, which is arm use without movement but which was often incorrectly classified as no arm use. Also 'no arm use with movements' (class 4) was less accurately detected (specificity unaffected arm: 53%; affected arm: 64%). As expected, when comparing the validity between the development and validation dataset, the sensitivity, specificity, and agreement was -10 to 11 points lower (Table 5.2, Validation dataset).

Table 5.2 Data on sensitivity, specificity, and agreement in total time between Activ8-AUM and video recording (all in %) in the development dataset and validation dataset.

		Development dataset			Validation dataset		
		Sensitivity	Specificity	Agreement	Sensitivity	Specificity	Agreement
Lying/ Sitting	(A) Unaffected arm	80	74	77	71	80	76
	(B) Affected arm	78	90	89	78	78	78
Standing	(C) Unaffected arm	77	76	77	67	75	69
	(D) Affected arm	77	82	80	87	74	78

Table 5.3 Data on sensitivity, specificity, and agreement in total time between Activ8-AUM and video recording (all in %) in the validation dataset.

			n	Sensitivity	Specificity	Agreement
Overall data			5359	73 (3-100)	77 (37-95)	75 (27-88)
Per arm		Unaffected arm	2802	69	79	73
		Affected arm	2557	82	76	78
Per class	Arm use without movement (class 1)	Unaffected arm	267	24	N/A	24
		Affected arm	154	42	N/A	42
	Arm use with movement (class 2)	Unaffected arm	1360	78	N/A	78
		Affected arm	600	93	N/A	93
	No arm use without movement (class 3)	Unaffected arm	1055	N/A	82	82
		Affected arm	1490	N/A	79	79
	No arm use with movement (class 4)	Unaffected arm	116	N/A	53	53
		Affected arm	298	N/A	64	64
Per activity	Lying without an arm task	Unaffected arm	109	N/A	90	90
		Affected arm	118	N/A	89	89
	Sitting without an arm task	Unaffected arm	495	54	81	77
		Affected arm	455	77	79	79
	Standing without an arm task	Unaffected arm	318	8	85	55
		Affected arm	311	N/A	84	84
	Sitting with an arm task	Unaffected arm	842	69	78	73
		Affected arm	731	77	73	75
	Standing with an arm task	Unaffected arm	311	82	80	82
		Affected arm	278	78	64	69
	Vacuuming	Unaffected arm	119	57	52	56
		Affected arm	117	93	68	77
	Hanging laundry	Unaffected arm	130	98	N/A	94
		Affected arm	126	100	90	94
	Packing a bag	Unaffected arm	62	97	N/A	92
		Affected arm	41	100	44	78
	Kitchen activities	Unaffected arm	263	58	50	57
		Affected arm	228	96	65	79
	Personal care activities	Unaffected arm	113	94	31	87
		Affected arm	112	59	88	76
	Throwing a ball	Unaffected arm	40	100	N/A	70
		Affected arm	40	N/A	54	68

DISCUSSION

In this study, we developed and validated the Activ8-AUM to measure arm use in people after stroke. This device consists of three simple and low-cost accelerometers (one on the unaffected thigh and the others on each wrist). The device provides data on the movement intensity of the arms, and on postures/movements based on the leg sensor. Combining these different types of data allowed to define body posture-specific movement intensity thresholds for arm use, and to separate arm movement during walking from arm movement during sitting and standing. In the validation part of the study, the Activ8-AUM showed similar results in detecting arm use as the previously developed Vitaport ULAM[20], which measured more detailed data on postures/movements and arm use. However, the Vitaport ULAM is not practical for use in daily life.

Arm use in people after stroke has also been measured by other groups. In the present study, the way of measuring arm use was conceptually similar to the approach of Schasfoort et al.[22] and Michielsen et al.[6] using the Vitaport ULAM, and to Rand & Eng[15] using accelerometers on the wrists and hip. Other studies used more simple sensor configurations based on sensors on each wrist[10,11,13,23-25]. Besides measuring arm use in daily life, Lemmens et al.[26] focused on the detection of specific activities of daily life such as 'drinking from a cup' and 'brushing hair'. For this they needed several accelerometers on the hand, wrist, arm and chest. Thus, most of the available devices do not use information on postures/movements or a movement intensity threshold; however, the effect of using this additional information and threshold has not yet been evaluated.

A general limitation of using accelerometry to quantify arm use is that not all arm movement should be considered as arm use and, vice versa, no arm movement is not necessarily an indication of no arm use. The Activ8-AUM has this limitation too: arm use was poorly detected during holding an object or leaning when arms are displaced little or not at all (Table 5.3, class 1). Idem, no arm use was less accurately detected when the arm was moving (class 4). However, adding data on postures/movements was helpful in reducing this latter form of mistakes: arm movement during walking was not incorrectly classified as arm use, due to the known body movement of walking. Although, during no arm use, arm movements due to slight general trunk movement during standing were still misclassified as arm use. This general limitation of accelerometry should not hamper future usage of the Activ8-AUM. Arm use which is difficult to detect with accelerometry (holding, leaning, small manipulations) is mainly preceded and followed by arm movements to bring the arm in the right position. While in people after stroke, less leaning and holding with the affected arm is expected, easily detectable arm movements will also be performed less often. Moreover, it was considered highly likely that arm movement and arm use is related[27]. Therefore, although it is not possible to directly measure arm use with accelerometry, the amount of arm movements were considered a meaningful parameter.

Development of the Activ8-AUM

In the development part of this study, we determined four movement intensity thresholds above which an epoch is optimally classified as arm use. Four different thresholds were used to take into account the differences in movement intensity between lying/sitting and standing, and between the affected and unaffected arm. This approach was supported by the data: the optimal threshold for standing (when more body movement affecting arm movement can be expected) was higher than for lying/sitting. Also, the optimal threshold for the affected arm (associated with slower movements and lower movement intensities) was lower than for the unaffected arm. It should be noted, however, that the severity of a stroke will affect the movement and movement intensity of the affected arm. In the present approach, thresholds are based on group level data, which may be suboptimal for individuals. In the future, more individualized thresholds could be explored, e.g., using different thresholds for different levels of arm function based on standardized tests (e.g., the Frenchay Arm Test[19]). To determine the four optimal movement intensity thresholds, the Youden's index was used because it combines sensitivity and specificity[21]. We felt that, for our device, sensitivity and specificity are equally important and that, therefore, the highest sum of both is the best criterion to define the thresholds. An alternative criterion could have been the highest agreement; however, the benefit derived from the highest sum of both the sensitivity and specificity would then be lost. Moreover, our data showed that agreement was a less discriminative criterion, because several thresholds showed comparable optimal agreement percentages. It is important to realize that the sensitivity and specificity and, therefore, the Youden's index are influenced by the activities included in the protocol, and the ratio of arm use and no arm use. Thus, whether the four determined thresholds will be as optimal to measure arm use in daily life will depend on the extent to which the activities of daily life differ from those in the protocol, and the ratio of arm use and no arm use in daily life. To take this into account, our data were adjusted to create a ratio comparable to that established previously in people after stroke[6].

Validation of the Activ8-AUM

In the present study an overall agreement of 75% was found between the Activ8-AUM data and the video data, which is comparable to the agreement scores of the previously developed Vitaport ULAM[20]. That earlier system provided meaningful outcomes in several studies in people after stroke[6] and in patients with complex regional pain syndrome[22], which supports the conclusion that the agreement percentage of 75% is sufficient for application in descriptive and evaluative studies. However, the large individual difference in overall sensitivity, specificity, and agreement showed that movement intensity thresholds, which are based on group level data, are not optimal for all individuals. One reason for this is the ratio of arm use and no arm use. Although in the total group we adjusted our data to create a ratio comparable to that in daily life of people after stroke[6], the individual data still show a large difference in that ratio, especially in participants with low agreement scores. Inspection of specific activities showed that standing without arm task was often detected incorrectly. During standing, although no arm tasks were imposed, some participants were holding onto a table or a walking aid. In the video analyses this was scored as arm use (without movement, class 1), whereas the Activ8-AUM detected this as no arm use due to the low movement intensity; this is a typical example of the above described source of misdetection.

Limitations

Some limitations of the study need to be addressed. First, we used one Activ8 on the thigh to detect postures/movements, in order to distinguish between lying/sitting, standing, and other body movements. This application of the Activ8 was previously validated to measure postures/movements in healthy persons[2] and people after stroke[3], and showed good discrimination between lying/sitting, standing, and other postures and movements. Nevertheless, detection of postures/movements is not flawless and might have influenced the periods in which arm use was determined. However, we expected this influence to be small, i.e., based on the accuracy of the Activ8, very few periods of actual lying/sitting or standing will be missed. A second limitation is that quantifying the reality (i.e., what actually happened), per second, based on the videos was difficult and prone to subjective interpretation. To decrease this effect, classification of arm use was carefully performed based on well-defined criteria for the different classes. Classification was first practiced and then performed by one researcher; agreement with a second researcher was obtained in case of doubt.

CONCLUSIONS

In this study a novel clinically applicable and easy-to-use arm activity monitor was developed. A good agreement between the Activ8-AUM and the video recordings was reached for measuring arm use when a movement intensity threshold for the arm accelerations was combined with postures/movement data. Besides this good agreement, the Activ8-AUM has an easy-to-use configuration with three simple and low-cost accel-

[2] Horemans et al. The Activ8 Activity Monitor: validation of posture and movement classification

[3] Fanchamps et al. The Accuracy of the Detection of Body Postures and Movements Using a Physical Activity Monitor in People after a Stroke

erometers placed on the leg and on both wrists. Therefore, the Activ8-AUM is a promising device for researchers and clinicians to measure arm use in people after stroke.

ACKNOWLEDGMENTS

The authors thank all the people after stroke who participated in this study, Gerard M Ribbers for his help in recruiting the participants, and the students involved in the collection of the data.

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