RELIABILITY OF THE MMAAS: A WEARABLE SYSTEM FOR MONITORING MOTION AND MUSCLE SYNERGIES IN CLINICAL SETTINGS

[1]Alessio Murgia, [2]Ellen Jaspers, [1]Hans Savelberg, [2]Kaat Desloovere and [1]Kenneth Meijer
[1]Department of Human Movement Sciences, Maastricht University Medical Centre + (MUMC+), Maastricht University, Maastricht, The Netherlands; email: alessio.murgia@maastrichtuniversity.nl
[2]Department of Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven, Belgium

SUMMARY

Objective measurement of movement during physical rehabilitation is central to quantifying patient's progress. We have developed a wearable system for recording upper limb motion and muscle synergies in a single unit. The device is primarily intended for clinical use, and it has been designed to provide information suitable for quantifying rehabilitation progresses. We present here a reliability study on the proposed device, together with a quantification of subject consistency during functional activities. Five healthy volunteers were tested on two occasions, one week apart, by the same investigator. The test consisted of a set of activities of daily living performed cyclically, according to a standardized protocol. Intraclass correlation coefficients (*ICCs*) and standard error of the measurement (*SEM*) were used to quantify test-retest reliability and individual subject consistency. A selection of parameters from the system's angular outputs was considered for analysis. Shoulder rotation active range of motion (*AROM*) was the most reliable measurement, followed by maximum elbow supination, shoulder flexion *AROM* and maximum elbow flexion. Subject consistency for the movements considered ranged between 2-7º. Considerations on the significance of these results in relation to optimal sample size, and applications to monitoring upper limb impairments are discussed.

INTRODUCTION

An objective measurement of upper limb movements during functional activities is necessary to evaluate the progress of patients undergoing physical rehabilitation. Established technologies such as optoelectronic systems allow capturing movements with few degrees of error but are limited, due to their elevated cost and lack of portability, to clinical locations where space and financial resources are adequate [1]. Following the increased accuracy and lower costs of microelectromechanical systems (MEMS), portable devices based on MEMS have become more widespread. However there are still limitations in the use of these systems for clinical analysis, as they are mostly confined to measuring movement with no information on parameters related to coordination. We have developed a wearable system that can be used to measure motion and muscle synergies in a single unit [2]. The MMAAS (Motion and Muscle Ambulatory Activity System) incorporates inertial, magnetic and EMG sensors for capturing motion and muscle activity, and is intended to be used in clinical settings. Through the software interface information on joint coordination and muscle activation can be conveyed to the user [2]. The intended use of the MMAAS is to monitor upper limb movements of patients undergoing rehabilitation following neurological impairments. Therefore, in order to develop an effective clinical monitoring tool, a reliability study is required in advance. In this study we report on the reliability of the MMAAS in a population of healthy individuals performing a series of activities of daily living. We draw conclusions for the first time on such system for upper limb monitoring in a clinical setting by quantifying intra-rater test-retest reliability and subject consistency.

METHODS

Five healthy volunteers, 3 right-handed and 2 left-handed, aged within the range expected for stroke subjects (mean age: 49.2 years; *SD*: 8.6 years), were asked to perform a series of daily activities according to a standardized protocol. The MMAAS sensors were attached to a grounded support parallel to the thorax, as well as to the sternum, the cranial edge of the scapular spine, the middle of the arm facing the lateral side and to the dorsal side of the distal end of the forearm. The MMAAS sensors were secured using Leukoplast® and, in the case of the arm and forearm, were mounted on top of an additional bandage. The setup is illustrated in Figure 1. The axes of the different body segments were oriented according to the ISB recommendations [3]. The joint angles were calculated in the MMAAS software from the inertial sensor data according to the procedure described in [2].

Subjects were set up and measured by the same investigator on two separate occasions, one week apart from each other. The same protocol was followed both times. Subjects were instructed to perform each task by starting and ending at the same point, clearly indicated, and to execute the movement in a sequence of four repetitions according to a set of instructions explained beforehand. Several activities were analyzed for reliability, as described in Table 1 and in the text. The following parameters were considered in the study: active range of motion (*AROM*) during the task, maximum angular value, and minimum angular value. Test-retest reliability was calculated in SPSS® using the intraclass correlation coefficient (*ICC*) for consistency in the two-way mixed effect model. In addition the standard error of the measurement (*SEM*), which quantifies the reliability within individual subjects, was also calculated as the square root of the error mean square term in the repeated measures ANOVA [4].

Figure 1: Location of MMAAS sensors, front and side view. Reflective markers are also shown as part of an additional validation study with an optoelectronic motion capture system.

RESULTS AND DISCUSSION

The significant *ICCs* and relative *SEM* are shown in Table 1. Shoulder rotation *AROM* was the most reliable measurement, followed by maximum elbow supination, shoulder flexion *AROM* and maximum elbow flexion. The latter was measured during a hand to mouth task (sitting with elbow at 90º, reach from middle to mouth) and it was not included in Table 1 since p = 0.055 (*ICC* = 0.717; *SEM* = 2.719º), although a significance level α = 0.05 cannot be considered a too strict threshold given the limited number of subjects [4].

The *ICCs* and *SEM* found in this study were comparable with those found in reliability studies on 3D gait measurements using optoelectronic motion capture systems [5]. A large *ICC* can, by definition, be the result of high between-subject variability, which can hide the effect of poor trial-to-trial consistency [4,6]. For this reason *ICC* should be interpreted in the context of the *SEM*, which represents subject consistency. A smaller *SEM* is indicative of a higher precision of individual scores. Based on the *SEM* shoulder rotation *AROM* was the measurement with the smallest amount of noise. A *SEM* of 2-5º is within the error range reported for reliability studies on 3D gait measurements [6].

This study is limited in that a small group of subjects and replicates (two measurements, one week apart) were included. As a consequence, several parameters considered in the reliability study resulted in non-significant *ICCs*. Therefore future research will be focused on increasing sample size in terms of number of replicates and subjects, factors that can also lower the *SEM* [7].

CONCLUSIONS

Intra-rater test-retest reliability of the MMAAS was found to be comparable with 3D gait data measurements using optoelectronic motion capture systems. Current developments are centred on designing more wearable sensors, validating the angular outputs against an optoelectronic motion capture system, and adjusting data presentation to the clinician’s needs and language. Current applications include monitoring the effect of robot-assisted rehabilitation therapy in stroke subjects.

ACKNOWLEDGEMENTS

This work was supported in part by the Department of Dutch Economic affairs and the EU (Interreg project grant IVA-VLANED-1.14).

REFERENCES

1. Peters A, et al., *Gait & Posture*. **31**: 1-8, 2010.
2. Murgia A, et al. Proceedings 32nd Annual International Conference of the IEEE EMBS, Buenos Aires, Argentina, 931-934, 2010.
3. Wu G, et al., *Journal of Biomechanics*. **38**: 981-992, 2005.
4. Weir JP, *Journal of Strength and Conditioning Research*. **19**: 231-240, 2005.
5. McGinley JL, et al., *Gait & Posture*. **29**: 360-369, 2009.
6. McGraw KO, et al., *Psychological Methods*. **1**: 30-46, 1996.
7. Walter SD, et al., *Statistics in Medicine*. **17**: 101-110, 1998.

Table 1: Results of the test-retest reliability and subject consistency analysis during the selected activities.

Activity	**Angle**	***ICC***	***SEM* (degrees)**
Sitting with elbow flexed at 90º and arm vertical, rotate arm externally	Shoulder Internal/External Rotation *AROM*	0.926 ($p < 0.01$)	2.210
Sitting with elbow flexed at 90º, execute full supination-pronation	Max Elbow Supination	0.802 ($p < 0.05$)	4.350
Sitting with elbow flexed at 90º, reach from middle to ipsilateral side at arm length. Target was at shoulder height and one shoulder width	Shoulder Flexion/Extension *AROM*	0.794 ($p < 0.05$)	4.983
As previous but with the target placed on the contralateral side	Shoulder Flexion/Extension *AROM*	0.779 ($p < 0.05$)	6.659