Neuromotor Pattern of the Upper Limb in Hygiene Activities Using Electromyography and Accelerometery Technology

Patrícia Santos[1,2,3][a], Inês Garcia[1][b], Carla Quintão[1,2][c] and Claúdia Quaresma[1,2][d]

[1]*LIBPhys, NOVA School of Science and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal*

[2]*Physics Department, NOVA School of Science and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal*

[3]*Health Department, Superior School of Health, Polytechnic Institute of Beja, 7800-111 Beja, Portugal*

Keywords: Upper Limb, Activities of Daily Living, Electromyography, Accelerometery, Technology, Biomechanics.

Abstract: The technology is a valuable resource for movement analysis, especially for complex movement patterns such as those of the upper limb during activities of daily living (ADLs). Characterizing these patterns in healthy individuals is crucial to detect abnormal and compensatory movements resulting from neurological dysfunctions. This study aimed to characterize the neuromuscular activation pattern of the upper limb during the washing of the contralateral limb in 36 healthy individuals. The Biosignalsplux® equipment was used to monitor the activity of the main shoulder muscles, that is, Pectoralis Major (PM), Anterior Deltoid (AD), Middle Deltoid (MD), Posterior Deltoid (PD), Upper Trapezius (UT) and Lower Trapezius (LT), through electromyography (EMG) and accelerometry (ACC). The results show variations in the contraction pattern in the different phases of the activity. With this study it was possible to establish the normalized pattern of the activity of EMG and ACC of the shoulder complex and respective movement phases.

1 INTRODUCTION

Technology is crucial in the analysis of movement patterns, especially when compared to more common assessment tools based on scales that do not provide a detailed and accurate analysis of motion (Alt Murphy, 2006; Gil-Agudo et al., 2013; de los Reyes-Guzmán et al., 2010). The use of sensors in movement analysis has increased (Bleser et al., 2015; Özdemir & Barshan, 2014), allowing the acquisition of high-precision data (Jalloul et al., 2018), particularly in the analysis of complex movement patterns, such as those performed during Activities of Daily Living (ADLs). Using biosensors, it is possible to identify normal movement patterns in ADLs.

The relationship between the variables obtained with the biosensors helps to understand in which phases of activity a movement pattern appears to be normal or not, helping to identify abnormal patterns and, thus, detecting the presence of associated dysfunctions early (Jalloul et al., 2018).

Impairment of the normal pattern of upper limb movement is one of the most common neurological sequelae (Nakayama et al., 1994), which leads to loss of autonomy due to functional changes in the elbow and shoulder, and consequently they also affect normal reaching and grasping (Klein et al., 2011). These motor compensations can result in musculoskeletal pain or overuse injuries (Levin et al, 2009), accentuating existing disability.

Given that the involvement of the upper limbs is a prerequisite for performing ADLs, it is essential to objectively analyse the neuromotor pattern of the upper limb in them (Gulde & Hermsdorfer, 2017), however, there is a gap in studies at this level.

ADLs such as hygiene involve multiple tasks and phases and need to be analysed from the perspective of movement variability and contraction patterns of

[a] https://orcid.org/0000-0002-3569-2495
[b] https://orcid.org/0009-0002-5357-5919
[c] https://orcid.org/0000-0003-1015-4655
[d] https://orcid.org/0000-0001-9978-261X

Santos, P., Garcia, I., Quintão, C. and Quaresma, C.
Neuromotor Pattern of the Upper Limb in Hygiene Activities Using Electromyography and Accelerometery Technology.
DOI: 10.5220/0012463900003657
In *Proceedings of the 17th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2024) - Volume 1*, pages 799-806
ISBN: 978-989-758-688-0; ISSN: 2184-4305

muscle groups most likely to develop compensatory patterns (Gulde & Hermsdorfer, 2017; Santos, P. et al., 2022a). Prevention of compensatory movement is one of the best practices, which includes early detection and retraining of appropriate movements. For prescribe restorative interventions, it is essential to understand movement patterns and underlying motor strategies (Valevicius et al., 2019).

1.1 Analysis of the Upper Limb Movement Pattern Based on the Phases of ADLs

Dividing complex motor tasks in different phases to better analyse and characterize the movements, began to be utilized in gait analysis studies. These studies aimed to characterize the gait cycle pattern in diversified groups through the analysis of kinematic and biosignal parameters (Buddhadev et al., 2020).

In this analysis, a full gait cycle is normalized to 100%, with each phase of the cycle given a corresponding percentage. The variables of each phase are then analysed (Ewins & Collins, 2014).

Subsequently, the movement pattern of the upper limb was also subjected to this type of analysis.

In studies of upper limb movement patterns, various phases of ADLs were analysed. However, the majority analysed, for example, the activity of drinking from a cup, by variables such as the range of motion in upper limb joints (Molina Rueda, 2012; Santos, G. et al., 2018; Stanfield et al., 2018), the duration of each phase (Stanfield et al., 2018), and the execution speed (Alt Murphy et al., 2018).

Although less common, some studies have examined the amplitude of muscle activation through electromyography (EMG) in various phases of the drinking activity (Molina Rueda et al., 2012, Santos, P. et al., 2022a, 2022b), filling a glass (Ricci et al., 2015), washing the contralateral limb, brushing hair, eating soup, and brushing teeth (Santos, P. et al., 2022a, 2022b). While some studies analyse phases of ADLs, few characterize the pattern of muscle activation through EMG and ACC, with normalization of the movement cycle.

1.2 Characterization of the Movement Pattern in ADLs Using EMG and ACC

There is a gap in the characterization of the muscle activation pattern in healthy subjects. Without this information, it is not possible to identify compensatory movements in individuals with neurological pathology. Few studies have focused on healthy subjects and the activation pattern of shoulder muscles: Pectoralis Major (PM), Anterior Deltoid (AD), Middle Deltoid (MD), Posterior Deltoid (PD), Upper Trapezius (UT), and Lower Trapezius (LT). These muscles are responsible for flexion (F), extension (E), abduction (ABD), adduction (AD), scapular elevation (SE), and scapular depression (SD), respectively (Esperança Pina, 2017).

Firstly, Molina Rueda et al. (2012), found that in the five phases of the activity of drinking from a cup, the UT was activated in phases 3 (raising the cup to the lips) and 4 (returning the cup to the table); the AD in phase 1 (start the capture by moving the hand to the cup) and phase 2 (grab the cup); the MD in phase 3 (raising the glass to the lips) and 4 (returning the glass to the table); and the PD in phase 5 (release the cup and the hand returns to the original position). Thus, the UT, AD, and MD are activated in the first three phases, corresponding to the range of movement from the initial position until the cup reaches the mouth. In the opposite movement, i.e., phases 4 and 5, there is activation of the UT and DP.

Ricci et al. (2015) observed that during the performance of ADL, specifically pouring water from a jug into a glass, there is distinct activation of the MD in the reaching phase, UT and MD in the transport phase, and AD and MD in the release phase. It is noteworthy that this activity deviates from others due to the absence of a movement directed to the face.

In our team's recent investigations (Santos, P. et al., 2022b), we identified that the muscles exhibiting the highest activation during the contraction phase (muscle activation increase) in the context of washing the contralateral arm are the AD, UT, and PM.

Furthermore, Santos, P. et al. (2022a) conducted a comprehensive analysis of the expected movements and corresponding amplitude of activation during the activity of washing the contralateral arm. The phases include grasping (involving ADD), transporting to the contralateral side (involving ADD, F, and SE), and reaching the contralateral side (involving ADD, F, and SE) as outlined in Table 1. These findings were validated through EMG, where ADD was executed in accordance with the anticipated patterns.

Regarding studies that analyse the linear acceleration of the shoulder (in the x, y, z axes) and relate these data to the phases of the activity, no study has been found. Most studies use Inertia Movement Units (IMU) or optoelectronic motion capture systems to analyse the joint range of motion.

The aim of this study is to analyse and explore the characteristics of the movement pattern during the washing of the contralateral arm, specifically the electrical activation amplitude the main shoulder muscles, as well as the linear acceleration of the arm in healthy individuals.

This activity is among the most disabling ADLs, a consequence of the neurological pathology sequelae, specifically hemiparesis. In these instances, individuals face challenges in adequately performing hygiene on the unaffected limb. Therefore, delving into the study of this ADL holds particular significance within a clinical context.

2 MATERIAL AND METHODS

This study was approved by the Ethics Council of NOVA School of Science and Technology, located in Almada, Portugal, and it was executed in the Physics Department. Volunteers signed an informed consent.

2.1 Study Participants

The protocol was applied to 39 individuals, but 3 were excluded due to Bluetooth connection issues between the Biosignalsplux® and the computer, leading to failures in signal acquisition. The sample was composed by 36 individuals (19 females and 16 males; 33 right-handed and 3 left-handed; age 28.8 ± 12.5 years; height 168.8 ± 7.1 cm). Exclusion criteria included diagnosis of neuromotor, musculoskeletal, cognitive or language injuries and changes in visual acuity not compensated by glasses or contact lenses. To each subject was attributed a code number, to guarantee anonymity (Alt Murphy et al., 2006).

2.2 Experimental Setup and Protocol

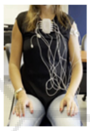
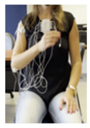
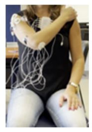
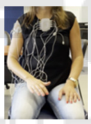
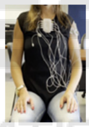
The movement phases were stablished through two cameras, placed at one meter away from the subject, one in the coronal and other in the sagittal anatomical plan, with a resolution of 30 frames per second.

EMG and ACC data was acquired through the Biosignalsplux®. This equipment was wirelessly connected to OpenSignals (r)evolution Software® version 2.2.1, software used to obtain and display the respective signals, and is specific to PLUX's® biological signal collection hardware platforms (PluX Wireless Biosignals, 2017). The acquisition frequency is 1000 Hz. This set includes 8 sensor inputs, 6 EMG electrode cables, an ACC with sensor in the 3 coordinate axes and its tape. Due to equipment limitations, it was decided to use only 2 axes, as the equipment has 8 cable connections, and 6 of them were being used in EMG.

The EMG sensors were placed using the bipolar method, defined by SENIAM, from the center of each electrode, in the belly of the same muscle and parallel to the fibers. The reference electrode was placed on the olecranon bone (zone of low electrical activity) (Freivalds, 2011; Stegeman & Hermens, 2007).

In summary, the procedures for carrying out this study were described in Santos, P. (2022b). The subjects began the activity with the feet on the floor, knees and hips flexed at 90º, upper limbs are supported on the thighs, shoulders in a neutral position, elbows flexed at 45º, forearms and hands rest on the thighs. Before data collection was given the opportunity to perform the movement, so that subjects feel comfortable with the execution of it. Participants were instructed to perform 5 trials. The activity phases of the ADL are resumed in Table 1.

Table 1: Activity phases of washing the contralateral limb.

Activity phases of washing the contralateral limb		
		
1. Grasping	2. Transporting to the contralateral side	3. Reaching the contralateral side
		
4. Return to the thigh	5. Return to initial position	

2.3 Data Analysis

2.3.1 Movement Phases

Matlab® was used to analyse .avi videos files frame by frame, with a function to register the frame where each phase initialized and ended in an Excel file (Table 1). The time (s) was retrieved from the frames and camera frequency and calculated the mean and standard deviation (SDT) of the time of each phase.

2.3.2 Electromyography

To obtain the EMG data in milli-Volt (mV), the transfer function was retrieved from the BioPluX website (PluX Wireless Biosignals, 2017). To reach the zero offset, the mean was subtracted from the signal and the absolute value was taken. The moving average was applied to smooth out the signal waves, considering that there should be a commitment to softening the signal and removing important information (Stegeman & Hermens, 2007).

2.3.3 Accelerometer

The same procedures were applied to ACC signals: subtraction of mean and move average filter. The ACC needed to be calibrated. That procedure was effectuated in the beginning of the study, and the transfer function was applied to the raw data (PluX Wireless Biosignals, 2019). The ACC was placed in the lateral region of the arm, vertically aligned with the lateral epicondyle (Curti et al., 2008). The x-vector corresponds to the coronal anatomical plane and y-vector to the sagittal.

2.3.4 Normative Pattern of Movement

The normative pattern for EMG and ACC describes the mean behavior of the all sample used in this study, and respective correlation with the ADL phases.

The ADL phases were determined by analyzing video frames from the frontal plane. For each subject's 5 activity cycles, frame numbers marking the start and end of each phase were recorded. Mean and SDT values for these frame numbers were calculated and converted to seconds based on the camera's acquisition frequency (30 frames/s). This frame analysis informed the definition of phase beginnings, ends, and durations, as well as the segmentation of the signal into 5 cycles and corresponding intervals. Since the goal was to obtain the normative pattern of EMG contraction in the present sample, the average of the signals was retrieved after resampling time and amplitude, so the dimensions of time and amplitude were equated.

Given that the duration of execution varies among subjects, and that would be not possible to do the mean, it was necessary to apply the MATLAB signal processing function resample to the signal. This was done to adjust the time axis in all signals to 8000 ms, as this represented the maximum duration of the ADL to avoid undersampling.

For graphical visualization, it was established that 8 seconds represent 100% of the activity duration. In the signal, it was observed that after the subject placed their hand on their thigh, marking the end of the activity in the video, the muscle did not immediately relax. It maintained some level of contraction beyond 100% until fully relaxing. Hence, the decision to include the interval between cycles, which was resampled to 2000 ms, corresponding to 25% of the total time. For Figures from 1 to 9, the following Matlab code was used:

```
figure;
function[lineOut,fillOut]=
stdshade(amatrix,0.1,[0,0,0],1:size(amatrix,
2),5);
%stdshade(amatrix,alpha,acolor,F,smth);
```

The function draws the mean EMG signal with the respective STD (Mussal, S., 2023). Variables of code: amatrix (matrix with all values); alpha (transparency of the line from 0 to 1); acolor (color of the SDT shade; F (x axis steps); smth (smoothing factor).

3 RESULTS

3.1 Phases

As observed in Table 2, on average, during the ADL, phase 4 is the task that takes the longest to be performed (56.2 ± 9.1), followed by phase 2 (18.4 ± 4.6), phase 5 (10.7 ± 8.0), phase 3 (10.4 ± 3.8) and phase 1 (4.4 ± 2.3). The estimate mean time, in absolute value, can be consulted in Table 2.

Table 2: Mean time interval of each movement phase (%) and phase duration (%) and respective SDT.

Phases	Interval of mean time (%)	Mean duration ±SDT (%)	Mean duration ±SDT (s)
1	[0, 4.4]	4.4 ±2.3	0.2 ±0.1
2	]4.4, 22.7]	18.4 ±4.6	0.7 ±0.2
3	]22.7, 33.1]	10.4 ±3.8	0.4 ±0.2
4	]33.1, 89.3]	56.2 ±9.1	2.1 ±0.5
5	]89.3, 100.0]	10.7 ±8.0	0.4 ±0.3

3.2 Electromyography

The figures from 1 to 6 represent the mean EMG and SDT, for all six muscles, during the 5 phases of the ADL. It is observed in the figures that the amplitude is increasing during phases 1 to 3, and the maximum amplitude is reached close to the beginning of the movement of phase 4 (33.1 time (%)), returning to the thigh, where we detect the first inflexion point. Muscles reach their maximum peak at different times, but with a difference not greater than 7.0%. In ascending order, the MD reaches the maximum value at 34.6%; AD 34.8%; PD 38.1%; PM takes 41.5%; UT and LT 41.5% (Table 3).

During phase 4, represented in yellow, for all muscles except the PM and AD, a second inflection point is observed, which counteracts the trend of decreasing amplitude. In the MD and PD muscles this inflexion point occurs in the middle of phase 4; in the UT and LT at the end of phase 4, being most noticeable in the UT. The third inflection point, which determines the decrease in amplitude until the end of activity, occurs for the MD, PD and LT muscles in the at the end of phase 4 and on the UT at the beginning

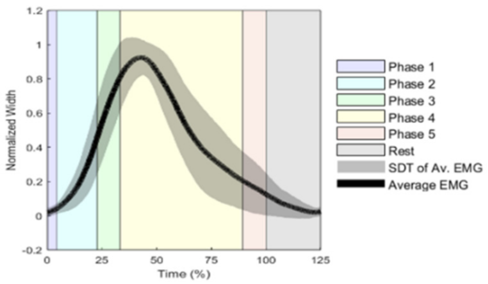


Figure 1: Mean EMG and SDT of the muscle PM and respective movement phases.

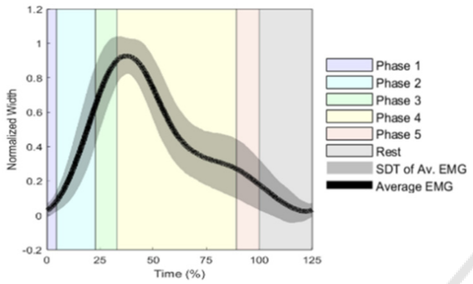


Figure 2: Mean EMG and SDT of the muscle AD and respective movement phases.

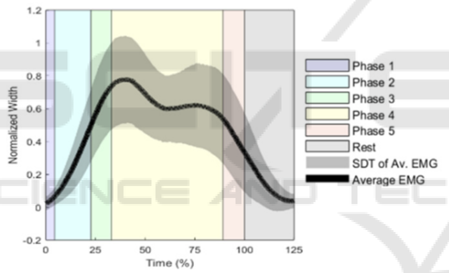


Figure 3: Mean EMG and SDT of the muscle MD and respective movement phases.

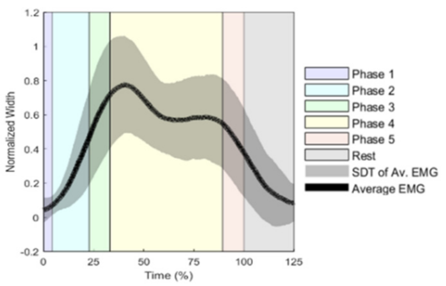


Figure 4: Mean EMG and SDT of the muscle PD and respective movement phases.

of phase 5. The mean amplitude of maximum peaks, in absolute values (mV), report the three muscles with higher amplitude contractions are AD, PM and UT. These values can be consulted in Table 3. In summary, the PM and AD muscles have, on average, one inflection point during activity, and the remaining four muscles three inflection points. The rest phase, represented in gray, gives information of the relaxation of the muscle, proving that minimum amplitude occurs after the end of phase 5, when subjects return to the initial position.

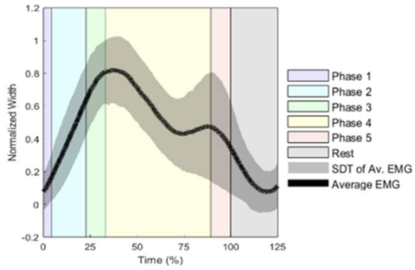


Figure 5: Mean EMG and SDT of the muscle UT and respective movement phases.

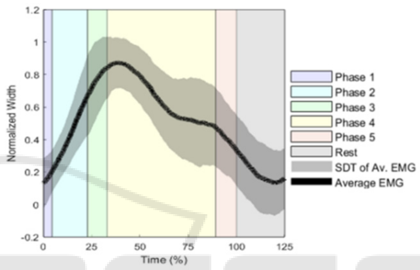


Figure 6: Mean EMG and SDT of the muscle LT and respective movement phases.

Table 3: Mean time (%) of maximum normalized peaks by muscle.

Muscle	Mean time of amplitude peak (%)	Mean amplitude contraction peak ± SDT (mV)
PM	41.5	0.07 ±0.06
AD	34.8	0.09 ±0.06
MD	34.6	0.04 ±0.02
PD	38.1	0.02 ±0.02
UT	41.5	0.06 ±0.04
LT	41.5	0.02 ±0.02

3.3 Accelerometer

The figures 7 to 9 represent the mean ACC and SDT, for x, y and sum of x and y vectors, during the 5 phases of the ADL. It is possible to observe that the behavior of the ACC, with the normalized g-unit amplitude from 0 to 1, is identical for the two anatomical planes represented in the linear acceleration. The sum of the two linear acceleration vectors is given by figure 9. The minimum acceleration occurs at the beginning of phase 1 and at rest. The maximum acceleration occurs in phase 4 at 53.0% for vectors x and y, and at 46.7% for the sum vector (Table 4).

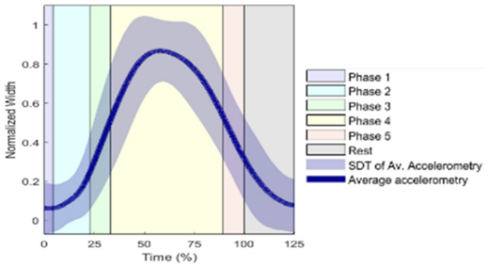


Figure 7: Coronal anatomical plan (vector x) linear acceleration.

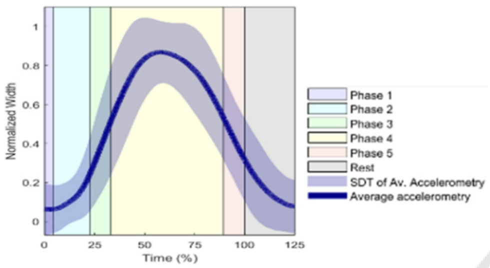


Figure 8: Sagittal anatomical plan (vector y) linear acceleration.

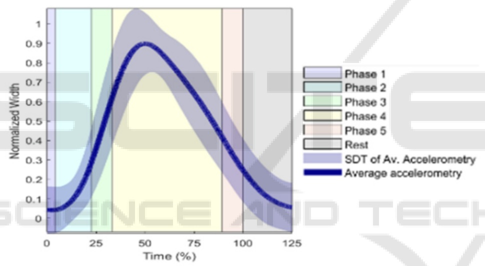


Figure 9: Sum of the vectors x and y linear acceleration.

Table 4: Mean time (%) of maximum normalized peaks by linear acceleration vector.

Vector	Mean time of amplitude peak (%)
X	53.0
Y	53.0
$\sqrt{X^2 + Y^2}$	46.7

4 DISCUSSION OF RESULTS

In EMG data results, two distinct phases (phase of increased activation amplitude and a phase of decreased amplitude) were observed in all muscle groups. This pattern aligns with Molina Rueda et al. (2012), Ricci et al. (2015), and Santos, P. et al. (2022a, 2022b). While the studies by Molina Rueda et al. (2012) and Ricci et al. (2015) focused on other ADLs, these phases were a transversal characteristic.

The initial phase (increased amplitude) corresponds to an isotonic concentric contraction. There is a shortening of sarcomeres in the muscle belly, leading to greater activation of muscle fibres and includes the three initial phases (grasp, carry to the contralateral side, and reach the contralateral side) and the initiation of the phase 4 (return to the thigh) in all muscles. This is supported by Table 2 and 3, where the average peak amplitudes are in the percentage of mean time amplitude peak corresponding to the beginning of phase 4. These results align with Santos, P. et al. (2022a), where, during washing the contralateral arm, the three primary phases (grasp, transport to the contralateral side, reaching the contralateral side) corresponded to the phase of increased muscle activation amplitude.

However, in the present study, by establishing the beginning and end of each phase, demarcated in Figures 1 to 6, we can analyse and confirm with more precision that the phase of muscle activation of increasing amplitude is associated at the beginning of phase 4, which was not possible in previous studies.

Based on the results of the peak amplitude of contraction in each muscle, we can see that the muscles AD, PM, UT (Table 3) exhibits the highest activation in motion from the thigh to the shoulder. This is evident as these peaks occur until the beginning of phase 4, which supports the motion Figure 9: Sum of the vectors x and y linear acceleration analysis in Santos, P. et al. (2022a), where the first movements are F, ADD and SE, in which the AD, PM and UT muscles are agonists (Esperança Pina, 2017).

Subsequently, the decrease in the amplitude, in which there is an eccentric isotonic contraction, that is, despite muscle activation, the amplitude decreases as there is a progressive stretching of the sarcomeres. According to Tables 2 and 3, this phase begins in phase 4 (immediately after the maximum peaks of activation of each muscle), continues until the final phase (return to the initial position) and the rest phase.

However, in this decreasing phase, it is observed (Figures 1 to 6) there are inflection points (MD, PD, UT, and LT), with the most pronounced ones in MD, PD and UT muscles between the second half of the phase 4 and the beginning of phase 5. These results supported by Santos, P. et al. (2022a), the inflection peaks are aligned with those observed in the previous study. According to the results, we can also infer that this inflection peak in MD and PD occurs between the last third of phase 4, that is, the phase in which contact with the distal part of the contralateral limb is lost and returns to the thigh requiring the activation of PD (E) and MD (ABD) as seeing in Santos, P. et al. (2022a).

The inflection peak in UT can be justified by motion analysis in the beginning of phase 5. To bring the limb back to a position over the thigh, there must be scapular elevation. The present study adds to the comprehensive motion analysis of this activity in phase 5 from our previous study P. et al. (2022a) by incorporating the movement of SE.

Regarding the results with ACC, there is a peak, a turning point, around the first half of phase 4. The acceleration values increase in phases 1 and 2, with increase observed in phase 3, reaching its maximum peak at the beginning of phase 4. After this, a regular decrease is noted until the end. This pattern is observed both in the displacement of the arm along the medio-lateral axis (x), the displacement of the arm segment along the longitudinal axis (y), and in the resultant vector of the sum of both.

Although in previous studies with EMG and ACC in ADLs, age and sex were not considered into result analysis, we believe these variables could impact the outcomes. Nakatake, et al. (2023) noted that, in drinking ADL, older individuals exhibited reduced shoulder ABD amplitude, and females completed the task more quickly. This prompts consideration for exploring the influence of age and sex on muscle activation amplitude patterns in future studies.

This study thus establishes a greater level of precision in the analysis of the movement pattern in the different phases of washing the contralateral limb.

5 CONCLUSIONS

This study unveils the normative movement pattern of an ADL renowned for its challenge among individuals with neuromotor diseases. The delineated pattern, consisting of two distinct phases, culminates in valuable insights into muscle activation dynamics. Notably, the PM, AD, and UT emerge as key players in the intricate sequence from thigh to shoulder, with inflection points observed in the diminishing amplitude phase, involving the MD, PD, and UT.

Conclusions drawn highlight the necessity for future studies to validate and extend these results across a wider age spectrum, particularly in contexts where neurological conditions, like stroke, prevail. Recommending the integration of EMG with gold standard technologies, such as optoelectronic motion capture systems, further emphasizes the commitment to methodological precision. Despite equipment constraints, these findings offer nuanced insights with profound implications for clinical practice.

The comprehensive understanding of muscle activation sequences, inflection points, and phase-related nuances presented in this study has the potential to revolutionize clinical interventions. Tailoring rehabilitation programs to target specific muscle groups can optimize motor function recovery, profoundly impacting the quality of life and independence of individuals. The acknowledgment of limitations informs future research methodologies, emphasizing a dedication to advancing clinical assessment and treatment strategies.

ACKNOWLEDGEMENTS

This work was supported by national funds from FCT – Foundation for Science and Technology, I.P. through the UIDB/FIS/04559/2020 (LIBPhys-UNL).

REFERENCES

Alt Murphy, M., Sunnerhagen, K. S., Johnels, B., & Willén, C. (2006). Three-dimensional kinematic motion analysis of a daily activity drinking from a glass: a pilot study. Journal of neuroengineering and rehabilitation, 3, 18. https://doi.org/10.1186/1743-0003-3-18

Alt Murphy, M., Murphy, S., Persson, H. C., Bergström, U. B., & Sunnerhagen, K. S. (2018). Kinematic Analysis Using 3D Motion Capture of Drinking Task in People With and Without Upper-extremity Impairments. Journal of visualized experiments: JoVE, (133), 57228. https://doi.org/10.3791/57228

Bleser, G., Steffen, D., Reiss, A., Weber, M., Hendeby, G., Fradet, L. (2015). Personalized Physical Activity Monitoring Using Wearable Sensors. In: Holzinger, A., Röcker, C., Ziefle, M. (eds) Smart Health. Lecture Notes in Computer Science(), vol 8700. Springer, Cham. https://doi.org/10.1007/978-3-319-16226-3_5

Buddhadev, H. H., Smiley, A. L., & Martin, P. E. (2020). Effects of age, speed, and step length on lower extremity net joint moments and powers during walking. Human movement science, 71, 102611. https://doi.org/10.1016/j.humov.2020.102611

Cutti, A. G., Giovanardi, A., Rocchi, L., Davalli, A., & Sacchetti, R. (2008). Ambulatory measurement of shoulder and elbow kinematics through inertial and magnetic sensors. Medical & biological engineering & computing, 46(2), 169–178. https://doi.org/10.1007/s11517-007-0296-5

de los Reyes-Guzmán, A., Gil-Agudo, A., Peñasco-Martín, B., Solís-Mozos, M., del Ama-Espinosa, A., & Pérez-Rizo, E. (2010). Kinematic analysis of the daily activity of drinking from a glass in a population with cervical spinal cord injury. Journal of neuroengineering and rehabilitation, 7, 41. https://doi.org/10.1186/1743-0003-7-41

Engdahl, S. M., & Gates, D. H. (2018). Reliability of upper limb and trunk joint angles in healthy adults during activities of daily living. Gait & posture, 60, 41–47. https://doi.org/10.1016/j.gaitpost.2017.11.001

Esperança Pina, J. E. (2017). Locomotion Anatomy (4th ed.). Lisbon: Lidel.
Ewins, D., & Collins, T. (2014). Clinical Gait Analysis. In A. Taktak, P. Ganney, D. Long, & P. White (Eds.), A Handbook for Clinical and Biomedical Engineers (pp. 389-401). Academic Press.
Freivalds, A. (2011). Biomechanics of the upper limbs: mechanics, modeling and musculoskeletal injuries. CRC press.
Gil-Agudo, A., de Los Reyes-Guzmán, A., Dimbwadyo-Terrer, I., Peñasco-Martín, B., Bernal-Sahún, A., López-Monteagudo, P., Del Ama-Espinosa, A., & Pons, J. L. (2013). A novel motion tracking system for evaluation of functional rehabilitation of the upper limbs. Neural regeneration research, 8(19), 1773–1782. https://doi.org/10.3969/j.issn.1673-5374.2013.19.005
Gulde, P., & Hermsdörfer, J. (2017). Both hands at work: the effect of aging on upper-limb kinematics in a multi-step activity of daily living. Experimental brain research, 235(5), 1337–1348. https://doi.org/10.1007 /s00221-017-4897-4
Horak, F., King, L., & Mancini, M. (2015). Role of body-worn movement monitor technology for balance and gait rehabilitation. Physical therapy, 95(3), 461–470. https://doi.org/10.2522/ptj.20140253
Jalloul, N., Poree, F., Viardot, G., L Hostis, P., Carrault, G., Jalloul, N., Poree, F., Viardot, G., L' Hostis, P., & Carrault, G. (2018). Activity Recognition Using Complex Network Analysis. IEEE journal of biomedical and health informatics, 22(4), 989–1000. https://doi.org/10.1109/JBHI.2017.2762404
Klein, A., Sacrey, L. A., Dunnett, S. B., Whishaw, I. Q., & Nikkhah, G. (2011). Proximal movements compensate for distal forelimb movement impairments in a reach-to-eat task in Huntington's disease: new insights into motor impairments in a real-world skill. Neurobiology of disease, 41(2), 560–569. https://doi.org/10.1016/j.nbd.2010.11.002
Levin, M. F., Kleim, J. A., & Wolf, S. L. (2009). What do motor "recovery" and "compensation" mean in patients following stroke?. Neurorehabilitation and neural repair, 23(4), 313–319. https://doi.org/10.1177/1545968308328727
Molina Rueda, F., Rivas Montero, F. M., Pérez de Heredia Torres, M., Alguacil Diego, I. M., Molero Sánchez, A., & Miangolarra Page, J. C. (2012). Análisis del movimiento de la extremidad superior hemiparética en pacientes con accidente cerebrovascular: estudio piloto. *Neurologia* (Barcelona, Spain), 27(6), 343–347. https://doi.org/10.1016/j.nrl.2011.12.012
Musall, Simon (2023). stdshade (https://www.mathworks.com/matlabcentral/fileexchange/29534stdshade), MATLAB Central File Exchange.
Nakatake, J., Arakawa, H., Tajima, T., Miyazaki, S., & Chosa, E. (2023). Age- and sex-related differences in upper-body joint and endpoint kinematics during a drinking task in healthy adults. PeerJ, 11, e16571. https://doi.org/10.7717/peerj.16571
Nakatake, J., Totoribe, K., Arakawa, H., & Chosa, E. (2021). Exploring whole-body kinematics when eating real foods with the dominant hand in healthy adults. PloS one, 16(10), e0259184. https://doi.org/10.1371/journal.pone.0259184
Nakayama, H., Jørgensen, H. S., Raaschou, H. O., & Olsen, T. S. (1994). Compensation in recovery of upper extremity function after stroke: the Copenhagen Stroke Study. Archives of physical medicine and rehabilitation, 75(8), 852–857. https://doi.org/10.101 6/0003-9993(94)90108-2
Özdemir, A.T.; Barshan, B. Detecting Falls with Wearable Sensors Using Machine Learning Techniques. Sensors 2014, 14, 10691-10708. https://doi.org/10.3390/s140610691
Plux Wireless Biosignals (2019). Accelerometer ACC User Manual (Plux). http:// www.plux.info
Plux Wireless Biosignals (2017). Electromyography EMG User Manual (Plux). http:// www.plux.info
Ricci, F. P., Santiago, P. R., Zampar, A. C., Pinola, L. N., & Fonseca, M.deC. (2015). Upper extremity coordination strategies depending on task demand during a basic daily activity. Gait & posture, 42(4), 472-478.https://doi.org/10.1016/j.gaitpost.2015.07.061
Santos, G. L., Russo, T. L., Nieuwenhuys, A., Monari, D., & Desloovere, K. (2018). Kinematic Analysis of a Drinking Task in Chronic Hemiparetic Patients Using Features Analysis and Statistical Parametric Mapping. Archives of physical medicine and rehabilitation, 99(3), 501–511.e4. https://doi.org/10.1016/j.apmr.2017.08.479
Santos, P., Quaresma, C., Garcia, I., Quintão, C. (2022a, July). Neuromotor Evaluation of the Upper Limb During Activities of Daily Living: A Pilot Study. In: Camarinha-Matos, L.M. (eds) Technological Innovation for Digitalization and Virtualization. DoCEIS 2022. IFIP Advances in Information and Communication Technology, vol 649. Springer, Cham. https://doi.org/10.1007/978-3-031-07520-9_11
Santos, P., Garcia, I., Quaresma, C., & Quintão, C. (2022b, October). Analysis of Upper Limb Contraction Pattern Using Electromyographic Signal During Activities of Daily Living: a Pilot Study. In HEALTHINFO 2022 Editors (Eds.), The Seventh International Conference on Informatics and Assistive Technologies for Health-Care, Medical Support and Wellbeing. https://www.thinkmind.org/download_full.php?instance=HEALTHINFO+2022
Stansfield, B., Rooney, S., Brown, L., Kay, M., Spoettl, L., & Shanmugam, S. (2018). Distal upper limb kinematics during functional everyday tasks. Gait & posture, 61, 135-140.https://doi.org/10.1016/j.gaitpost.2018.01.004
Stegeman, D., & Hermens, H. (2007). Standards for surface electromyography: The European project Surface EMG for non-invasive assessment of muscles (SENIAM). Roessingh Research and Development, 10, 8-12. https://www.researchgate.net/publication/228486725
Valevicius, A. M., Boser, Q. A., Lavoie, E. B., Chapman, C. S., Pilarski, P. M., Hebert, J. S., & Vette, A. H. (2019). Characterization of normative angular joint kinematics during two functional upper limb tasks. Gait & posture, 69, 176–186. https://doi.org/10.1016/j.gaitpost.2019.01.037