Characterization of upper limb use in health care workers during regular shifts: A quantitative approach based on wrist-worn accelerometers

doi 10.1016/j.apergo.2023.104046

Revised version of the manuscript JERG-D-23-00018R1 on May 09th, 2023

Micaela Porta[a]*, Simona Porceddu[b], Bruno Leban[a], Giulia Casu[a], Giovanni M. Mura[b], Marcello Campagna[b] and Massimiliano Pau[a]

[a]*Department of Mechanical, Chemical and Materials Engineering University of Cagliari, Italy*

[b]*Department of Medical Sciences and Public Health, University of Cagliari, Italy*

***Corresponding author**: Micaela Porta, Ph.D., Department of Mechanical, Chemical and Materials Engineering, University of Cagliari, Piazza d'Armi, 09123 Cagliari, Italy. Tel. +39-070-6753264. E-mail: micaela.porta@unica.it

Characterization of upper limb use in health care workers during regular shifts: A quantitative approach based on wrist-worn accelerometers

Revised version of the manuscript JERG-D-23-00018R1 on May 09th, 2023

Abstract

Despite the high prevalence of upper limb (UL) work-related musculoskeletal disorders (WRMSD) among health care workers (HCWs), little is known about their relationship with exposure to biomechanical risk factors. This study aimed to assess UL activity features under actual working conditions using two wrist-worn accelerometers. Accelerometric data were processed to obtain duration, intensity, and asymmetry of UL use in 32 HCWs during the execution of commonly performed tasks (e.g., patient hygiene, transfer, and meal distribution) within a regular shift. The results show that such tasks are characterized by significantly different patterns of UL use, in particular, higher intensities and larger asymmetries were observed respectively for patient hygiene and meal distribution. The proposed approach appears, thus, suitable to discriminate tasks characterized by different UL motion patterns. Future studies could benefit from the integration of such measures with self-reported workers' perception to elucidate the relationship between dynamic UL movements and WRMSD.

Keywords

Upper limb; accelerometer; asymmetry

1. Introduction

Statistical data from most industrialized countries indicate that work-related musculoskeletal disorders (WRMSD) are widespread among health care workers (HCWs). Indeed, according to the recent European Working Condition Survey (de Kok et al., 2019), almost half of HCWs complained of at least one occurrence of either low back or upper limb (UL) pain in the previous 12 months. Similar figures were reported in the review by Davis and Kotowski (2015), who calculated a worldwide yearly prevalence of 55% for low back disorders and of 44% and 26%, respectively, for shoulders and UL. HCWs are exposed to highly demanding tasks from a physical point of view as they are required to transfer patients, repeatedly execute movements, stand for long periods of time, and adopt non-neutral posture (De Jong et al., 2014). Such factors have been associated with the onset of WRMSD in the low back and UL (Anderson and Oakman, 2016; Soylar and Ozer, 2018), and it is not surprising that HCWs are among those most affected by WRMSD (Harcombe et al., 2014).

It is noteworthy that while a significant portion of research on HCWs has been focused on the analysis of low back symptoms and their relationship to different aspects of the working tasks (Nourollahi et al., 2018; Serranheira et al., 2012 and 2015; Kuijer et al., 2014; Freitag et al., 2014), less is known about UL-WRMSD. For instance, manual patient handling, a task typical of health professions, has been studied (to the best of our knowledge) only as a risk factor for the development of low back disorders, although it may also potentially exert an excessive burden on the upper extremities during reaching, pushing, and pulling tasks (Ando et al., 2000; Hoozemans et al., 2002; Smedley et al., 2003). Indeed, repetitiveness and movement asymmetries have been hypothesized to play an important role in the development of UL-WRMSD. The study of Shiri et al. (2007), who investigated the prevalence of UL-WRMSD in more than 6000 Finnish workers aged 30-64 years, reported that several UL disorders are more commonly diagnosed in the dominant limb. Typically, this phenomenon has been attributed to the specific nature of the working tasks, which may require more intensive use of one of the two limbs (Hansson et al., 2009; 2010; Filgueiras et al., 2012) or to the fact that workers have a natural predisposition to use their dominant hand more frequently. In any case, regardless of the cause, the unbalanced use of the UL may lead to the accumulation of higher levels of physical stress in the dominant limb with respect to the non-dominant one (Kucera and Robins 1989).

It should also be noted that, other than being limited in number, the studies on UL-WRMSD in HCWs are mostly based on subjective perception ratings (for instance, using the Nordic Musculoskeletal Questionnaire) or observational methods like the Rapid Upper Limb Assessment method (RULA, Occhionero et al., 2014). It appears, therefore, important to provide new insight for the assessment of exposure to biomechanical factors associated with the development of UL-WRMSD, possibly based on quantitative, objective, and robust approaches. In this context, the use of wearable accelerometers appears particularly intriguing. Indeed, previous studies aimed to assess workers' exposure to biomechanical risk factors in occupational contexts highlighted their ability to collect data continuously over long periods of time and their unobtrusiveness for the tested subject (Roman-Liu et al., 1996; Estill et al., 2000; Hansson et al., 2001; Søgaard et al., 2001; Amasay et al., 2010; Korshøj et al., 2014, Schall et al., 2016; West et al., 2018; Lim and D'Suoza, 2020, Picerno et al., 2021).

Based on the aforementioned considerations, the present study aims to characterize the main features associated with UL use in HCWs during the execution of tasks commonly performed within a regular shift using a simple setup based on two wrist-worn accelerometers. Such an approach, which was originally proposed to characterize UL use during daily activities in individuals affected by neurological conditions (Bailey et al., 2015; Hoyt et al., 2019; Pau et al., 2021), has been recently applied in occupational contexts to characterize the intensity, duration, and asymmetry of UL use in blue- and white-collar workers (Porta et al., 2022a). Acceleration-based parameters may represent an important source of information useful for better understanding the biomechanical exposure of this category of workers and, consequently, for designing suitable UL-WRMSD prevention strategies.

2. Methods

2.1. Participants

Thirty-two professional HCWs (27 females and 5 males), full-time employed at the University Hospital "Policlinico Universitario, D. Casula" (University of Cagliari, Italy), having a mean (SD) age of 48.7 (7.5) years, a height of 162.1 (7.8) cm, a body mass of 60.5 (12.3) kg, and seniority in service of 14.6 (9.0) years, voluntarily participated in the study. Although belonging to different wards (neurology, n = 5; cardiology, n = 5; gastroreumatology, n = 5; general surgery, n = 5; general medicine, n = 5; emergency medicine, n = 7), they were routinely assigned, on a daily basis, to the same series of tasks which include patient care (e.g., hygiene, feeding and dressing), adjustment (e.g., sitting, and pull-up) and transfer (e.g., wheelchair, stretchers and bed handling) as well as bed making, restore linen cart, and waste disposal. Prior to data collection, hand dominance was assessed through the single-item handedness measure proposed by Coren (1993). The study was promoted and supported by the Health and Safety division of the hospital and carried out in compliance with the ethical principles for research involving human subjects expressed in the Declaration of Helsinki and its later amendments. All the participants signed an informed consent form after a detailed explanation of the purposes and methodology of the study.

2.2. Experimental protocol

On a regular working day, participants were requested to wear on each wrist, for four consecutive hours, a clinically validated tri-axial accelerometer (Actigraph GT3X-BT, Acticorp Co., Pensacola, Florida, USA), previously employed in occupational contexts to assess the amount and intensity of the performed physical activity (Straker et al., 2014; Schall et al., 2016; Porta et al., 2021; Porta et al., 2022b), body posture (Hallman et al., 2021), as well as UL inclination (Korshøj et al., 2014). They were required not to remove the devices and to perform the usual working tasks in the most natural manner. In addition, they were constantly visually monitored by a trained observer (with a specific background in health care activities) who tracked/annotated type and duration of each performed task. All the accelerometers were initialized, according to the procedure described by the manufacturer, using a PC which had the clock automatically adjusted by the time.nist.gov server. The same PC served also to set the observer's smartwatch, so to have it synchronized with the devices when start and end of each monitored activity were annotated.

2.3. **Data processing**

At the end of the acquisition period, the raw accelerations (collected at a 30 Hz frequency) were downloaded to a PC via USB cable using the dedicated software (Actilife v6.13.3, Acticorp Co., USA), while the observational data were organized in a spreadsheet containing the type, start time, and end time of each task performed. Before the acceleration data process, thanks to the information derived from interviews with the wards' supervisors, the most commonly performed tasks were identified. In particular, the following nine tasks were identified: patient hygiene, patient comfort adjustment in bed, bed making (occupied or empty), patient transfer from bed to stretcher or wheelchair, materials manual handling (e.g., medications, waste, water bottle, etc.), pushing-pulling (beds, wheelchairs, linen trolleys, waste trolleys), meal distribution, changing the diuresis bag, and patient feeding. Such tasks were then pooled into three groups of macro-activities due to the impossibility of separating different activities that are performed contextually (e.g., patient hygiene and bed making) or because of the substantial similarity between tasks (e.g., pushing beds, wheelchairs, charts, etc.). The three macro-activities (task types) identified are:

1. Bed making and patient hygiene (including any activity associated with bed making and patient hygiene)
2. Patient transfer (including pushing-pulling of beds and wheelchairs)
3. Meal distribution.

The files generated by the software Actilife, which contains the accelerometric counts collected for each HCWs on a 1-minute basis (i.e., shortest available interval) were segmented and labelled according to the information about start/end time and type of task as annotated by the observer. Then all homogeneous segments were merged. The resulting signals were then processed with a custom routine developed under the MATLAB environment (R2019a, MathWorks, Natick, Massachusetts, USA) to calculate the following parameters:

- Vector magnitude (VM) counts: the magnitude of the accelerometric counts on the three planes of motion is calculated as follows: $VM = \sqrt{x^2 + y^2 + z^2}$ where x, y, and z represent the accelerometric counts recorded on each plane of motion;
- Use Ratio (UR): the ratio between the minutes of use of the non-dominant and dominant UL, where the minutes of use are defined as the sum of time periods in which VM is greater than zero (Lang et al., 2017). UR = 1 indicates equal use of the dominant and non-dominant limbs during the monitoring period, while UR < 1 indicates longer periods of use for the dominant limb, and UR > 1 denotes longer periods of use of the non-dominant limb;
- Bilateral magnitude: the sum of the VM calculated for the dominant and non-dominant UL (Bailey et al., 2014; Lang et al., 2017). This parameter was normalized with respect to the total duration (in minutes) of the activity considered so that it could be compared to tasks with different durations;
- Magnitude Ratio (MR): the natural logarithm of the ratio between the non-dominant VM and the dominant VM (Bailey et al., 2014; Lang et al., 2017). A value of MR = 0 indicates the perfect balance in the use of UL in terms of movement intensity. MR < 0 (> 0) indicates higher intensity activity of the dominant (non-dominant) UL;
- Mono-arm Use Index (MAUI): is a parameter, calculated using the following Equation (1)

$$MAUI = \frac{\sum_{\forall t\, VM_{dominant(t)=0}} VM_{nondominant}(t)}{\sum_{\forall t\, VM_{nondominant(t)=0}} VM_{dominant}(t)} \quad (1)$$

  where VM is the vector magnitude, as previously described and t the time period sample. MAUI quantifies the intensity of use of the dominant and the non-dominant limb during the performance of unilateral movements in work activities (i.e., a movement of one UL when the other is steady). In other words, MAUI quantifies the frequency and the intensity of the unilateral activities performed using only the non-dominant limb with respect to those performed using only the dominant one. A MAUI value of 1 indicates that the unilateral movement performed with the dominant limb and the unilateral movement performed with the non-dominant limb, are performed at the same intensity (i.e., both ULs are used equally based on their activity counts), whereas values below and above 1 indicate unbalanced activity towards the dominant and non-dominant UL, respectively (Hoyt et al., 2019);
- Bilateral-arm Use Index (BAUI), calculated using Equation (2)

$$BAUI = \frac{\sum_{\forall t\, VM_{dominant(t)\neq 0}} VM_{nondominant}(t)}{\sum_{\forall t\, VM_{nondominant(t)\neq 0}} VM_{dominant}(t)} \quad (2)$$

  is a parameter that provides information on activity that simultaneously involves both UL. In particular, BAUI express the contribution, in terms of intensity, of each limb during the performance of the activities characterized by the use of both limbs. A BAUI value of 1 indicates that the UL are used with the same intensity (as it occurs, for example, when an individual carries a tray with both hands) while values lower (or higher) than 1 indicate that during the performance of bilateral activities the dominant (or non-dominant) UL is used more intensively (e.g., one hand is used to stabilize an object while the other is used to perform a dynamic task, Hoyt et al., 2019).

2.4. Statistical analysis

Two separate statistical analyses were conducted to investigate the potential differences in the previously listed parameters across the macro-activities (task types) identified.

1. One-way Analysis of Variance (ANOVA) on UR (which is a time-related parameter) by setting UR as a dependent variable and task type (i.e., “bed making + patient hygiene”; “patient transfer”; “meal distribution”) as an independent variable.
2. One-way Multivariate Analysis of Variance (MANOVA) on intensity-related parameters by setting Bilateral Magnitude, MR, MAUI, and BAUI as dependent variables and task type as an independent variable.

The level of significance was set at $p = 0.05$, and the effect of size was assessed using the eta-squared (η^2) coefficient. Where necessary, univariate ANOVAs were carried out as a post-hoc test on the adjusted group means, reducing the level of significance to $p = 0.0125$ (0.05/4) for intensity-related parameters. All analyses were performed using the IBM SPSS Statistics v.20 software (IBM, Armonk, NY, USA).

3. Results

Of the 32 participants who accepted to participate in the study, 28 were simultaneously monitored with the accelerometers and by the professional observer for the whole 4-hour period, while the remaining four were observed for about 3.5 hours due to the impossibility of following the HCWs in hospital areas occupied by COVID patients or during the execution of particularly difficult patient’s assistance. The analysis includes all the accelerations data associated with type and duration of the activities recorded by the professional observer.

The results in terms of UL use associated with the three main task types identified are summarized in figures 2–3 (and in the Appendix in Tables A.1–A.2). ANOVA detected a significant main effect of task type on the UR parameter [$F(2,136) = 4.39$, $p = 0.014$, $\eta^2 = 0.06$]. In all the investigated task types, individuals were employed for a longer period of time with their dominant limb, as indicated by the value of UR<1, and the post-hoc analysis revealed that meal distribution was the task type characterized by the most marked asymmetry when compared to “bed making + patient hygiene” or “patient transfer” tasks (0.95 vs. ~0.98, $p = 0.007$).

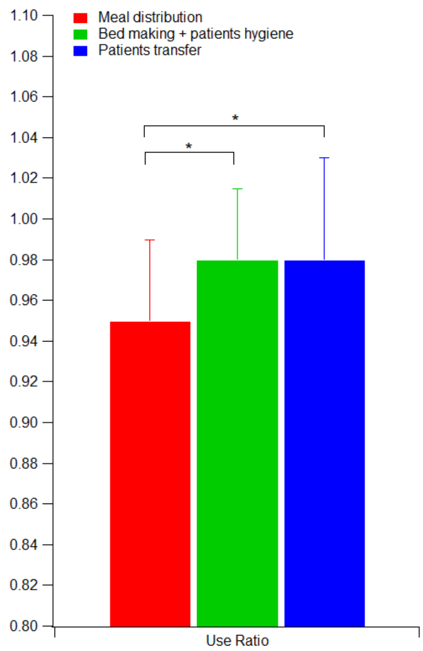

Figure 1 Use Ratio values for the three task types performed by HCWs (lower values indicate longer time of use for the dominant limb, and UR = 1 indicates perfect symmetry of use). The symbol * denotes a statistically significant difference ($p<0.05$)

As regards the intensity parameters, MANOVA detected a significant main effect of the task type [F (2,264) = 18.20, $p < 0.001$, Wilks' $\lambda = 0.35$, $\eta^2 = 0.41$], and in particular, the post-hoc analysis revealed that the group activity "bed making + patient hygiene" was characterized by significantly higher values of bilateral magnitude with respect to "patient transfer" and "meal distribution" (49.15 x 10^3 vs. 29.43 x 10^3, and 37.24 x 10^3, respectively, $p < 0.001$ in both cases), and values of bilateral magnitude for "meal distribution" were found to be significantly higher with respect to "patient transfer" (37.24 x 10^3 vs. 29.43 x 10^3, $p < 0.001$). Moreover, the "meal distribution" task was found to be characterized by a markedly unbalanced UL use in terms of intensity, as demonstrated by the lower values of MR (-0.209) and MAUI (0.561) when compared to both "bed making + patient hygiene" and "patient transfer," respectively (-0.141, p = 0.014; -0.127, p = 0.006), while the MAUI value was found to be significantly lower only with respect to the "patient transfer" task (0.932, p = 0.008). Finally, BAUI values decrease, passing from "patient transfer" (0.938) to "bed making + patient hygiene" (0.905) and "meal distribution" (0.873), indicating a progressively less balanced UL use during bimanual activities, although this difference is not statistically significant (p = 0.014).

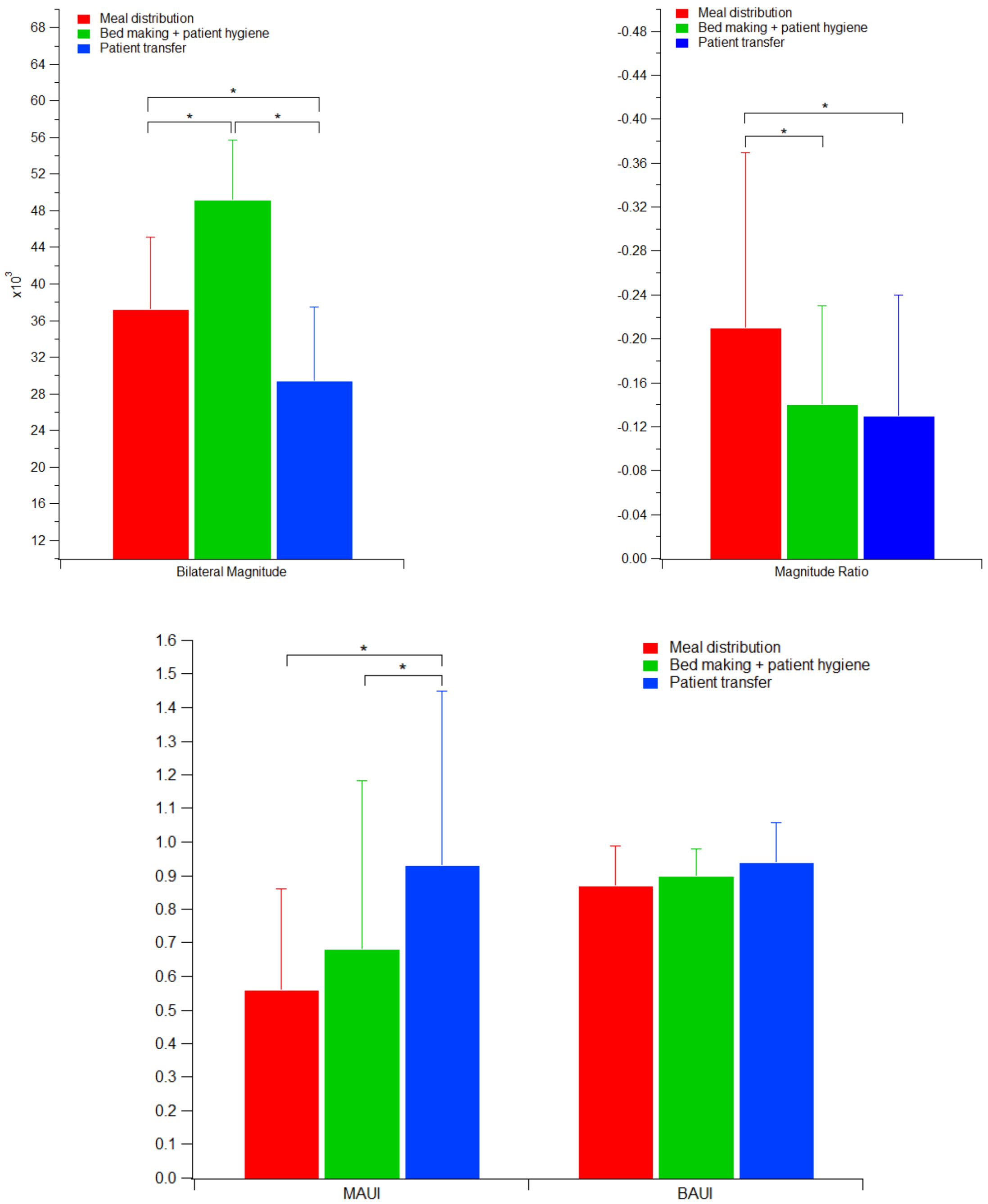

Figure 2 Intensity parameters' mean values for the three most common tasks performed by HCWs. The symbol * denotes a statistically significant difference ($p<0.05$). From top to bottom:
Bilateral magnitude: the sum of the VM calculated for the dominant and non-dominant UL (higher values represent more dynamic movements, irrespective of the UL);
Magnitude Ratio: the natural logarithm of the ratio between the non-dominant VM and the dominant VM (values <0 indicates a more intense use of the dominant limb with respect to the non-dominant, more negative magnitude ratio values, represent a more unbalanced UL use);
MAUI (Monolateral Arm Use Index): a MAUI value lower than 1 indicates that most of the unilateral activities are performed with the dominant limb;
BAUI (Bilateral Arm Use Index): the interpretation of this parameter is the same as MAUI, but considering activities that requires both arms simultaneously.

4. Discussion

The primary objective of the present study was to verify the feasibility of a quantitative approach based on the use of two wrist-worn accelerometers to characterize UL intensity and (a)symmetry of use associated with typical working tasks performed by HCWs during a regular work-shift. This methodology, which was previously employed to assess UL use during activities of daily living in special populations (Bailey et al., 2015; Hoyt et al., 2019; Pau et al., 2021) and to explore the existence of possible differences in UL use for physically demanding and sedentary jobs (Porta et al., 2022a), is potentially suitable for providing quantitative data useful to better define the exposure to biomechanical factors associated with the development of UL-WRMSD in HCWs as repetitiveness and movement asymmetries have been hypothesized to play a relevant role in the development of such disorders (Kucera and Robins 1989; Shiri et al. 2007; Filgueiras er t al., 2012).

The results obtained from the experimental analysis allowed to identify significantly different patterns of UL use during the performance of the three groups of activities, composed of the basic tasks typical of the HCWs' duties. In particular, the "bed making + patient hygiene" task was identified as the most demanding in terms of UL intensity of use, as indicated by the bilateral magnitude value, followed by the "meal distribution" and "patient transfer" tasks. However, the "meal distribution" task, although not the most intense, was found to be the most asymmetrical (both in terms of time and intensity of UL use) and is characterized by a strong use of the dominant UL. In contrast, "patient transfer" and "bed making + patient hygiene" were the groups of activities that were most symmetrical.

However, it should be noted that UR and MR values alone cannot provide sufficient data to fully characterize UL use. Indeed, while "patient transfer" and "bed making + patient hygiene" were found similar in terms of UR and MR, they were characterized by quite different MAUI values (0.932 vs. 0.685, respectively). This fact suggests that, during the performance of the latter groups of activities, the dominant UL is much more involved in unilateral movements. This apparent discrepancy (i.e., symmetrical activity from the point of view of overall intensity and minutes of use, but predominant use of dominant UL during unilateral movements) can be explained by recalling that a perfect symmetry in terms of UR (UR = 1) would equally summarize two very different scenarios: 1) either both UL are constantly moving simultaneously, or 2) one UL is moving for half the time while the other is still, and vice versa. Similarly, it is possible to achieve perfect symmetry in terms of intensity of use (MR = 0) either when the two UL move simultaneously at the same intensity or when one UL moves with higher intensity half of the time and vice versa in the remaining time. To have a detailed and accurate representation of the actual UL engagement during the performance of occupational tasks, it is necessary to also examine MAUI and BAUI values, the former being representative of the effort exerted by each UL and capable of quantifying the frequency of independent movements, and the latter being indicative of the different (similar) contribution of each UL during the performance of bilateral activities.

Although, to the best of our knowledge, no previous study used wrist worn accelerometers to characterize UL motion in HCWs, it may be of some interest to compare the results here presented with those of previous similar studies even though they involved different populations. In a sample of 28 healthy adults, during a regular weekday (which included working and leisure time and sleeping hours), Pau et al (2021), calculated a daily Bilateral Magnitude of $6.2 \cdot 10^6$, an UR = 0.96 (vs. 0.973 of the present study for the whole 4-hour working period, Table A.2), a MR = -0.08 (here -0.117), a MAUI = 0.87 (here 0.70) and a BAUI = 0.94 (here 0.922). Such valued depict a condition closer to perfect symmetry with respect to occupational task we measured, but that still indicates a predominant use of the dominant UL. The study of Porta et al. (2022a) analyzed symmetry and intensity of UL use in workers employed in metalworking industry, belonging to departments characterized by either technical or administrative tasks. The values here obtained for HCWs in terms of Bilateral Magnitude (assessed for the entire 4-hours monitoring, Table A.2) were found higher with respect to individuals engaged in administrative tasks ($2.70 \cdot 10^6$ vs. $1.20 \cdot 10^6$) but, surprisingly, also higher with respect to machine tool operators ($1.90 \cdot 10^6$) and assembly operators ($1.95 \cdot 10^6$) thus indicating the existence of highly dynamic UL movement in HCWs activities.

Moreover, although blue collar and HCWs duties are very different, some similarities in terms of UL use actually exist. For instance, in machine tool operators' activities, the dominant UL is used to perform dynamic tasks, while the non-dominant UL is used to stabilize an object. A similar behavior has been observed in HCWs during meal distribution task where the dominant limb is used to move bottles and plates, while the non-dominant limb is used as support (e.g. to hold up a tray). These similarities are reflected by comparable values of MAUI (0.561 vs. 0.586 for meal distribution and machine tool operations respectively) which is a parameter representative of unilateral activities. Instead, when considering BAUI and MR values, we found that meal distribution required a predominant use of the dominant UL with respect to machine tool operators' tasks (BAUI=0.873 vs. 0.972; MR= -0.209 vs. -0.153 for meal distribution and machine tool operators' tasks respectively). Another interesting consideration emerges by comparing the results obtained in the present study for the patient transfer tasks and those reported in Porta et al (2022a) for the fabrication and assembly operators employed in metalworking industry. Both these tasks required a similar involvement of both the ULs (regardless of the intensity) as demonstrated by quite similar values of UR (0.981 vs. 0.976 for patient transfer and assembly respectively). However, in terms of intensity, patient transfers require a more intense use of the dominant limb (MR = -0.127), while UL use in assembly operations is almost perfectly symmetrical (MR = -0.047).

As already mentioned, to the best of our knowledge, no previous studies have quantitatively analyzed the tasks of HCWs to identify specific features potentially associated with the development of UL-WRMSD, some information (obtained by means of questionnaires and observational methods) is available regarding the association between job characteristics and the risk of developing UL-WRMSD. The studies of Alexopulus et al. (2003) and Smith et al. (2006) reported that shoulder

WRMSD are associated with strenuous shoulder movement, repetitive tasks, and manual handling. Abdalla et al. (2014) employed the Rapid Entire Body Assessment (REBA) method to investigate a series of tasks commonly performed by HCWs (e.g., handling the bed cranks, disposal of materials, bed bath, placing patients in bed, etc.), suggesting that they are characterized by excessive biomechanical exposure of both the spine and UL. At last, Leifer et al. (2019) hypothesized that handedness represents a possible risk factor for the development of UL disorders. The relevance of this latter aspect, rarely considered in similar studies, was attributed to the ergonomic design of the equipment, which induced a different use of the right and left hand.

Task-related risk factors for the development of UL-WRMSD are scarcely studied in the health care professions, despite the high prevalence of such disorders in this category of workers. For this reason, we believe that the proposed approach, might effectively support actions for risk prevention by identifying specific characteristics associated with the different tasks commonly performed by HCWs. Although the calculated acceleration parameters, cannot consider the exposure to static posture or the effect of static loads (as movement is absent), they still provide useful information related to repetitive motions (e.g., intensity and symmetry or asymmetry of UL use) that has been described as important biomechanical factors for the development of UL-WRMSD. Particularly, the detailed knowledge about the way the various tasks originated different patterns of UL use, may result strategic to optimizing the sequence and duration of the activities routinely performed by HCWs in order to reduce their cumulative exposure to specific biomechanical factors. Moreover, the accelerometers were well tolerated by the participants in our study and did not influence task performance or movement, making them suitable for studies requiring long period of continuous monitoring. Such characteristics of acceptability, opens new insight to better understand dose-response relationship for the development of UL-WRMSD, as accelerometers provide a set of quantitative variables that can effectively integrate self-report data about exposure (which are often incorrectly estimated by workers, Karlqvist et al., 1991).

Some limitations of the study should be acknowledged. Firstly, while the proposed methodology may provide a detailed picture of UL use under ecological conditions, it does not provide information on the magnitude of the loads associated with any performed activity, neither about sustained static muscular contraction for which the physical effort is not accompanied by significant movement. To have a comprehensive assessment of the overall physical demand associated with the performed task it would be desirable to include additional biomechanical and physiological measures. Among the former, adding accelerometers on the humerus would allow performing a reliable assessment of upper arm elevation, while in-sole sensor systems would provide data about the external load.

As regards physiological measures previous studies aimed to assess physical effort and fatigue associated with working tasks employed mostly sEMG and, less frequently, heart rate, photoplethysmography, electrodermal activity, and skin temperature (see Santos et al., 2016; Mehta et al., 2017). Of course, the limited quality of data obtainable under actual working conditions, as well as the discomfort associated to the long term use of sEMG electrodes make impractical to employ such approach “in-field” to monitor a sufficient number of muscles in large sample of workers for the entire shift or even part of it. However, in a near future, it is likely that workers might be equipped with smart clothing able to record muscular activity. On the other hand, several physiologic parameters (other than accelerations) might be obtained using multisensors (wristwatch or armband) which are able to simultaneously collect heart rate, oxygen saturation, respiration rate, etc., although their accuracy is often reduced with respect to clinically validated mono-sensors. The combination of such measures might provide further elements to better assess the risk factors for UL-WMSD, but inevitably will increase the complexity of the assessment. However, further important information about the exertion associated to the work task might be obtained without a significant increase in worker’s burden, by analyzing the subjective rating of exertion (for instance using the Borg CR-10 scale).

Moreover, it is noteworthy that the onset of UL-WRMSD depends not only on the nature of the performed tasks but also on other psychosocial and stress factors, which may vary in different wards and thus should be included in the analysis. At last, since our sample of HCWs was predominantly composed of women (84%, a value that reflects the actual European gender ratio in health care professions, Eurostat, 2020), the results here presented should be generalized with caution since it is possible that some aspects of UL use are moderated by workers’ sex (this aspect was found relevant in previous similar studies, Dahlberg et al., 2004; Kjellberg et al., 2003).

5. Conclusion

Based on the obtained results and on the overall degree of acceptance by the participants, the use of a simple setup based on two wrist-worn accelerometers may represent a valid solution to characterize, under actual working conditions, a wide range of tasks commonly performed by HCWs in hospital settings and appears suitable to plan long-term monitoring of large cohorts of workers with minimal financial and organizational effort. The possibility of calculating several acceleration-derived parameters (i.e., intensity, duration, and movement asymmetry) that have been recognized as influential in the development of UL-WRMSD may result in helpfully highlighting potentially harmful conditions, both on a single-worker or ward basis. In future studies, the proposed methodology could benefit from the integration with physiological (e.g., hearth rate monitoring, perceived effort scales, etc.) and biomechanical (e.g., upper arm elevation) elements known as influent in the development of UL-WRMSD.

Conflict of interest

The authors report no conflicts of interest.

Acknowledgments

The authors would like to thank all the workers who volunteered for the study. In particular, the support provided by the head nurses during data collection is greatly appreciated**.**

Fundings

This research did not receive a specific grant from funding agencies in the public, commercial, or not-for-profit sectors**.**

References

Abdalla, D.R, Sisconeto de Freitas, F., Chieregato Matheus, J.P., Porcatti de Walsh, I.A., Bertoncello, D. 2014. “Postural biomechanical risks for nursing workers” Fisioterapia em Movimento. 27 (3).

Alexopoulos, E. C., Burdorf, A., & Kalokerinou, A. 2003. “Risk factors for musculoskeletal disorders among nursing personnel in greek hospitals”. International Archives of Occupational and Environmental Health, 76(4), 289-294. doi:10.1007/s00420-003-0442-9

Amasay, T., Latteri, M., Karduna, A.R. 2010. “In vivo measurement of humeral elevation angles and exposure using a triaxial accelerometer”. Human Factors. 52(6):616-26. doi: 10.1177/0018720810386951.

Ando, S., Ono, Y., Shimaoka, M., Hiruta, S., Hattori, Y., Hori, F., & Takeuchi, Y. 2000. Associations of self estimated workloads with musculoskeletal symptoms among hospital nurses. Occupational and Environmental Medicine, 57(3), 211-216. doi:10.1136/oem.57.3.211

Bailey, R.R., Klaesner, J.W., Lang, C.E. 2014. An accelerometry-based methodology for assessment of real-world bilateral upper extremity activity. PLoS One. 9(7):e103135. doi: 10.1371/journal.pone.0103135.

Bailey, R.R., Klaesner, J.W., Lang, C.E. 2015. Quantifying Real-World Upper-Limb Activity in Nondisabled Adults and Adults with Chronic Stroke. Neurorehabilitation & Neural Repair. 29(10):969-78. doi: 10.1177/1545968315583720

Coren, S. 1993. Measurement of handedness via self-report: the relationship between brief and extended inventories. Perceptual and Motor Skills. 76 (3 Pt 1): 1035-42. doi: 10.2466/pms.1993.76.3.1035

Davis, K. G., & Kotowski, S. E. 2015. Prevalence of musculoskeletal disorders for nurses in hospitals, long-term care facilities, and home health care: A comprehensive review. Human Factors, 57(5), 754-792. doi:10.1177/0018720815581933

Dahlberg, R., Karlqvist, L., Bildt, C., & Nykvist, K. 2004. Do work technique and musculoskeletal symptoms differ between men and women performing the same type of work tasks? Applied Ergonomics, 35(6), 521-529. doi:10.1016/j.apergo.2004.06.008

De Jong, T., Bos, E., Pawlowska-Cyprysiak, K., Hildt-Ciupińska, K., Malińska, M., Nicolescu, G., Trifu, N. 2014. European Agency for Safety and Health at Work. Current and emerging issues in the healthcare sector, including home and community care. in the EU European Risk Observatory Report. EU OSHA. 2014. https://data.europa.eu/doi/10.2802/33318

de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K., van Dorst P., Isusi I. European Agency for Safety and Health at Work. 2019. Work-related musculoskeletal disorders: prevalence, costs and demographics in the EU European Risk Observatory Report. EU OSHA. 2019. https://osha.europa.eu/en/publications/work-related-musculoskeletal-disorders-prevalence-costs-and-demographics-eu/view. doi:10.2802/66947

Estill, C.F., MacDonald, L.A., Wenzl, T.B., Petersen, M.R. 2000. Use of accelerometers as an ergonomic assessment method for arm acceleration - a large-scale field trial. Ergonomics. 43(9):1430-45. doi: 10.1080/001401300421842.

Eurostat 2020. Health care workers in the European Union. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200409-2

Filgueiras, E.; Rebelo, F.; da Silva, M. 2012. Support of the upper limbs of office workers during a daily work journey. Work.41 Suppl 1:676-82. doi: 10.3233/WOR-2012-0225-676

Freitag, S., Seddouki, R., Dulon, M., Kersten, J. F., Larsson, T. J., Nienhaus, A. 2014. The effect of working position on trunk posture and exertion for routine nursing tasks: An experimental study. Annals of Occupational Hygiene, 58(3), 317-325. doi:10.1093/annhyg/met071

Hallman, D.M., Gupta, N., Bergamin Januario, L., Holtermann, A. 2021. Work-Time Compositions of Physical Behaviors and Trajectories of Sick Leave Due to Musculoskeletal Pain. International Journal of Environmental Research and Public Health.18(4):1508. doi: 10.3390/ijerph18041508

Hansson, G. Å., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., Skerfving, S. 2009. Physical workload in various types of work: Part II. neck, shoulder and upper arm. International Journal of Industrial Ergonomics. 40(3), 267-281. doi:10.1016/j.ergon.2009.11.002

Hansson, G. Å.; Balogh, I.; Ohlsson, K.; Granqvist, L.; Nordander, C.; Arvidsson, I.; Skerfving, S. 2010. Physical workload in various 423 types of work: Part II. neck, shoulder and upper arm. Int. J. Ind. Ergon.40(3), 267-281. doi:10.1016/j.ergon.2009.11.002

Hansson, G.A., Asterland, P., Holmer, N.G., Skerfving, S. 2001. Validity and reliability of triaxial accelerometers for inclinometry in posture analysis. Medical & Biological Engineering & Computing. 39 (4), 405–413. doi: 10.1007/BF02345361.

Harcombe, H., Herbison, G. P., McBride, D., & Derrett, S. 2014. Musculoskeletal disorders among nurses compared with two other occupational groups. Occupational Medicine (Oxford, England), 64(8), 601-607. doi:10.1093/occmed/kqu117

Hoozemans, M. J. M., Van der Beek, A. J., Frings-Dresen, M. H. W., Van der Woude, L. H. V., & Van Dijk, F. J. H. 2002. Pushing and pulling in association with low back and shoulder complaints. Occupational and Environmental Medicine 59:696–702. doi:10.1136/oem.59.10.696

Hoyt, C.R., Van, A.N., Ortega, M., Koller, J.M., Everett, E.A., Nguyen, A.L., Lang, C.E., Schlaggar, B.L., Dosenbach, N.U.F. 2019. Detection of Pediatric Upper Extremity Motor Activity and Deficits With Accelerometry. JAMA Network Open. 2019 2(4):e192970. doi: 10.1001/jamanetworkopen.2019.2970

Karlqvist, L., Wiktorin, C., & Winkel, J. 1991. Validity of Questions Estimating Manual Materials Handling, Working Postures and Movements. Designing for Everyone : Proceedings of the Eleventh Congress of the International Ergonomics Association, Paris 1991, Vol. 1, 251–253.

Kjellberg, K., Lagerström, M., & Hagberg, M. 2003. Work technique of nurses in patient transfer tasks and associations with personal factors. Scandinavian Journal of Work, Environment and Health, 29(6), 468-477. doi:10.5271/sjweh.755

Korshøj, M., Skotte, J.H., Christiansen, C.S., Mortensen, P., Kristiansen, J., Hanisch, C., Ingebrigtsen, J., Holtermann, A. 2014. Validity of the Acti4 software using ActiGraph GT3X+accelerometer for recording of arm and upper body inclination in simulated work tasks. Ergonomics. 57(2):247-53. doi: 10.1080/00140139.2013.869358.

Kucera, J.D., Robins, T.G. 1989. Relationship of cumulative trauma disorders of the upper extremity to degree of hand preference. Journal of Occupational Medicine. 31(1):17-22.

Kuijer, P.P.F.M., Verbeek, J.H.A.M., Visser, B., Elders, L.A.M., Van Roden, N., Van den Wittenboer, M.E.R, Hulshof, C.T.J. 2014. An evidence-based multidisciplinary practice guideline to reduce the workload due to lifting for preventing work-related low back pain. Annals of Occupational and Environmental Medicine, 26(1) doi:10.1186/2052-4374-26-16

Lang, C.E., Waddell, K.J., Klaesner, J.W., Bland, M.D. 2017. A Method for Quantifying Upper Limb Performance in Daily Life Using Accelerometers. Journal of Visualized Experiments. (122):55673. doi: 10.3791/55673.

Leifer, S., Choi, S. W., Asanati, K., & Yentis, S. M. 2019. Upper limb disorders in anaesthetists – a survey of association of anaesthetists members. Anaesthesia, 74(3), 285-291. doi:10.1111/anae.14446

Lim, S., D'Souza, C. A. 2020. Narrative Review on Contemporary and Emerging Uses of Inertial Sensing in Occupational Ergonomics. International Journal of Industrial Ergonomics. 76:102937.

Mehta, R. K., Peres, S. C., Kannan, P., Rhee, J., Shortz, A. E., Sam Mannan, M. 2017. Comparison of objective and subjective operator fatigue assessment methods in offshore shiftwork. Journal of Loss Prevention in the Process Industries, 48, 376–381. https://doi.org/10.1016/j.jlp.2017.02.009

Nourollahi, M., Afshari, D., Dianat, I. 2018. Awkward trunk postures and their relationship with low back pain in hospital nurses. Work, 59(3), 317-323. doi:10.3233/WOR-182683

Occhionero, V., Korpinen, L., Gobba, F. 2014. Upper limb musculoskeletal disorders in healthcare personnel. Ergonomics, 57(8), 1166-1191. doi:10.1080/00140139.2014.917205

Pau, M., Leban, B., Deidda, M., Porta, M, Coghe, G., Cattaneo, D., Cocco, E. 2021. Use of wrist-worn accelerometers to quantify bilateral upper limb activity and asymmetry under free-living conditions in people with multiple sclerosis. Multiple Sclerosis and Related Disorders. 53-103081. doi.org/10.1016/j.msard.2021.103081

Picerno, P., Iosa, M., D'Souza, C., Benedetti, M. G., Paolucci, S., & Morone, G. 2021. Wearable inertial sensors for human movement analysis: A five-year update. Expert Review of Medical Devices, 18(sup1), 79-94. doi:10.1080/17434440.2021.1988849

Porta, M., Orrù, P. F., Pau, M. 2021. Use of wearable sensors to assess patterns of trunk flexion in young and old workers in the metalworking industry. Ergonomics, 64(12), 1543-1554. doi:10.1080/00140139.2021.1948107

Porta, M., Leban, B., Orrù, P. F., Pau, M. 2022a. Use of bilateral wrist-worn accelerometers to characterize upper limb activity time, intensity and asymmetry of use in physically demanding and sedentary working task. International Journal of Industrial Ergonomics, 92 doi:10.1016/j.ergon.2022.103359

Porta, M., Porceddu, S., Mura, G. M., Campagna, M., Pau, M. 2022b. Continuous assessment of trunk posture in healthcare workers assigned to wards with different MAPO index. Ergonomics, doi:10.1080/00140139.2022.2113920

Roman-Liu, D., Wittek, A., Kędzior, K. 1996. Musculoskeletal Load Assessment of the Upper Limb Positions Subjectively Chosen as the Most Convenient. International Journal of Occupational Safety and Ergonomics. 2(4):273-283. doi: 10.1080/10803548.1996.11076356.

Santos, J., Baptista, J. S., Monteiro, P. R. R., Miguel, A. S., Santos, R., Vaz, M. A. P. 2016. The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review. International Journal of Industrial Ergonomics, 52, 78–91. https://doi.org/10.1016/j.ergon.2015.09.010

Schall, M.C. Jr, Fethke, N.B., Chen, H. 2016. Working postures and physical activity among registered nurses. Applied Ergonomics. 54:243-50. doi: 10.1016/j.apergo.2016.01.008.

Serranheira, F., Cotrim, T., Rodrigues, V., Nunes, C., & Sousa-Uva, A. 2012. Nurses' working tasks and MSDs back symptoms: Results from a national survey. Work, 41(SUPPL.1), 2449-2451. doi:10.3233/WOR-2012-0479-2449

Serranheira, F., Sousa-Uva, M., Sousa-Uva, A. 2015. Hospital nurses tasks and work-related musculoskeletal disorders symptoms: A detailed analysis. Work, 51(3), 401-409. doi:10.3233/WOR-141939

Shiri, R., Varonen, H., Heliövaara, M., Viikari-Juntura, E. 2007. Hand dominance in upper extremity musculoskeletal disorders. Journal of Rheumatology. 34(5):1076-82.

Smedley, J., Inskip, H., Trevelyan, F., Buckle, P., Cooper, C., & Coggon, D. 2003. Risk factors for incident neck and shoulder pain in hospital nurses. Occupational and Environmental Medicine, 60(11), 864-869. doi:10.1136/oem.60.11.864

Smith, D. R., Mihashi, M., Adachi, Y., Koga, H., & Ishitake, T. 2006. A detailed analysis of musculoskeletal disorder risk factors among japanese nurses. Journal of Safety Research, 37(2), 195-200. doi:10.1016/j.jsr.2006.01.004

Søgaard K, Laursen B, Jensen BR, Sjøgaard G. 2001. Dynamic loads on the upper extremities during two different floor cleaning methods. Clinal Biomechanics (Bristol, Avon). 16(10):866-79. doi: 10.1016/s0268-0033(01)00083-3.

Soylar, P. & Ozer, A. 2018. Evaluation of the prevalence of musculoskeletal disorders in nurses: a systematic review Medical Sciences, vol. 7, pp. 479–485, 2018.

Straker, L., Campbell, A., Mathiassen, S.E., Abbott, R.A., Parry, S., Davey, P. 2014. Capturing the pattern of physical activity and sedentary behavior: exposure variation analysis of accelerometer data. Journal of Physical Activity and Health. 11(3):614-25. doi: 10.1123/jpah.2012-0105.

West, N., Snodgrass, S.J., James, C. 2018. The effect of load on biomechanics of the back and upper limb in a bench to shoulder lift during the WorkHab Functional Capacity Evaluation. Work. 59(2):201-210. doi: 10.3233/WOR-172677.

Appendix

Table A.1 Comparison of upper limb time parameter for type of tasks. Values are expressed as mean (SD)

	Making bed/ patients hygiene	Patients transfer (push-pull wheelchair/bed)	Meal distribution	All monitoring (4-hours)
Use Ratio(1)	0.979 (0.04)	0.981 (0.05)	0.950 (0.05)	0.973 (0.03)

The symbol *a* denotes a statistically significant difference with respect to Meal distribution ($p < 0.05$)
(1) Lower values indicate higher activity of the dominant limb

Table A.2 Comparison of upper limb intensity parameters for type of activities. Values are expressed as mean (SD)

	Making bed/patient's hygiene	Patients' transfer (push-pull wheelchair/bed)	Meal distribution	All monitoring (4-hours)
Bilateral Magnitude/min $x10^3$	49.15 (65.6)	29.43 (80.7)	37.24 (7.9)	2.70 (0.48) $x10^3$
Magnitude Ratio(1)	-0.141 (0.09)	-0.127 (0.11)	-0.209 (0.16)	-0.117 (0.10)
MAUI(2)	0.686 (0.50)	0.932 (0.52)	0.561 (0.31)	0.700 (0.29)
BAUI(2)	0.905 (0.08)	0.938 (0.12)	0.873 (0.13)	0.922 (0.08)

(1) Negative (positive) values indicate higher activity intensity of the dominant (non-dominant) upper limb. Larger negative (positive) values correspond to higher unbalance towards the dominant (non-dominant) upper limb
(2) Lower values indicate higher activity of the dominant limb

Supplementary material

Table S.1	Univariate ANOVAs post-hoc test on intensity parameters		
	F	**p-value**	**η^2**
Bilateral Magnitude/min	103.3	<0.001	0.603
Magnitude Ratio	4.2	0.016	0.059
MAUI	5.6	0.005	0.076
BAUI	3.3	0.038	0.047