Human Factors and Wearable Technologies, Vol. 29, 2022, 94–100
https://doi.org/10.54941/ahfe1001479

Simultaneous Assessment of Upper Limb Usage and Sedentary Behavior Time Among White- and Blue-collar Workers Using Wrist-worn Accelerometers

Micaela Porta , Bruno Leban, and Massimiliano Pau

Department of Mechanical, Chemical and Materials Engineering, University of Cagliari, Piazza d'Armi, 09123 Cagliari, Italy

ABSTRACT

In the present study, wrist-worn accelerometers were employed to estimate intensity and symmetry of use of upper limbs (UL) and characterize sedentary behavior during 4 hours of shift in 22 full-time workers assigned to tasks of different physical engagement (i.e., machine tool operators and administrative staff). In particular, the raw accelerations were processed to calculate minutes of use of each limb and vector magnitude counts (as overall measures of limb activity) magnitude ratio and use ratio as symmetry parameters. The same data also allowed to calculate the time spent in sitting position. The results identified the existence of significant asymmetries in the machine tool workers in terms of both duration of UL use and activity intensity, while administrative staff exhibit a marked sedentary activity but no asymmetries in UL use. Such findings suggest that accelerometer-based data allow discriminating among important features of different tasks, highlighting potentially harmful conditions.

Keywords: Upper limbs, Accelerometer, Asymmetry, Metalworking

INTRODUCTION

The use of wrist-worn accelerometers to perform various types of ecological assessment of physical activity amount and intensity and posture recognition in both healthy and pathological individuals, has significantly increased in the last two decades, due to their continuously improved performance in terms of miniaturization, power consumption, accuracy, and data storage/transmission capabilities, not to mention the very affordable cost. Although less widespread in ergonomic contexts, this approach has been proven valuable, for instance to discriminate among individuals assigned to different working tasks (Estill et al. 2000) or to estimate the magnitude of shoulder movements (Akuna and Karduna, 2012). However, to our knowledge, no studies employed wrist-worn accelerometers to investigate symmetry of use of upper limbs (UL) associated with a specific working task, despite such information would be of great interest to identify potentially

unbalanced use of dominant and non-dominant limb. In this regard, it is useful to recall that several studies reported the existence of differences, in terms of increased susceptibility of one of the UL to musculoskeletal disorders, in a wide range of working tasks. For instance, Kucera and Robins (1989) found a greater predisposition to carpal tunnel syndrome in the dominant hand since a strong hand preference leads to accumulation of higher levels of physical stress with respect to the non-dominant one. A more recent study performed by Shiri et al. (2007), who investigated the prevalence of work-related UL disorders in a large sample of more than 6000 Finnish workers aged 30–64 years, reported that among men, rotator cuff tendinitis and lateral epicondylitis were more common in the dominant compared to the non-dominant arm. Thus, since there are several occupations in industry, as well as in the tertiary sector, which require a more intensive use of one of the two limbs (Hansson et al., 2009; 2010; Filgueiras et al., 2012), or simply because workers may have a natural predisposition to exploit their dominant hand more often, it may be important to have available quantitative techniques able to provide information on the way individuals use UL when engaged in uni- or bilateral activities. Based on the aforementioned considerations, we here propose a preliminary study aimed to quantitatively and objectively characterize both intensity and symmetry of use of UL as well as the amount of time spent in sedentary behavior in a sample of workers engaged in physically demanding and sedentary tasks, during their regular shifts, and thus in the most ecologically possible conditions.

METHODS

Participants

Twenty-two full-time male workers currently employed at "IMI Remosa Srl" (Cagliari, Italy), a metalworking company specialized in design and manufacture of large valves used in oil refineries, were recruited for the study on a voluntary basis. According to self-reports and company medical records, at the time of the experimental campaign and in the previous six months, all of them resulted free from acute or chronic musculoskeletal conditions.

Participants were divided into two groups according to the task they usually perform as follows:

- Machine tools operators (n=11). These workers are required to program the machine by specifying speed, feed and cut of the toolpath; set clamps, load, tighten and untighten cutting tools on machines, unload machines manually or using cranes, inspect and measure the worked parts and perform several kinds of machining processes such as cutting, turning, milling, rectification etc.
- Administrative staff (n = 11). These workers spend most of their shift time on a desk, in a sitting position using a PC, mouse and keyboard.

Prior to data collection, demographic and anthropometric characteristics of participants, as well as their hand dominance were assessed. They are reported in Table 1.

Table 1. Participants' demographic and anthropometric characteristics. Values are expressed as mean (SD).

	Machine Tool Operators (n=11)	Administrative Staff (n=11)
Age (years)	38.5 (9.9)	41.0 (14.8)
Body Mass (kg)	69.3 (9.6)	80.6 (11.8)
Height (cm)	171.3 (7.2)	175.6 (7.0)
Handedness (R, L)	(10 R, 1 L)	(10 R, 1 L)

Data Collection and Processing

Upper limb activity was measured for 4 consecutive hours of a regular working shift using 2 wrist-worn tri-axial accelerometers (Actigraph GT3X-BT, Acticorp Co., Pensacola, Florida, USA). Such devices were previously employed in occupational contexts to assess intensity of the performed physical activity (Straker et al. 2014; Schall et al., 2016), body posture (Hallman et al., 2021), and UL and trunk inclination (Korshøj et al., 2014; Brandt et al., 2018). Participants were asked not to remove the devices for any reason and, at the end of the acquisition period, the raw accelerations (collected at 30 Hz frequency) were downloaded to a PC by means of dedicated software (Actilife v6.13.3 Acticorp Co., USA). Raw data were then processed in two different modalities as follows:

- Upper Limb use. Starting from the accelerometric counts recorded for the three axes of the device on a 1s basis provided by the Actilife v6.13.3 software as CSV file, the following parameters were calculated:
    1. Vector Magnitude (VM) counts, that is a composite measure of the accelerometric counts on the three planes of motion;
    2. Bilateral Magnitude (BLM), which is the sum of the VM values calculated for both dominant and non-dominant limb;
    3. Use Ratio (UR): is the ratio between the minutes of use calculated for the non-dominant and the dominant limb respectively, regardless of the intensity of the movement performed (Lang et al. 2017). UR = 1 indicates an equal use of dominant and non-dominant limb during the monitoring period, while UR < 1 indicates longer periods of use for the dominant limb and UR > 1 denote longer periods of use of the non-dominant limb;
    4. Magnitude Ratio (MR) is the natural logarithm of the ratio between the VM counts calculated for the non-dominant and the dominant limbs respectively (Bailey et al. 2014; Lang et al. 2017). A value of MR = 0 indicates perfect symmetric use of both limbs in terms of movement intensity. MR < 0 (> 0) denotes higher intensity activity of the dominant (non-dominant) limb;
- Time spent in sedentary (sitting) behavior (TS) was calculated according to the procedure proposed by Straczkiewicz et al. (2020), which assess the time spent with the forearm in horizontal (sitting) and vertical (standing) position;

All data processing was performed using a custom routine developed in Matlab (R2019a, MathWorks, Natick, Massachusetts, USA).

Statistical Analysis

The statistical analysis was designed to assess the capabilities of the experimental approach to discriminate between typically sedentary activities (administrative staff) from the more physically demanding occupations (machine tool operators). Preliminarily, we carried out a simple t-test to assess whether the number of steps traveled by the 2 groups was significantly different. This is an important confounding factor for UL activity analysis because the physiologic arm swing associated with walking itself represents a source of accelerometric counts and thus, regardless of the task performed, more steps would lead to higher VM counts.

In particular, we performed a one-way MANCOVA using the number of steps as covariate and group (i.e., machine tools operator or administrative staff) as independent variable to investigate the existence of possible differences on the UL parameters (i.e., BLM, MR and UR). The number of steps was introduced as covariate because the physiologic arm swing associated with walking itself represents a source of accelerometric counts and thus, regardless of the task performed, more steps would lead to higher VM counts, thus also possibly altering BLM, MR and UR values. We also ran a one-way ANOVA to investigate the existence of possible differences on the time spent in sedentary (sitting) behavior (i.e., TS). Again, the group (i.e., machine tools operator or administrative staff) was considered as independent variable. The level of significance was set at $p = 0.05$ and the effect of size was assessed using the eta-squared coefficient. All analyses were performed using the IBM SPSS Statistics v.20 software (IBM, Armonk, NY, USA).

RESULTS

After controlling for number of steps, MANCOVA detected a significant main effect of group on upper limb activity and symmetry parameters [$F(3,17) = 5.512$; $p = 0.008$ Wilks'$\Lambda = 0.507$; $\eta^2 = 0.493$]. In particular, the follow-up analysis revealed that machine tool operators performed a more asymmetrical activity in favor of their dominant limb with respect to those engaged in office tasks, both in terms of intensity (MR = −0.18 vs. −0.02, p=0.004) and minutes of use (UR = 0.89 vs. 0.99, p=0.001), while no differences were found on the overall bilateral activity (BLM = 1.76×10^6 vs 0.93×10^6, $p = 0.083$) (see Table 2). As regards the sedentary behavior, the ANOVA revealed that the administrative staff spent significantly longer time in sitting position with respect to machine tool workers (158 minutes vs. 70, p=0.021). These values represent approximately 66% and 29% of the monitored period.

DISCUSSION AND CONCLUSION

The main goal of this study was to verify the feasibility of application of a quantitative approach based on the use of two wrist-worn accelerometers to

Table 2. Upper limb use parameters and time spent in sedentary behavior. Values are expressed as mean (SD).

	Machine Tool Operators	Administrative Staff
Bilateral Magnitude (10^6)	1.76 (0.48)	0.93 (0.35)
Magnitude Ratio	**0.89 (0.09)***	0.99 (0.13)
Use Ratio	**−0.19 (0.16)***	−0.02 (0.16)
Sedentary Behavior (min)	**69.90 (35.82)***	158.54 (40.0)

The symbol * indicate a significant difference with respect to Administrative staff.

assess intensity and symmetry of use of UL as well as the amount of time spent in sedentary behavior (sitting position) during actual work shifts.

The results obtained from the experimental analysis identified the existence of moderate asymmetry in terms of both duration and intensity of UL use among machine tool operator workers. In particular, they exhibited a marked higher intensity of use of their dominant limb with respect to the administrative staff which showed an almost perfect symmetry of UL use as indicated by a MR=0.99 and an UR= −0.02. Such unbalanced activity is probably associated with the different role played by dominant and non-dominant limb to optimally perform the activities associated with the specific task. Indeed, machine tool operators perform technological processes (such as cutting, turning, milling, rectification) for which the dominant UL tends to perform dynamic tasks, while the non-dominant one is more devoted to stabilizing position by contrasting the forces imposed by the dominant UL (Wang and Sainburg, 2007). Another interesting finding of the study regards the overall activity intensity (and thus bilateral magnitude). Although higher values were calculated for workers engaged in physically demanding occupations, when the number of steps traveled was introduced as a co-variate, the MANCOVA analysis failed to identify statistical differences between the two groups of workers. This result is of some interest because it suggests that a not negligible part of the accelerometric counts is associated with walking, thus emphasizing the difference of the physical profile in the tasks performed by blue- and white-collar workers (the latter being characterized by a significantly lower number of steps traveled). This concept is also supported by the significant difference found in the time spent by the two group of workers in sitting position. In this regard it appears important to note that our value (approximately 66% of the working time) is consistent with those reported in previous studies (Clemes et al. 2014 65%, and Hodgraft et al. 2016, 69.5%) despite the methodological differences, thus confirming the validity of the accelerometric-based measure. Such behavior has been identified as independent risk factor for the development of adverse heath outcome such as type 2 diabetes or cardiovascular disease (Katzmarzyk et al. 2009; Wilmot et al. 2012). In summary, the findings of the present study suggest that accelerometer-based data recorded using wrist-worn devices allow to highlight potentially harmful health conditions for both blue- and white-collars workers. In the first case the results indicate asymmetrical use of the dominant and non-dominant limbs, a potentially risky condition for the development of UL musculoskeletal disorder as evidenced by the existing

literature which clearly indicates a higher prevalence of musculoskeletal UL disorders in the dominant limb with respect to the non-dominant one (Kucera and Robins, 1989; Shiri et al., 2007). In the second case, that is among the white-collar workers, no significant asymmetries emerged from the analysis but, using the same setup, it has been possible to evaluate the time spent in sitting position and thus identify critical situations worthy of ergonomic interventions.

These results show that a simple measurement setup based on two wrist-worn accelerometers is able to provide extremely useful information to protect the workers' health status. In particular, for the specific cases here considered, in presence of prolonged sitting period it might be desirable to promote a more active lifestyle by encouraging workers to perform physical activity during the lunchtime or, to adopt sit-stand workstation while, in presence of strongly asymmetrical UL activities, it is possible to redesign work task to promote the use of the non-dominant hand for a greater part of the work-shift to reduce the cumulative workload.

In conclusion, the findings of the present study suggest that wrist-worn accelerometers represent a suitable and effective way to collect data about intensity and asymmetry of use among dominant and non-dominant limb, as well as sitting time, under actual working conditions in both physically demanding and sedentary jobs. Such data may provide important information to support a more accurate assessment of the risk of work-related disorders.

ACKNOWLEDGMENT

The authors wish to thank the IMI Remosa Company and all workers who participated in the study for their availability. In particular, the support provided by engineers Alberto Porcu and Alessia Murgia during the test organization was greatly appreciated.

REFERENCES

Acuna, M. & Karduna, A.R. 2012, "Wrist activity monitor counts are correlated with dynamic but not static assessments of arm elevation exposure made with a triaxial accelerometer", Ergonomics, vol. 55, no. 8, pp. 963–970.

Bailey, R.R., Klaesner, J.W. & Lang, C.E. 2014, "n accelerometry-based methodology for assessment of real-world bilateral upper extremity activity", PLoS ONE, vol. 9, no. 7.

Brandt, M., Madeleine, P., Samani, A., Ajslev, J.Z.N., Jakobsen, M.D., Sundstrup, E. & Andersen, L.L. 2018, "Effects of a participatory ergonomics intervention with wearable technical measurements of physical workload in the construction industry: Cluster randomized controlled trial", Journal of Medical Internet Research, vol. 20, no. 12.

Clemes, S.A., Patel, R., Mahon, C. & Griffiths, P.L. 2014, "Sitting time and step counts in office workers", Occupational Medicine, vol. 64, no. 3, pp. 188–192.

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, vol. 43, no. 9, pp. 1430–1445.

Filgueiras, E., Rebelo, F. & Da Silva, M. 2012, "Support of the upper limbs of office workers during a daily work journey", Work, vol. 41, no. SUPPL.1, pp. 676–682.

Hadgraft, N.T., Healy, G.N., Owen, N., Winkler, E.A.H., Lynch, B.M., Sethi, P., Eakin, E.G., Moodie, M., LaMontagne, A.D., Wiesner, G., Willenberg, L. & Dunstan, D.W. 2016, "Office workers' objectively assessed total and prolonged sitting time: Individual-level correlates and worksite variations", Preventive Medicine Reports, vol. 4, pp. 184–191.

Hallman, D.M., Gupta, N., Januario, L.B. & 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, vol. 18, no. 4, pp. 1–11.

Hansson, G.-., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., Åkesson, I., Unge, J., Rittner, R., Strömberg, U. & Skerfving, S. 2009, "Physical workload in various types of work: Part I. Wrist and forearm", International Journal of Industrial Ergonomics, vol. 39, no. 1, pp. 221–233

Hansson, G.-., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., Åkesson, I., Unge, J., Rittner, R., Strömberg, U. & Skerfving, S. 2010, "Physical workload in various types of work: Part II. Neck, shoulder and upper arm", International Journal of Industrial Ergonomics, vol. 40, no. 3, pp. 267–281.

Katzmarzyk, P.T., Church, T.S., Craig, C.L. & Bouchard, C. 2009, "Sitting time and mortality from all causes, cardiovascular disease, and cancer", Medicine and science in sports and exercise, vol. 41, no. 5, pp. 998–1005.

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, vol. 57, no. 2, pp. 247–253.

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, vol. 31, no. 1, pp. 17–22.

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, vol. 2017, no. 122.

Schall, M.C., Fethke, N.B. & Chen, H. 2016, "Working postures and physical activity among registered nurses", Applied Ergonomics, vol. 54, pp. 243–250.

Shiri, R., Varonen, H., Heliövaara, M. & Viikari-Juntura, E. 2007, "Hand dominance in upper extremity musculoskeletal disorders", Journal of Rheumatology, vol. 34, no. 5, pp. 1076–1082.

Straczkiewicz, M. Glynn, N., Zipunnikov, V., Harezlak J. 2020. "Fast and Robust Algorithm for Detecting Body Posture Using Wrist-Worn Accelerometers". Human Kinetics. Vol. 3, no. 4, pp. 285–293

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, vol. 11, no. 3, pp. 614–625.

Wang, J. & Sainburg, R.L. 2007, "The dominant and nondominant arms are specialized for stabilizing different features of task performance", Experimental Brain Research, vol. 178, no. 4, pp. 565–570.

Wilmot, E.G., Edwardson, C.L., Achana, F.A., Davies, M.J., Gorely, T., Gray, L.J., Khunti, K., Yates, T. & Biddle, S.J.H. 2012, "Sedentary time in adults and the association with diabetes, cardiovascular disease and death: Systematic review and meta-analysis", Diabetologia, vol. 55, pp. 2895–2905.