Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Kailiang Xu

Associations between awkward work postures and musculoskeletal pain in home care workers: a cross-sectional study

Master's thesis in Physical Activity and Health, Movement Science
Supervisor: Marius Steiro Fimland
Co-supervisor: Fredrik Klæboe Lohne & Skender Elez Redzovic
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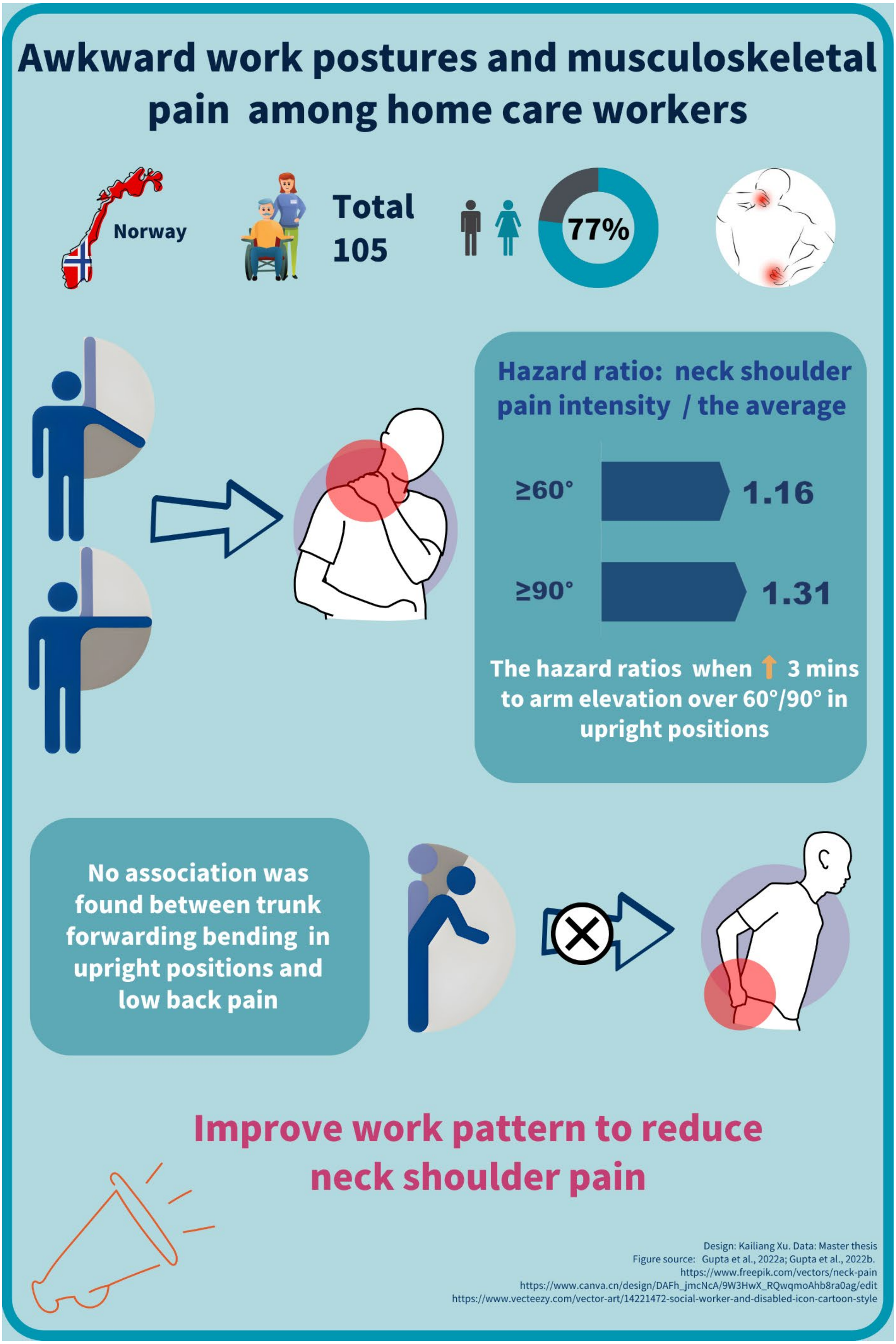
Awkward work postures and musculoskeletal pain among home care workers
Norway
Total 105
77%
Hazard ratio: neck shoulder pain intensity / the average
≥60° 1.16
≥90° 1.31
The hazard ratios when ↑ 3 mins to arm elevation over 60°/90° in upright positions
No association was found between trunk forwarding bending in upright positions and low back pain
Improve work pattern to reduce neck shoulder pain
Design: Kailiang Xu. Data: Master thesis
Figure source: Gupta et al., 2022a; Gupta et al., 2022b.
https://www.freepik.com/vectors/neck-pain
https://www.canva.cn/design/DAFh_jmcNcA/9W3HwX_RQwqmoAhb8ra0ag/edit
https://www.vecteezy.com/vector-art/14221472-social-worker-and-disabled-icon-cartoon-style

Abstract

Objectives: Arm elevation and trunk forward bending in upright positions at work are considered risk factors for musculoskeletal pain. However, no studies have investigated their associations using precise objective measurements among home care workers. This study aimed to explore the association between awkward work postures and neck/shoulder pain (NSP) and low back pain (LBP) among home care workers using wearable sensors.

Methods: Home care workers (N=105) from 11 home care units in Trondheim, Norway, completed a questionnaire, and a diary about pain assessment and working hours, and wore three accelerometers (Axivity AX3) for up to seven consecutive days. The data of work postures were transformed into compositional data expressed as the isometric log ratios (*ilrs*). The negative binomial generalized linear mixed models were used to analyze the relationship between awkward work postures and NSP and LBP, respectively.

Results: In the adjusted model, controlling for age, gender, and BMI, a positive association was found between time spent with arm elevation ≥60° in upright positions and NSP (P=0.045, B=0.504; B represents the efficient) and a trend of a positive association between time spent with arm elevation ≥90° in upright positions and NSP (P=0.064, B=0.297). Adding three more minutes to arm elevation ≥60° in upright positions from <60° will increase the NSP intensity by 16% compared to the average pain, while adding three more minutes to arm elevation ≥90° in upright positions from <90° will increase that by 31%. No significant association was found between different degrees of trunk forward bending in upright positions and LBP.

Conclusions: There was a positive dose–response association between arm elevation ≥60° in upright positions and NSP, as well as a tendency of a positive association between arm elevation ≥90° in upright positions and NSP. Further, the NSP intensity increases more with higher degrees of arm elevation. However, there was no association between trunk forward bending in upright positions and LBP.

Keywords: Occupational health; accelerometer; arm elevation; trunk forward bending; upright positions; neck/shoulder pain; low back pain; compositional data

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List of Abbreviations (In alphabetical order)

BMI	Body mass index
CoDA	Compositional data analysis
HR	Hazard ratio
ilr	Isometric log ratio
LBP	Low back pain
NPRS	Numeric Pain Rating Scale
NSP	Neck/shoulder pain
SD	Standard deviation
T	Thoracic vertebra

1 Introduction

The world is gradually stepping into an aging society due to life expectancy increases. In Norway, there are currently over 240 000 people above 80 years old, and the number will double by 2040 [1, 2]. This aged population often has limited physical function due to aging, disability, or chronic diseases and needs care from others, and will further strain healthcare systems and increase public expenditures. To address this issue, Norwegian authorities have identified improving the life and health of older persons as a crucial strategy [3]. Home care workers, including nurses, occupational therapists, health assistants, physiotherapists, and social workers, play an indispensable role in caring for the old and disabled population.

However, home care workers in Norway have a very high sick leave rate (11%), almost twice the national average [4, 5]. Meanwhile, nurses are getting harder to recruit in the Norwegian elderly care services, and one-quarter of young nurses desire to leave their current job [6]. Under these circumstances, the available home care workers would be even fewer. Additionally, musculoskeletal pain in the neck/shoulder area and low back is highly prevalent in the working population [7, 8] and among the leading causes of sick leave [9, 10]. A recent study showed that 36% of Norwegian home care workers reported long-term neck/shoulder pain and 34% reported long-term low back pain in the past year [7]. Besides, musculoskeletal pain reduces work ability [8, 10, 11] and constitutes a severe public health burden [11-13]. Thus, identifying the relevant risk factors of musculoskeletal pain and taking practical preventive measures is crucial for home care workers' health and workability and alleviating the public health burden.

Several studies have indicated that awkward postures at work, e.g., arm elevation and trunk forward bending, are considered risk factors for neck/shoulder pain (NSP) and low back pain (LBP) [13-16]. Most of the studies using questionnaires or other self-reported methods for assessing the work exposures reported a positive association between arm elevation and NSP, but they are considered inaccurate due to recall bias

[11, 13, 17]. In terms of the studies using objective accelerometers/inclinometers to measure the work exposures, conflicting results have been found on the association between arm elevation and NSP. Some studies reported a positive relationship between arm elevation above shoulder level (≥ 90˚) at work and NSP [13-15], while other articles showed a negative association or no association [18, 19]. In recent years, the viewpoint has shifted towards NSP probably being more related to arm elevation in the upright body position, as elevated arms while in nonupright positions (e.g., sitting) are more likely to be supported, leading to the arm elevation not adding extra strain on the shoulder [20] and thus not increasing the risk of NSP [20, 21].

However, studies focusing on arm elevation in upright positions separately and NSP are still rare. A study by Gupta et al. [21] divided the workday into nonupright, upright with arm elevation over the threshold (30˚, 60˚, and 90˚), and upright with arm elevation below the threshold and found a positive dose-response association between the time spent with arm elevation over 30˚, 60˚ and 90˚ in upright positions and the risk of long-term sickness absence in health care workers. But it did not specifically explore the association between those postures and NSP. Meanwhile, a recent study on Norwegian home care workers [7] presented the time of exposure to arm elevation in upright positions at work and long-term NSP but did not analyze their association. To date, no studies explore the quantitative association between arm elevation in upright positions at work and NSP in home care workers.

Another prevalent awkward work posture related to LBP is trunk forward bending. Several studies reported that trunk forward bending at work was a risk factor for LBP of workers [22-24]. By contrast, some studies found no association [25, 26] or even a tendency towards negative association [27] between trunk forward bending and LBP in blue-collar workers. These studies giving conflicting results might also be related to different positions while bending the trunk. Recently, some studies have suggested that trunk forward bending in upright positions is a risk factor for LBP [7, 11, 28]. A study by Andersen et al. [11] using the questionnaires for work exposures reported that trunk forward bending while standing/walking will increase the risk of LBP in the general working population. But it is considered imprecise due to the subjectiveness and recall bias. A longitudinal study using objective accelerometers suggested that exposure to trunk forward bending ≥30° in upright positions was associated with an increase in LBP intensity in healthcare workers [16]. But it was mainly regarding healthcare distributors whose work exposures could be different from home care workers. A study by Tjøsvoll et al. [7] also using accelerometers presented the time spent with trunk forward bending in upright positions and long-term LBP in home care workers but did not explore their association in detail. Hence, to my knowledge, the relationship between trunk forward bending in upright positions at work and LBP in home care workers is still unclear.

Therefore, given the increasing number of the aged population, the health and workability of home care workers, and the high socioeconomic burden, it is of paramount importance to understand and promote suitable working conditions and reduce the occurrence and intensity of musculoskeletal pain in home care workers. This study aims to investigate if there is an association between awkward work postures and NSP and LBP in home care workers. The study seeks to test the following hypotheses: (i) there is a positive association between arm elevation in upright positions at work and NSP in home care workers, and (ii) there is a positive association between trunk forward bending in upright positions at work and LBP.

2 Methods

2.1 Study population

Home care workers were recruited from 11 of 13 home care service units in Trondheim, the third largest city in Norway. All participants had more than 50% employment. Exclusion criteria were physical disabilities not allowing normal activities, having a fever, being allergic to plastic tapes, or pregnancy.

All participants received written information about the research and provided informed written consent before the start of this study. Each participant was given a number as an identity to protect their private information. The study was approved by the Regional Committees for Medical Research Ethics—Central Norway (No. 315556) and conducted in line with the Helsinki Declaration.

2.2 Data collection

The data were collected by questionnaires, anthropometric measurements, and device measurements from August to November 2022. The data collection also served as the baseline data for a randomized controlled trial – aiming at improving workers' health by redesigning the work without compromising productivity [29].

2.2.1 Basic information and anthropometrics

Information regarding age, gender, occupation, and health status was collected by questionnaire. Participants' weight was measured by a digital body weight scale and height by a wall-mounted SECA 206 measuring tape. Body mass index (BMI) was calculated based on the formula [BMI = Weight/Height^2 (kg/m^2)].

2.2.2 Physical behaviors and exposures measurements

Three triaxial AX3 accelerometers (Axivity Ltd, Newcastle upon Tyne, UK) were used on each participant to monitor their physical behaviors and exposure to awkward postures during workdays. Home care workers wore the accelerometers with double-sided adhesive tape (3M; Witre, Halden, Norway) and waterproof medical tape (Opsite Flexifix; 5cm×10cm cut into 5cm×7cm，10cm×10cm cut into 10cm×8cm) for up to 7 consecutive days. The sampling frequency was 25 Hz with a range of ±8 g.

The accelerometers were mounted on the following locations [7, 29]:

(1) Thigh: approximately 10 cm above the upper edge of the patella. (2) Dominant upper arm: approximately below the insertion of the deltoid muscle. (3) Upper back: approximately 5 cm beside the spinous process at the T1-T2 level of thoracic vertebrae. These accelerometers can measure different physical behaviors with high sensitivity and specificity, including standing still, moving, walking, running or stairs-climbing, sitting, lying, cycling, or rowing, as well as different degrees of arm elevation and trunk forward bending [7, 21, 28, 30].

Additionally, participants were given a paper activity diary to fill in every day to register the time of getting up in the morning, arriving at work, finishing work, and going to sleep.

2.2.3 Pain assessment

Participants were also asked to assess the intensity of NSP and LBP after work through the activity diary, which participants answered when leaving work. The pain was evaluated by a Numeric Pain Rating Scale (NPRS) with 11 integers from 0 to 10 representing the pain intensity [31]. This study defined 0 as no pain and 10 as extreme pain. The NPRS has been shown to be validated and reliable [30] and is widely used for assessing musculoskeletal pain [10, 23, 31, 32].

2.3 Data processing

Data from the questionnaire were manually entered into an Excel sheet for further utilization. Configuration of AX3 accelerometers and downloading of completed measurements were conducted in the software OMGUI (version 1.0.0.43; Axivity Ltd, Newcastle upon Tyne, UK). The downloaded accelerometer data were then processed by MATLAB software (Acti4, the National Research Centre for the Working Environment, Copenhagen, Denmark; the Federal Institute for Occupational Safety and Health, Berlin, Germany) [7]. Besides, the software would classify non-wear time if the time without movement lasted more than 1.5 hours in non-sleep periods. The activity diaries were plotted into an Excel sheet which Acti4 used to separate activity into periods of work, leisure, and sleep. A batch analysis was performed, and all the data were exported to a CSV file [7], then converted into an Excel sheet.

Microsoft Office Excel was used to derive working hours from the dataset. Valid accelerometer data was set with ≥75% of working time on the workday to be included in further analysis.

This study focused on the exposures to arm elevation and trunk forward bending in upright positions. As 30°, 60°, and 90° are the most commonly used cut-off values in existing literature [7, 27], three compositions were created for arm and trunk exposures during working time accompanied by three partitions for each composition [21, 28]. Details are illustrated in Table 1.

Table 1. Compositions of arm and trunk physical postures in the study

Category	Composition	Partition
Arm	A	Arm elevation ≥30˚ in upright positions Arm elevation <30˚ in upright positions Nonupright positions
	B	Arm elevation ≥60˚ in upright positions Arm elevation <60˚ in upright positions Nonupright positions
	C	Arm elevation ≥90˚ in upright positions Arm elevation <90˚ in upright positions Nonupright positions
Trunk	A	Trunk forward bending ≥30˚ in upright positions Trunk forward bending <30˚ in upright positions Nonupright positions
	B	Trunk forward bending ≥60˚ in upright positions Trunk forward bending <60˚ in upright positions Nonupright positions
	C	Trunk forward bending ≥90˚ in upright positions Trunk forward bending <90˚ in upright positions Nonupright positions

2.4 Statistical analysis

2.4.1 Description of work exposures and musculoskeletal pain

The valid accelerometer data of each working day and corresponding pain scores were used for analysis. The compositional means and percentage of different exposures in the compositions and the means of NSP and LBP were calculated to get an overall view of the participants' work exposures and pain information. Besides, the pain information was summarized according to the pain grades, which were no pain (pain score 0), mild pain (1-3), moderate pain (4-6), and severe pain (7-10) [32].

2.4.2 Transforming work exposures into compositional data

The time spent on different postures was first transformed into compositional data since compositional data analysis (CoDA) was recommended and appropriate for time-based data regarding physical behaviors [33-35]. As the time spent in an activity changes, the time spent in one or more other activities will necessarily have to change as well. By only including one part of the composition in the analysis, one is liable to lose the importance of how all the parts of the composition interact [33]. The essence of the CoDA method is to express the time-based data in relative terms as a cluster of log ratios, which are the logs of ratios of time-based partitions [e.g., the log of the ratio of arm elevation ≥30° in upright positions to the remaining partitions of the composition (arm elevation <30°in upright positions and total nonupright time)] [34].

The most common transformation within physical behavior research is the isometric log ratio (*ilr*) transformation [33]. For example, regarding arm elevation 60°, three partitions in a composition of working time will result in two *ilrs*. *Ilr1* represents the log of the ratio of arm elevation ≥60° in upright positions to the geometric mean of arm elevation <60°in upright positions and total nonupright time, and *ilr2* represents the log of the ratio of arm elevation <60° in upright positions to total nonupright time. The subscript *i* represents one worker, and the exposure unit is irrelevant to calculating *ilrs* [21, 28]. The formulas are as below.

$$ilr1_i = \sqrt{\frac{2}{3}}\, ln\left(\frac{Arm\ elevation \geq 60°\ upright_i}{\sqrt[2]{Arm\ elevation < 60°\ upright_i \times Nonupright_i}}\right)$$

$$ilr2_i = \sqrt{\frac{1}{2}}\, ln\left(\frac{Arm\ elevation < 60°\ upright_i}{Nonupright_i}\right)$$

The transformation was done in CoDaPack, a software developed specifically to transform, explore and conduct analysis with compositional data [36]. Thereafter, the transformed data, the *ilrs*, could be analyzed using the standard statistical methods.

2.4.3 Standard statistical analysis

Since each participant in the study had several days of pain measurements and the data of NSP and LBP were not normally distributed but integers and non-negative, and were found to best approximately follow a Poisson distribution, I decided upon using a *generalized linear mixed model* with a Poisson distribution for analysis. However, the data were then found to be over-dispersed, therefore, the *negative binomial generalized linear mixed models* were used to analyze the relationship between work exposures and musculoskeletal pain, which was recommended by an article by Payne et al. [37].

The transformed *ilrs* and corresponding pain scores on each working day were included to explore the associations between arm elevation in upright positions and NSP, and between trunk forward bending in upright positions and LBP. Age, gender, and body mass index (BMI) were also included in the models as potential confounders [16, 21, 38]. Therefore, the final model was defined as NSP or LBP as the dependent variable, the *ilr1*, *ilr2*, age, gender, and BMI as independent variables, and the subject ID as the random effect to control the repeated pain measures within participants [16]. Besides, I also analyzed the associations using *ilr1* and *ilr2* as independent variables without confounders.

2.4.4 Sensitivity analysis

The adjusted models in the main analysis were found not perfectly fit the data. Therefore, to check if the results were similar when giving the outliers less weighing in the analysis, a generalized linear mixed model using robust estimation was conducted as a sensitivity analysis.

2.4.5 Interpretation method

As the coefficients were based on log-transformed data, the recommended "compositional iso-temporal substitution" method was used to visualize and interpret the results [21, 28, 33]. It includes two steps.

Step 1. **Build new theoretical compositions by reallocations based on "average composition".** The "average composition" was taken as a reference, which included the means of the time of different exposures, *ilrs,* and pain scores. New theoretical compositions were obtained by reallocating time from one exposure to another in upright positions while keeping the nonupright time and total time unchanged. For example, based on an "average composition" (7.3 mins arm elevation ≥60° and 196.8 mins <60° in upright positions and 254.2 mins nonupright positions), reallocating 2 mins to arm elevation ≥60° from <60° would lead to a new theoretical composition with 9.3 mins ≥60°, 194.8 mins <60˚ in upright positions and 254.2 mins nonupright time. The scope of the reallocations was supposed to be within the possible range of the measured exposures [28]. (Refer to Appendix A).

Step 2. **Transform into *ilrs* and do prediction.** The new theoretical compositions were also transformed into *ilrs* through CoDaPack. After that, the difference of each *ilr* of the new theoretical compositions from the average *ilr* in the "average composition" were calculated. Then, the difference from the average composition was multiplied by the coefficients from statistical models. The resulting coefficient was then exponentiated to have an interpretable hazard ratio (HR) [21, 28], expressed in HR for each increase/decrease in minutes of exposure. HR represents the ratio of the intensity of NSP or LBP in a new composition divided by the average pain in the "average composition". (Refer to Appendices A and B).

The statistical analysis was conducted in Microsoft Excel (Microsoft Office Home and Student, 2019) and SPSS (IBM SPSS Statistics, version 28.0.1.0), and CoDaPack Software (version 2.03.01). The significance level was set at 0.05.

3 Results

3.1 Flow chart and characteristics of participants

A total of 132 participants from 11 home care units in Trondheim, Norway, participated in the study. Eventually, 105 participants with complete data were included for analysis. The flow chart of participants is shown in Figure 1. Descriptive information, including demographics, health, and work status of included participants, is displayed in Table 2. The average age of participants was 32.5 years old, with 77.1% female and 22.9% male and an average BMI of 26.9.

3.2 Work exposures and musculoskeletal pain

A total of 419 working days of valid arm accelerometer data with NSP and 416 valid trunk accelerometer data with LBP were analyzed. The average working time is 458 mins (7.6 hs) per day for 4.0 working days with valid data. Compositional means and percentage of different exposures at work are presented in Table 3. Additionally, the mean of NSP was 1.7 (SD 2.2), and 55% of the working days reported NSP with 38% mild pain, 12% moderate pain, and 5% severe pain. The mean of LBP was 1.4 (SD 1.9), and 53% of the working days reported LBP with 39% mild pain, 12% moderate pain, and 2% severe pain.

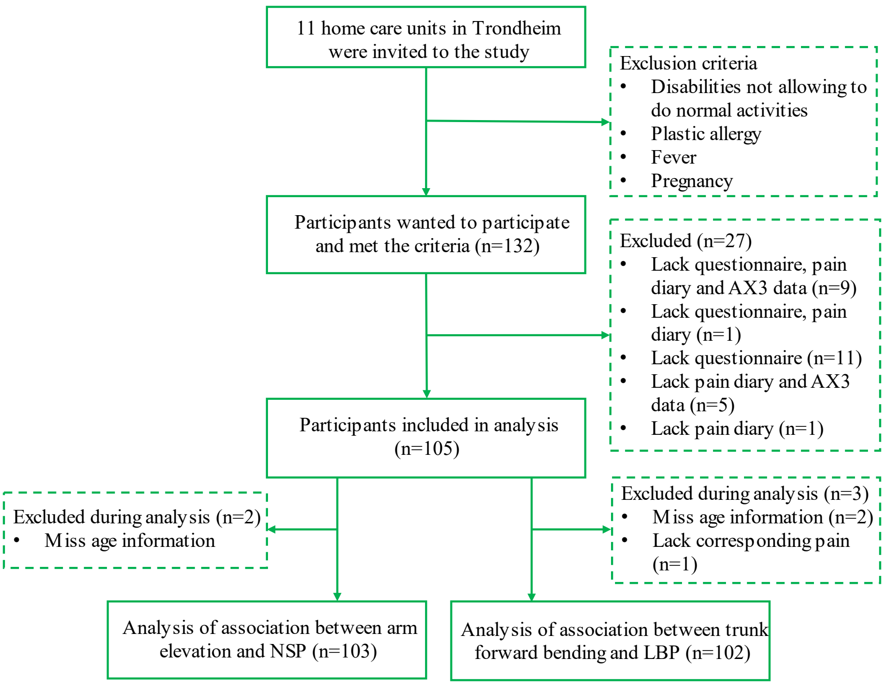

Figure 1. Flow chart of participants

Table 2. Descriptive information of the participants included in the analysis (N = 105)

Demographic characteristics	%	Mean (SD)	*N*
Age(years)		32.5 (10.6)	103
Gender			105
Female	77.1		81
Male	22.9		24
Body mass index (BMI)		26.9 (5.1)	105
Marital status			102
Not married/living alone	67.6		69
Married/partner	32.4		33
Origin			104
Scandinavian countries	92.3		96
Non- Scandinavian countries	7.7		8
Job title			105
Nurse	34.3		36
Occupational therapist	10.5		11
Social worker	9.5		10
Health assistant	35.2		37
Other	10.5		11
Sick leave in the last 12 months	80.0		84
<2 weeks	44.8		47
>2 weeks	35.2		37

Table 3. Compositional mean and percentage of work exposures of the participants (N = 105)

Composition	Category	%	Mean (min)	SD (min)
	Total time	100	458.2	48.5
A	Arm elevation ≥30° in upright positions	11.0	50.5	20.1
	Arm elevation <30° in upright positions	33.5	153.5	48.3
	Nonupright	55.5	254.2	65.8
B	Arm elevation ≥60° in upright positions	1.6	7.3	4.5
	Arm elevation <60° in upright positions	42.9	196.8	59.8
	Nonupright	55.5	254.2	65.8
C	Arm elevation ≥90° in upright positions	0.3	1.5	2.0
	Arm elevation <90° in upright positions	44.2	202.5	61.6
	Nonupright	55.5	254.2	65.8
	Total time	100	458.2	48.7
A	Trunk forward bending ≥30° in upright positions	7.8	36.0	19.6
	Trunk forward bending <30° in upright positions	36.7	167.8	53.3
	Nonupright	55.5	254.4	65.9
B	Trunk forward bending ≥60° in upright positions	3.5	16.1	10.3
	Trunk forward bending <60° in upright positions	41.0	187.7	58.4
	Nonupright	55.5	254.4	65.9
C	Trunk forward bending ≥90° in upright positions	0.9	4.1	4.0
	Trunk forward bending <90° in upright positions	43.6	199.7	61.1
	Nonupright	55.5	254.4	65.9

Mean: the mean value of exposure to different postures on 419 working days from the arm accelerometer and 416 from the trunk accelerometer. SD: standard deviation. Upright positions: include the postures of standing still, moving, walking, running, or stair-climbing.

3.3 Association between awkward postures and musculoskeletal pain

For a better understanding of the results, regarding the composition of arm elevation 30° in upright positions, *ilr1* and *ilr2* are expressed as *"ilr arm ≥30°"* and *"ilr arm <30°"* respectively; and the same goes for the rest compositions (see Table 4). Regarding the association between arm elevation in upright positions and NSP, models not controlling for confounders showed *ilr arm ≥60°* and *ilr arm ≥90°* in the compositions were statistically significant (P=0.027, B=0.547; P=0.032, B=0.331, respectively; B represents coefficient). Analyzing the adjusted model, controlling for age, gender, and BMI, only the *ilr arm ≥60°* showed statistical significance (P=0.045, B=0.504), while the *ilr arm ≥90°* indicated a tendency of significance (P=0.064, B=0.297). Meanwhile, none of the confounders, age, gender, and BMI, showed statistical significance. Regarding the association between trunk forward bending in upright positions and LBP, none of the *ilrs* or confounders in all the statistical models displayed statistical significance regardless of unadjusted or adjusted models. The coefficients of *ilrs* and P-value from the adjusted statistical models are presented in Table 4.

Table 4. Coefficients and P-value of ilrs adjusted with confounders in statistical analysis

Composition	ilr	Coefficient	Exp (Coefficient)	P value
A	*ilr arm ≥30°*	0.411	1.509	0.253
	ilr arm <30°	0.183	1.201	0.523
B	*ilr arm ≥60°*	**0.504**	1.656	**0.045**
	ilr arm <60°	0.104	1.110	0.706
C	*ilr arm ≥90°*	**0.297**	1.345	**0.064***
	ilr arm <90°	0.276	1.318	0.256
A	*ilr trunk ≥30°*	0.107	1.113	0.680
	ilr trunk <30°	0.344	1.410	0.269
B	*ilr trunk ≥60°*	0.147	1.158	0.430
	ilr trunk <60°	0.284	1.328	0.342
C	*ilr trunk ≥90°*	0.121	1.128	0.384
	ilr trunk <90°	0.313	1.368	0.308

***:** Close to the significance level (0.05), it did show significance with the same coefficient in the robust statistical model where the data fit better (P=0.014).

Ilr arm ≥30° (ilr trunk ≥30°): refers to *ilr1* in the formula, which is the log of the ratio of arm elevation (trunk forward bending) ≥30° in upright positions to the geometric mean of arm elevation (trunk forward bending) <30°in upright positions and total nonupright time; *ilr arm <30° (ilr trunk <30°):* refers to *ilr2* in the formula, which is the log of the ratio of arm elevation (trunk forward bending) <30° in upright positions to total nonupright time; the rest *ilrs* can be explained similarly.

3.4 Sensitivity analysis

When using the robust estimation to test the results of the adjusted models, not only the *ilr arm ≥60°* but also the *ilr arm ≥90°* showed statistical significance (P=0.015, P=0.014, respectively) and all the coefficients were the same, which confirmed the significance of results from the adjusted statistical models.

3.5 Results of compositional iso-temporal substitution

Since the *ilr arm ≥60°* showed statistical significance and the *ilr arm ≥90°* a tendency of significance, I conducted a compositional iso-temporal substitution for these results. Figure 2 A and B show how HR of having neck/shoulder pain changes when reallocating time from arm elevation <60° to ≥60° and from arm elevation <90° to ≥90° in upright positions, respectively; and vice versa. (Also refer to Appendices A and B). The results show that reallocating 3 mins *(approximately 1 SD)* to arm elevation ≥60° in upright positions from <60° will increase the NSP intensity by 16% compared to the average pain in "average composition", while reallocations of 6 mins *(approximately 2 SD)* in the same direction will increase HR by 29% (Figure 2-A). Similarly, reallocating 1.5 mins *(approximately 1 SD)* to arm elevation ≥ 90° from <90° in upright positions will increase the NSP intensity by 18% compared to the average pain while reallocating 3 mins *(approximately 2 SD)* in the same direction will increase the HR by 31% (Figure 2-B).

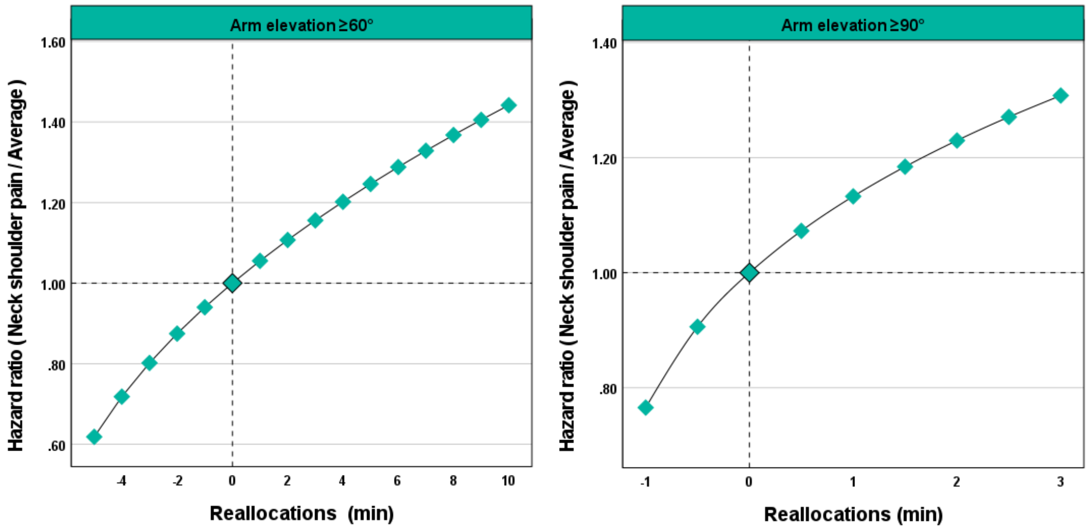

Figure 2. Hazard ratio and reallocations between different arm elevation exposures in upright positions (left: A; right: B)

Zero on the X axis represents the average time of exposures shown in "average composition". Positive numbers on the X axis represent minutes reallocated to arm elevation ≥60° (≥90°) from arm elevation <60° (<90°) in upright positions, and negative numbers vice versa. Y axis indicates the relative hazard ratio, the ratio of the neck/shoulder pain in new theoretical compositions divided by the average pain. For example, 2 mins reallocations to arm elevation ≥60° from arm elevation <60° in upright positions will increase the NSP intensity by 11%, while 2 mins reallocations to arm elevation ≥90° from arm elevation <90° in upright positions will increase by 23%. (Refer to Appendices A and B).

4 Discussion

To the best of my knowledge, this study is the first to investigate the dose-response relationship between device-measured arm elevation in upright positions and NSP, as well as between trunk forward bending in upright positions and LBP in home care workers. I found a positive dose–response association of NSP with arm elevation ≥60° in upright positions and a tendency of positive association with arm elevation ≥90° in upright positions. Further, the NSP intensity increases more with higher degrees of arm elevation. However, I found no significant association between trunk forward bending in upright positions and LBP. These results confirmed the hypothesis regarding the relationship between arm elevation and NSP but did not support the hypothesis regarding the association between trunk forwarding bending and LBP.

4.1 Arm elevation in upright positions and NSP

The result of the positive association between arm elevation and NSP is consistent with some previous studies. Most high-quality studies using self-reported exposure assessment, expert ratings, and video recordings showed a significantly positive association between arm elevation and NSP [13]. However, these studies are considered imprecise due to subjectivity and recall bias [17, 19, 39]. Studies are more valid when the physical behaviors are measured by the accelerometers/inclinometers because of their objectiveness and accuracy [7, 21, 28, 30]. However, very few studies using objective measurements focus on arm elevation in upright positions separately to explore their relationship with NSP. Compared to the studies regarding arm elevation in all positions, a study by Hanvold et al. [40] reported a positive association between arm elevation and NSP for women but did not find any association for men. By contrast, a study by Svendsen et al. [14] found a positive association in male participants. The results in my study are in line with the positive association but did not indicate significant gender differences. However, a study by Koch et al. [18] suggested a trend of negative association, which is not in line with the results of my study. But the author argued that it might be caused by the pain-avoidance behavior making the workers avoid performing higher degrees of arm elevation due to fear of pain. Nonetheless, the mixed results may be partly because they did not focus on the arm elevation in upright positions separately, as elevated arms while sitting are more likely supported (e.g., driving); they should place a limited load on the neck/shoulder area.

A few studies mainly investigated arm elevation in upright positions but did not focus on the association with NSP. Gupta et al. [21] found that reallocating two more minutes to arm elevation ≥60° (≥ 90°) in upright positions from <60° (< 90°) will increase the risk of long-term sickness absence by 3% (14%) and the risk increases more with higher degrees of arm elevation. Since NSP is one of the leading causes of sick leave [10], the results are partly consistent with my study – the positive association of arm elevation ≥60° (≥ 90°) in upright positions and NSP, and NSP intensity increases with higher degrees of arm elevation when reallocating the same minutes to them.

There are many possible mechanisms to explain the association, such as reduced microcirculation, muscular fatigue, prolonged muscle activation, and inflammatory process [13]. One possible explanation could be that the intramuscular pressure on the neck and shoulder muscles increases as the arm elevation degree increases. This can reduce or even block blood flow and tissue oxygenation, which may lead to muscle fiber damage [41]. Another possible explanation may be that sustained motor unit activity due to prolonged arm elevation leads to an accumulation of Ca^{2+} and degradation of membrane proteins for the muscle and thereby the pain sensations in the damaged muscle [41]. However, none of the hypotheses can fully explain the mechanisms regarding the association yet.

4.2 Trunk forward bending in upright positions and LBP

A prospective study of Lagersted-Olsen et al. [25] using accelerometers did not find any significant association either; my study is consistent with this but against the general assumption that trunk forward bending is a risk factor for low back pain [22]. Besides, trunk forward bending in upright positions in that study did not include the time spent with trunk forward bending during walking, which may have underestimated the time spent in this position and thus limited the ability to detect a significant association. However, a study by Andersen et al. [11] using questionnaires for work exposures reported a positive association between trunk forward bending in upright positions and LBP in the general working population, and a study by Lunde et al. [16] using objective accelerometers also confirmed a positive association between trunk forward bending ≥30° in upright positions and change of LBP intensity in healthcare distributors. By contrast, one study by Villumsen et al. [27] using objective accelerometers indicated a tendency of negative association among blue-collar workers. But the author argued that it might be due to pain-avoidance behaviors, assigning less strenuous tasks to workers with LBP by employers, or healthy worker effects- workers with LBP might have dropped out from work with a long duration of forwarding bending [27]. The results in my study are different from these studies, probably in part because of the difference in occupations and work conditions. On the other hand, there may be several explanations for the results from my study failing to show a positive association between trunk forward bending in upright positions and LBP.

It could be that a positive association exists but is reduced by other factors. One reason may be because of pain-avoidance behaviors [42]. People with existing pain might avoid painful/awkward postures like trunk forward bending (when that is possible), which could reduce the association between exposure and pain. Another reason might be selection bias. Workers with severe LBP were likely on sick leave and not recruited in the study because of being unable to move freely or handle work tasks. In my study, 35.2% of the participants reported sick leave for more than 2 weeks in the last 12 months, probably partly due to the LBP, one of the leading causes of sick leave [24]. This will reduce the true association between trunk forward bending and LBP as well. Additionally, the study population is younger than the average of the Norwegian home care workers in another study (an average of 36.7 years old) [7]. At the same time, the prevalence of LBP increases with age [43]. It is plausible that when the participants have lower levels of LBP, it would be difficult to show a significant association.

Another possible explanation is that the LBP is associated with other time patterns of exposures rather than the accumulated time of trunk forwarding bending. It may be more related to long continuous duration or frequent repetitive short durations of trunk forward bending [25]. My study analyzed the association using the accumulative time of trunk forward bending in upright positions without considering the time pattern. Besides, another possible explanation might be that trunk forward bending is a risk factor of LBP when accompanied by other factors such as trunk rotation or load in hand that could add extra strain to the back [25, 44]. Future studies can take these factors into consideration.

4.3 Awkward postures at work

In upright positions, arm elevation ≥30°, ≥60° and ≥90° during working time occurred 50.5 mins, 7.3 mins, and 1.5 mins, while the time of trunk forward bending with these degrees was 36.0 mins, 16.1 mins, and 4.1 mins, respectively. Compared with a recent study using a similar objective method in Norwegian home care workers [7], the participants spent much less time with arm elevation ≥30° and ≥60° in upright positions in my study than in that study (143.7 mins and 18.8 mins, respectively) while the time regarding arm elevation ≥90° and trunk forward bending with different degrees in upright positions is quite similar.

This is interesting because both studies used similar methods, and the participants were from the same population except for the difference of from 6 home care units in Trondheim in the previous study or from 11 in my study. But that might not be the main reason for the difference regarding arm elevation ≥30° and ≥60° in upright positions since the operation mode of Norwegian home care units are pretty homogeneous and the time of other exposures is similar. A possible reason for the difference is that the work tasks performed by the home care workers could be changed since the previous study was conducted during the COVID-19 pandemic when many people were likely infected with the disease. Several aged people might be very sick due to the pandemic and need more help from the home care workers using hands and arms, for example, to pull or lift them to turn over or sit up. Besides, as high as 80% of the home care workers reported sick leave in the last 12 months, and 44.8% had sick leave less than 2 weeks, most probably due to the pandemic (see Table 2). The higher sick leave rates among home care workers during the pandemic might also have increased the work burden of the available workers in the previous study. Another possible reason might be because of the occupational selection bias that many nurses and occupational therapists (44.8% in total) were included in my research who did not handle patients as often as other home care workers such as health assistants.

4.4 Musculoskeletal pain in home care workers

The incidence rates of NSP and LBP in home care workers (55% and 53%) are much higher than a recent study on the same population by Tjøsvoll et al. (36% and 34%, respectively) [7]. One possible reason is the difference in the methods and the pain type. The participants in my study assessed their current pain according to NRPS, while the pain assessment from that study used a questionnaire to look at experiencing continuous pain for at least three months in the past year. It is reasonable that the pain of certain individuals did not last such a long time. It also might be due to the recall bias in the previous study that people did not remember their experiences accurately or omitted details after a while. Another possible reason may be because of the low cut-off point. My study classified the pain group with scores ≥1 [25], while there was a study ranking the pain group with scores above 4 [8]. Using this cut-off point, the incidence rates of NSP and LBP will be 17% and 14%, which are lower than the reported rate in Tjøsvoll's study.

The average values of NSP and LBP of the participants (1.7 and 1.4, respectively) in my study belong to mild pain [32] and are lower than those in the general working population (2.7 and 2.4, respectively) [11]. One reason might be that the participants in my study are younger (average of 32.5 years versus 46.7 years) and thereby healthier with less musculoskeletal pain since age is a risk factor for NSP [38] and LBP [43]. Besides, it may also be associated with the healthy worker effect - people who were experiencing too much pain while working quit or were on sick leave, and the healthy ones stayed, which could be another selection bias.

When it comes to age, however, this study failed to show a significant association of NSP or LBP with age, probably also related to the selection bias due to the relatively young population with low pain levels or the healthy worker effect. Moreover, this study showing no associations of NSP or LBP with gender and BMI might be because of the same reasons as well.

4.5 Implications

This study provided accurate physical work exposure information, including arm elevation and trunk forward bending during work and the associations with NSP and LBP in home care workers. The findings indicated that more time spent with elevated arms in upright positions increased the risk of experiencing NSP at the end of the workday. They also suggested that higher arm elevation increases risks more than lower levels of arm elevation. Combined with the study from Tjøsvoll et al. [7] showing a larger variation in some awkward exposures among workers, it indicated some workers were exposed to more of these awkward postures; therefore, an intervention evening out the exposure could help. Besides, for home care workers, taking care of patients is likely a major exposure to arm elevation and trunk forward inclination, which is related to musculoskeletal pain. A certain amount of arm elevation is inherent during home care work and impossible to avoid because several patients need others to help them to sit up, stand or move. Also, home care workers work in other people's homes, which may not be suited for this kind of work, making awkward postures more common for workers. However, this study suggested that the time spent with arm elevation above 60° and 90° should be limited to a low level during working time.

According to the "Goldilocks Principle" [45], preventive measures can be taken to promote the workers' health while keeping the work quality and productivity. Besides, the work demands of home care workers could be approximately evaluated by certain rating scales, such as the activities of daily living score of the patients [29]. By combining the relevant information, the managers, researchers, and stakeholders related to home care services can design the work pattern and arrange the tasks for home care workers to improve their health without reducing productivity. If it works, this may be generalized to other parts of Norway due to the similarity of the organization of Norwegian home care units. In that case, it can not only bring benefits to the home care workers' health and the patient's care but also to the alleviation of the public health burden.

4.6 Methodological considerations

Many previous methods of assessing physical behaviors through observations or questionnaires are considered imprecise due to subjectivity and recall bias [17, 19, 39]. Device-based measurements (e.g., accelerometer) have been more extensively used to assess physical behaviors due to their objectiveness and accuracy in recent years. Nonetheless, even the objective measurements also give mixed results regarding the association between awkward postures at work and musculoskeletal pain [14, 16, 18, 27]. This might partly be because most studies take time spent on one posture as a single risk factor to analyze their association with health outcomes ignoring that the time of different behaviors is interrelated and codependent [33]. We should consider the whole and how the parts of the whole lead to health outcomes rather than just thinking of one single part [33, 34]. Given this, CoDA is recommended as an appropriate method for dealing with the time-use data [33, 34]. Studies have suggested that the results using CoDA are more correct than those without [46, 47]. Therefore, this study utilized an objective measurement for work exposures and a CoDA method to explore the association between awkward work postures and musculoskeletal pain in home care workers.

On the other hand, muscle torque while rotating the arm or trunk could also be related to musculoskeletal pain [44]. Assessing muscle torque would help reveal the association between exposure and musculoskeletal pain. But currently, there are no good ways of doing it, so this study does not measure it.

4.7 Strengths and limitations

There are several strengths in this study. First, one strength is using the objectively device-based measurement to record the arm elevation and trunk forward bending for several consecutive days, which provided accurate information on work exposures and excluded subjective biases while using a self-reported method. Second, another strength is using the CoDA method to explore the relationship between awkward postures at work and musculoskeletal pain by considering the time-use data as forming parts of the whole, which is reported as more correct and reliable than the traditional method [46, 47]. Third, using NRPS is considered another strength since it is reported to be more accurate than other methods when assessing pain intensity [48]. Meanwhile, doing the assessment immediately after finishing work can make it a good representative of the pain status related to work while reducing the recall bias to the largest extent. Lastly, using a generalized linear mixed model for analysis allows us to utilize the entire data instead of means of exposure and pain to explore their associations and thus gives a more accurate reflection of the actual relationship.

Admittedly, this study also has limitations. First, this study can tell if awkward work postures and musculoskeletal pain have an association and the dose-response relationship but cannot differentiate the direction of cause and effect since it is a cross-sectional study. However, it is reasonable that awkward work postures could lead to musculoskeletal pain, as several prospective studies have supported this [16, 40]. By contrast, the reverse causation that musculoskeletal pain leads to awkward postures is quite unlikely since people suffering from musculoskeletal pain tend to perform behaviors to avoid awkward postures [18, 42]. Second, only 24% of home care workers in Trondheim participated in the study; there might be selection bias due to the young participants with low pain intensity or healthy worker effect. Increasing the sample size in future studies would help address this. Third, this study only focused on the awkward postures in working time while sleep, leisure time, and time on non-work days could also affect health outcomes. Therefore, future studies including these domains for consecutive 7 days would be helpful to get a complete picture of the relationship between risk factors and musculoskeletal pain. Fourth, this study only collected the data in one week, but the exposures might change in different weeks, months, seasons, years, or during holidays. However, the time of most of the exposures is quite similar to the previous study of Tjøsvoll et al. [7] partly reducing this limitation. Fifth, the participants were only recruited in Trondheim municipality, so it should be cautious when generalizing the results to other places in Norway. Nonetheless, the operation mode of Norwegian home care services is quite similar, which is in favor of the generalizability to Norway. Sixth, the information on trunk rotation or load in hand during different exposures is lacking in this study, which could also be risk factors for musculoskeletal pain [44, 49]. Future studies could take this into consideration.

5 Conclusions

This study provided accurate work exposures and their associations with NSP and LBP among home care workers. There was a positive association between the exposure to arm elevation ≥60° in upright positions at work and NSP and a tendency of a positive association between arm elevation ≥90° in upright positions and NSP in home care workers, and the NSP intensity increases more with higher degrees of arm elevation. However, no significant association was found between trunk forward bending in upright positions and LBP. Related managers, researchers, and stakeholders can redesign the work pattern or give other interventions to balance the exposures to arm elevation in upright positions and reduce the incidence and intensity of NSP for home care workers.

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Appendices

Appendix A. Results after reallocations between arm elevation postures in upright positions

Number of compositions	Reallocation (min)	Arm elevation ≥60° (min)	Arm elevation <60°(min)	Nonupright (min)	ilr.1	ilr.2	Difference (ilr.1)	Times by coefficient	HR (exp)	NSP
1	-5	2.3	201.8	254.2	-3.748	-0.163	-0.953	-0.480	0.62	1.03
2	-4	3.3	200.8	254.2	-3.451	-0.167	-0.656	-0.331	0.72	1.19
3	-3	4.3	199.8	254.2	-3.233	-0.170	-0.438	-0.221	0.80	1.33
4	-2	5.3	198.8	254.2	-3.060	-0.174	-0.266	-0.134	0.87	1.45
5	-1	6.3	197.8	254.2	-2.917	-0.177	-0.122	-0.062	0.94	1.56
Average composition	**0**	**7.3**	**196.8**	**254.2**	**-2.794**	**-0.181**	**0.000**	**0.000**	**1.00**	**1.66**
7	1	8.3	195.8	254.2	-2.687	-0.185	0.107	0.054	1.06	1.75
8	2	9.3	194.8	254.2	-2.592	-0.188	0.202	0.102	1.11	1.84
9	3	10.3	193.8	254.2	-2.507	-0.192	0.287	0.145	1.16	1.92
10	4	11.3	192.8	254.2	-2.429	-0.195	0.365	0.184	1.20	2.00
11	5	12.3	191.8	254.2	-2.358	-0.199	0.436	0.220	1.25	2.07
12	6	13.3	190.8	254.2	-2.292	-0.203	0.502	0.253	1.29	2.14
13	7	14.3	189.8	254.2	-2.230	-0.207	0.564	0.284	1.33	2.21
14	8	15.3	188.8	254.2	-2.173	-0.210	0.621	0.313	1.37	2.27
15	9	16.3	187.8	254.2	-2.119	-0.214	0.675	0.340	1.41	2.33
16	10	17.3	186.8	254.2	-2.068	-0.218	0.726	0.366	1.44	2.39

Appendix B. Results after reallocations between arm elevation postures in upright positions

Number of compositions	Reallocation (min)	Arm elevation ≥90°(min)	Arm elevation <90°(min)	Non-upright (min)	ilr.1	ilr.2	Difference (ilr.1)	Times by coefficient	HR (exp)	NSP
1	-1.0	0.5	203.5	254.2	-4.997	-0.157	-0.899	-0.267	0.77	1.27
2	-0.5	1.0	203.0	254.2	-4.430	-0.159	-0.332	-0.099	0.91	1.50
Average composition	**0.0**	**1.5**	**202.5**	**254.2**	**-4.098**	**-0.161**	**0.000**	**0.000**	**1.00**	**1.66**
4	0.5	2.0	202.0	254.2	-3.862	-0.163	0.236	0.070	1.07	1.78
5	1.0	2.5	201.5	254.2	-3.679	-0.164	0.419	0.124	1.13	1.88
6	1.5	3.0	201.0	254.2	-3.529	-0.166	0.569	0.169	1.18	1.97
7	2.0	3.5	200.5	254.2	-3.402	-0.168	0.696	0.207	1.23	2.04
8	2.5	4.0	200.0	254.2	-3.292	-0.170	0.806	0.239	1.27	2.11
9	3.0	4.5	199.5	254.2	-3.195	-0.171	0.903	0.268	1.31	2.17

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