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ORIGINAL ARTICLE

Intensity of occupational physical activity in blue-collar workers: do self-reported rating and device-worn measurements agree?

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Abstract

Purpose High intensity occupational physical activity (OPA) seem to aggravate health and increase risk of sick leave and early retirement. Most intensity of OPA monitoring has been self-reported, e.g. by rating of perceived exertion (RPE). However, no studies have investigated the precision and risk of bias in RPE reporting during free-living OPA. This study investigated the agreement between OPA intensity in percentage of the heart rate reserve (%HRR) estimated from RPE and device-measured heart rate (HR), and potential bias factors on this agreement.

Methods The CR10 scale measured RPE at work. The Actiheart monitor measured HR during 24-h a day for 2–4 days. Both RPE and device-worn HR were converted to %HRR. The difference between both %HRR and their limits of agreement was determined in a Bland Altman plot. To detect bias factors, the difference between both %HRR was regressed on age, sex, cardiorespiratory fitness, occupational lifting, medication, consequences of musculoskeletal disorders and the interactions between these factors with device-work %HRR.

Results Six hundred and twenty-three participants were included in the analysis. Mean difference between RPE-based and device-worn %HRR was 54.6% (SD 19.5). The limits of agreement were wide (11.6–90.1%HRR). Age (0.48%HRR, 95% CI 0.18–0.79) occupational lifting (9.84%HRR, 95% CI 3.85–15.83) and cardiorespiratory fitness (0.41%HRR, 95% CI 0.03–0.79) significantly biased the agreement between the estimations of OPA intensity.

Conclusion RPE overestimated OPA intensity, and was biased by several factors. Device-worn %HRR should be preferred when evaluating OPA intensity among workers with physically demanding jobs.

Keywords Physical activity at work · Occupational physical activity · Intensity · Heart rate · Rate of perceived exertion · Rating of physical work strain · Deterioration

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Abbreviations

BMI	Body mass index
bpm	Beats per minute
CI	Confidence interval
CRF	Cardiorespiratory fitness
DPhacto	Danish PHysical ACTivity cohort with Objective measurements
h	Hours
HR	Heart rate
HRR	Heart rate reserve
%HRR	Percentage of heart rate reserve
MSD	Musculoskeletal disorders
OPA	Occupational physical activity
RPE	Rate of perceived exertion
SD	Standard deviation
SHR	Sleeping heart rate

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Introduction

Intensity of occupational physical activity (OPA) varies across occupations. Differences in OPA intensity are based on the combinations of the physical activity needed to perform the work tasks, and cardiorespiratory fitness (CRF), age, sex and BMI of the workers (Louhevaara 1999). Effects on heart rate (HR) from performance of the same OPA will, therefore, vary individually according to the CRF level (Hull et al. 1984; Light et al. 1987). Thus, a worker with a high CRF will have a lower HR while performing the OPA than one with a low CRF. Therefore, evaluations of OPA intensity should account for the individual level of CRF (Armstrong 1996). A mean for estimating OPA intensity taking CRF into account is using percentage of heart rate reserve (%HRR) (Karvonen et al. 1957; Krause et al. 2009).

Among workers with a low CRF an imbalance between CRF and OPA might occur (Armstrong 1996; Louhevaara 1999), and this may lead to high aerobic workloads (Krause et al. 2009; Korshøj et al. 2013) excessively straining the cardiovascular (Sukhova et al. 1999) and musculoskeletal system. Some studies have shown detrimental cardiovascular effects from OPA intensities equal to 1/3 of maximal capacity (Krause et al. 2009; Korshøj et al. 2013)—also being the recommended threshold by the International Labor Organisation (ILO) (Bonjer 1971). High OPA intensities have also been shown to increase risk of all-cause and cardiovascular mortality (Holtermann et al. 2010, 2011; Clays et al. 2012; Krause et al. 2009), as well as development of musculoskeletal disorders (MSD) (Andersen et al. 2012a) and increase long-term sickness absence (Andersen et al. 2012b).

Most studies investigating relations between OPA intensity and health outcomes is based on self-reports (Holtermann et al. 2010, 2011; Clays et al. 2012; Krause et al. 2009), as the rating of perceived exertion scale (RPE) (Borg). In comparison to device-worn HR, may self-reported information be limited in accuracy, precision and level of detail by recall bias and social desirability (Sallis and Saelens 2000; Kwak et al. 2011). Other factors, such as MSD, age, sex, BMI and use of heart medications, have also shown effects on RPE (Groslambert and Mahon 2006), as well as associations between RPE and device-worn HR (Scherr et al. 2013).

Previous lab and field studies evaluating agreement of RPE and device-worn HR for estimation of leisure time activity intensity finds RPE to overestimate intensity (Foster et al. 2001). However, to the best of our knowledge, the agreement between RPE and device-worn HR has not been investigated during free-living OPA. Moreover, to be able to easily evaluate the OPA intensity, knowledge of the agreement between RPE and device-worn HR in a working population is essential.

Thus, the aim of this study was to investigate the agreement between OPA intensity in %HRR converted from RPE and device-worn HR during free-living work, and the effects from potential bias factors on this agreement.

Methods

Study design and population

Data from the Danish PHysical ACTivity cohort with Objective measurements (DPhacto) were used for these analyses, the overall aim for DPhacto was to investigate the association between objectively measured physical activities at work and frequent prospective measurements of MSD among blue-collar workers (Jørgensen et al. 2013). Between December 2011 and March 2013 the participants were recruited from 15 companies across cleaning, transport and manufacturing companies in collaboration with a large Danish labor union for low skilled workers (Jørgensen et al. 2013). Although the administrative staff at the included companies also took part in the data collection, they were due to shortage of monitors not all mounted with a heart rate monitor. DPhacto was conducted according to the Helsinki declaration and approved by the Danish data protection agency and local Ethics Committee (H-2-2012-011). The baseline measurements included questionnaires, objective measurements of anthropometrics and 24 h HR across 2–4 continuous days including work. More details are published in previous studies based on the DPhacto cohort.

Prior to participation, a written informed consent was provided by all workers. Participants having allergy to bandages or adhesives were excluded from the HR measures as adhesives attached the HR monitor; also being pregnant excluded from all participation in the DPhacto (Jørgensen et al. 2013). Inclusion criteria for this analysis were HR measurement for ≥ 4 h of work, beat error of the HR measures $< 50\%$ (Gupta et al. 2015; Skotte et al. 2014) and reporting of RPE.

Assessment of subjective exposure—rating of perceived exertion

The self-reported OPA intensity was measured by the RPE in the CR10 scale (Borg), assessed by the question: "*How physically demanding do you normally consider your present work?*" with a 10 point response scale from 1 ("*sedentary, not demanding*") to 10 ("*very demanding*") (Jørgensen et al. 2013). The CR10 scale was initially chosen to streamline the questionnaire, by making similar response scales. To estimate the HR from the RPE the CR10 scale was converted to the original 6–20 RPE scale (Borg). The original

RPE scale was then converted to beats/min (bpm) by the HR = 10 × RPE (Borg), and then converted to %HRR. The %HRR were defined as the difference between the estimated HR_{max} (Tanaka et al. 2001) and the sleeping HR (SHR), with SHR defined as the 10th lowest recorded HR value during 24 h (Brage et al. 2004) by the following equation $\%HRR = ((HR_{work} — SHR)/(HR_{max} — SHR)) \times 100\%$ (Karvonen et al. 1957).

Assessment of device-worn measured exposure—heart rate

The device-worn measured OPA intensity was conducted by diurnal measures of HR, by use of the Actiheart (www.camntech.com). Actiheart has shown to be valid for field measurements of HR (Barreira et al. 2009; Assah et al. 2011; Kristiansen et al. 2011). Actiheart measures the electrocardiographic raw signals with a sensitivity of 0.25 mV and the numbers of R peaks in the QRS complex per minute was used for calculating the HR. Before the measurement, Actiheart was initialized with the sex and age of the participants. The Actiheart monitor was mounted at one of the validated positions (Brage et al. 2005) with pre-gelled ag–ag electrodes (Ambu blue sensor VL-00-S/25). The protocol stated that the aim was to measure HR during 2–4 working days (Jørgensen et al. 2013). The participants were shown how to replace the electrodes and asked to fill in a log of working hours, sleeping and waking time and time periods spent without monitors. In addition, the participants were asked to live their normal every-day life.

When processing the data for analysis, only measurements of HR with beat error of ≤ 50% were included to meet the data quality criteria set by Skotte and colleagues (Skotte et al. 2014). To estimate OPA intensity the %HRR was calculated as previously stated by use of the device-worn HR.

Assessment of potential bias factors

Previously, a variety of factors has been suggested to affect OPA intensity (Groslambert and Mahon 2006), as well as the relation between RPE and device-worn HR (Scherr et al. 2013). Thus, some of these factors, that were available in the collected data, were taken into consideration as potential bias factors, when building the model for analysis. The included factors were: age; sex; smoking; BMI; level of occupational lifting; occupational group; number of work hours per week; CRF level, use of anti-hypertensive medication and consequences of MSD affecting strenuous OPA and daily work (Groslambert and Mahon 2006).

Age was based on the participants' date of birth. Sex was determined from the question: "*are you male or female?*". Smoking was assessed by the question *"Do you smoke?"* using a merged dichotomized version of the original four response categories: yes *("yes daily"*, *"yes sometimes"*) or no (*"used to smoke"*, *"I have never smoked"*). BMI (kg/m^2) was calculated by use of the objective measurements of body weight (in kg; Tanita BC418) and height (in m; Seca model 1231721009). A single item from the Danish Work Environment Cohort Survey was used to assess the level of occupational lifting and carrying: *"How much of your working time do you carry or lift?"* with a six-point response scale from 1 (*"almost all the time"*), 2 ("*Approximately ¾ of the working time*"), 3 ("*Approximately ½ of the working time"*), 4 ("*Approximately ¼ of the working time*"), 5 ("*Rarely/very little*") to 6 (*"never"*). Occupational group was determined by the workplace of the participant and whether the participant stated to be working in the administration (white-collar work) or in the production (blue-collar work). The following occupational groups were represented: cleaning, manufacturing, transportation and administration (irrespective of occupational group). Number of work hours per week was assessed by the question: "*How many hours per week do you work in your main occupation, incl. extra hours?"*. Level of CRF (mlO_2/min/kg) was estimated by the one point Aastrand bike ergometer test (Åstrand and Ryhming 1954). Use of anti-hypertensive medication were determined by the following question: *Do you use any prescription medication, and if yes due to which disease?* With response categories of various diseases including hypertension. Consequences of MSD pain were determined by use of the following questions: *"In the last 3 months, has pain in muscle og joints affected the performance of your most demanding physical work"* with a response scale from 0 (*"no impact"*) to 10 (*"completely prevented"*) and *"In the last three months, how much have pain in muscles or joints troubled your daily work?"* with a response scale from 1 (*"not at all"*) to 5 (*"really much"*).

Statistical analysis

Differences between %HRR from RPE and device-worn HR were estimated by measures of dis-agreement for each participant, and plotted against the golden standard estimation of the intensity of occupational physical activity, visualized in a Bland Altman plot (Bland and Altman 1986). To check for bias, the difference between %HRR converted from RPE and device-worn HR was linear least-square regressed on age, sex, CRF, occupational lifting, use of anti-hypertensive medication, consequences of MSD affecting strenuous OPA and daily work as well as the interactions between these factors and the %HRR converted from device-worn HR. Age and CRF were inserted in the model as continuous variables and the following as categorical, reference value in parenthesis; sex (male), occupational lifting (≤ 50% of work hours), use of anti-hypertensive medication (none), consequences of MSD affecting strenuous OPA (no impact) and daily work (not at all). The interactions were evaluated by their level of significance, where those with a p value ≥ 0.05 were excluded from the analyses of the main effect estimating impact by each possible bias factor. To check that the assumptions of the linear regression model were met, the multicollinearity between independent variables were checked by variance inflation estimates, as well as equality of variances and normality of standardized residuals also were assessed and checked. To visualize the impact from bias factors being statistically significant, Bland Altman plots stratified by dichotomized bias factors was planned. SPSS version 24 was used for all analyses.

Results

Flow of participants

Figure 1 shows the flow of the DPhacto participants included in this study. Of the 909 participants taking part in the device-worn HR measurements, 623 participants were included in the analysis, based on the quality criteria for device-worn HR data described above and answering the question on RPE.

Baseline characteristics of the included study population

The included population for this study consisted of 623 participants from DPhacto (Fig. 1), 269 females and 354 males (Table 1), aged between 18 and 68 years, and with a median seniority in their current job of 10 years (IQR 15 years) (Table 1).

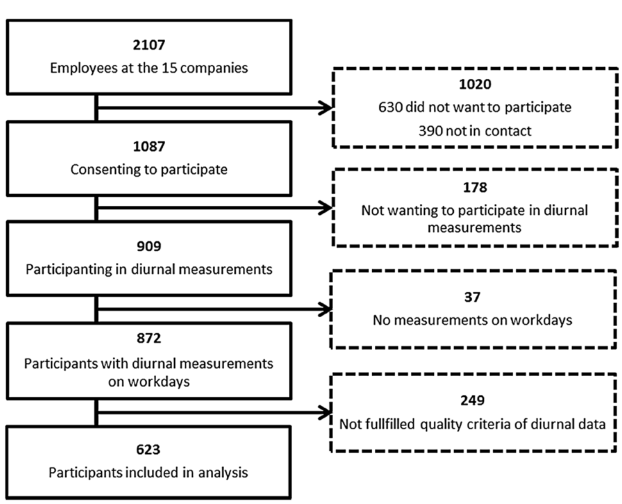

Fig. 1 Flow of participants

The median RPE was 6 (IQR 4) and the mean device-worn HR during working hours was 85.8 beats/min (SD 11.5) (Table 1). Device-worn HR data were measured across a median of 2 days in each participant (IQR 1), in total comprising a median of 17 h (ICR12 h) of valid recordings at work (Table 1). Overall, a total of 11,561 working hours with device-worn HR measurements was included in the analysis.

Building of statistical models

Variance inflation estimates did not indicate any critical multicollinearity among the potential bias factors. The models including interaction terms between exposure variables (difference in estimated %HRR by conversion of RPE and device-worn HR) and potential bias factors did not show any significant interactions. Thus, all potential bias factors were entered as main effect terms.

Agreement between estimations of intensity of occupational physical activity

The mean difference in HR between conversion of RPE and device-worn measures of HR during work was 70.8 bpm (SD 24.7 bpm). When estimated in %HRR, the mean difference between conversion of RPE and device-worn HR during work was 54.6%HRR (SD 19.5%HRR). The Bland–Altman plot (Fig. 2) showed that %HRR estimated from conversion of RPE overestimated %HRR by 51%, compared to device-worn HR converted to %HRR. The limits of agreement of the difference was 11.6–90.1%HRR, and 596 of the 623 (95.7%) measurements were within the limits of agreement (Fig. 2).

Potential bias factors

In the model not including interactions, age, self-reported exposure to occupational lifting ≥ 50% of working hours and CRF significantly biased the difference in %HRR estimated by conversion of RPE and device-worn HR during work (Table 2).

To visualize the magnitude of the effect from the bias factors, Bland Altman plots stratified by the dichotomized bias factors were generated. The significant bias factors were dichotomized into categories of high age (≥ 50 years old, $n = 230$) and low age (< 50 years old, $n = 393$); high exposure to occupational lifting (self-reported exposure to occupational lifting ≥ 50% of work hours, $n = 249$) and low lifting (self-reported exposure to occupational lifting < 50% of work hours, $n = 371$); high level of CRF (≥ 30 mLO_2/min/kg, $n = 251$) and low level of CRF (< 30 mLO_2/min/kg, $n = 225$). For the stratification by age 373 measurements were inside the limits of agreement among the low age group and 219

Table 1 Baseline characteristics of the study population ($N=623$)

	Median	IQR	Mean	SD	*n*	*n* (%)
Age (years)	46.0	12.0			623	
Sex (females)					269	43.2
Job seniority (years)	10.0	15.0			611*	
Current smoker					180	29.1
CRF (mlO_2/min/kg)	30.6	11.7			476*	
Body mass index (kg/m^2)	26.1	5.7			611*	
Body mass index ≥ 25 kg/m^2					401	64.4
Occupational lifting and carrying at work (scale 1–6)¤	4.0	2.0			620*	
Lifting and carrying ≥ 50% of working hours					249	40.2
Occupational group[b]						
Cleaning					104	16.7
Manufacturing					422	67.7
Transport					58	9.3
Administration					39	6.3
Rating of perceived exertion at work (scale 1 –10)[a]	6.0	4.0			623	
Mean heart rate during work, estimated from RPE (beat/min)	160.0	40.0			623	
Mean heart rate reserve during work, estimated from RPE (%HRR)	87.7	30.1			623	
Mean heart rate during work, device-worn measured (beat/min)			85.8	11.5	623	
Mean heart rate reserve during work, device-worn measured (%HRR)			30.1	7.2	623	
Work hours per week	37.0	2.0			615*	
Total duration of included measurements of working hours (h)	16.9	12.0			623	
Included working days	2.0	1.0			623	
Included measurements of working hours (h/day)	7.4	1.7			623	

*Due to technical errors not all participants had the opportunity to answer the questions regarding psychosocial work environment, also not all participants answered all questions nor participated in the CRF test

[a] 1 ("*sedentary, not demanding*") to 10 ("*very demanding"*)

[b] 1 (*"almost all the time"*), 2 ("*Approximately ¾ of the working time"*), 3 ("*Approximately ½ of the working time"*), 4 ("*Approximately ¼ of the working time*"), 5 ("*Rarely/very little*") to 6 (*"never"*)

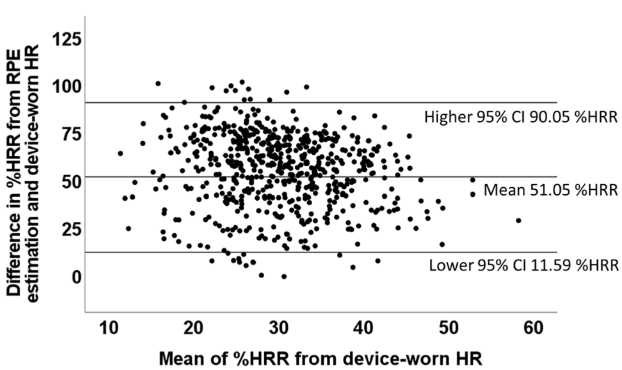

Fig. 2 Bland–Altman plot of the intensity of occupational physical activity, estimated by conversion of rate of perceived exertion and device-worn measures of heart rate to percentage of heart rate reserve (%HRR) during work, and plotted against mean level of %HRR from device-worn measures (golden standard for estimating the intensity of occupational physical activity), among 623 participants, whereof 596 were inside the limits of agreement

among the high age group. For the stratification by cardiorespiratory fitness, 214 measurements were inside the limits of agreement, among the low level of cardiorespiratory fitness group, and 238 measurements were inside the limits of agreement among the high level of cardiorespiratory fitness group. For the stratification by occupational lifting 352 measurements were inside the limits of agreement, among the group exposed to a low level of occupational lifting, and 237 measurements were inside the limits of agreement among the group exposed to a high level of occupational lifting (Fig. 3). These stratified Bland–Altman plots shows that the mean differences in %HRR estimated by conversion of RPE and device-worn HR during work vary in the dichotomized groups of the bias factors, indicating that among participants aged ≥ 50 years old the mean differences in %HRR estimated by RPE and device-worn HR were 9.18%HRR higher than among participants aged < 50 years old. Among participants having a CRF ≥ 30 mLO_2/min/kg the mean differences in %HRR estimated from RPE and device-worn HR were 2.44%HRR higher than among participants having

Table 2 Multiple regression analysis of bias in difference in percentage of heart rate reserve (%HRR) estimated by conversion of rate of perceived exertion (RPE) and device-worn measures of heart rate (HR) to percentage of heart rate reserve (%HRR) during work

Potential bias factors for RPE estimated %HRR	B	95 % CI
Model WITH interactions		
Age * %HRR	– 0.01	– 0.05 to 0.04
Sex * %HRR	0.89	– 0.08 to 1.87
Occupational lifting * %HRR	– 0.09	– 1.07 to 0.90
CRF * %HRR	0.01	– 0.04 to 0.06
MSD affecting your daily work * %HRR	– 0.72	– 1.92 to 0.48
Model WITHOUT interactions		
Intercept	21.55	– 7.84 to 50.94
Age	**0.48**	**0.18 to 0.79**
Sex	– 2.51	– 8.51 to 3.49
Occupational lifting	**9.84**	**3.85 to 15.83**
CRF	**0.41**	**0.03 to 0.79**
Heart rate based intensity estimate (%HRR)	– 0.07	– 0.54 to 0.41
MSD affecting your daily work	– 7.03	– 16.21 to 2.16

The evaluated potential bias factors were age, sex, occupational lifting and cardiorespiratory fitness (CRF) among the included participants. The 95% confidence intervals (CI) not including 0 are marked in bold

MSD musculoskeletal disorders

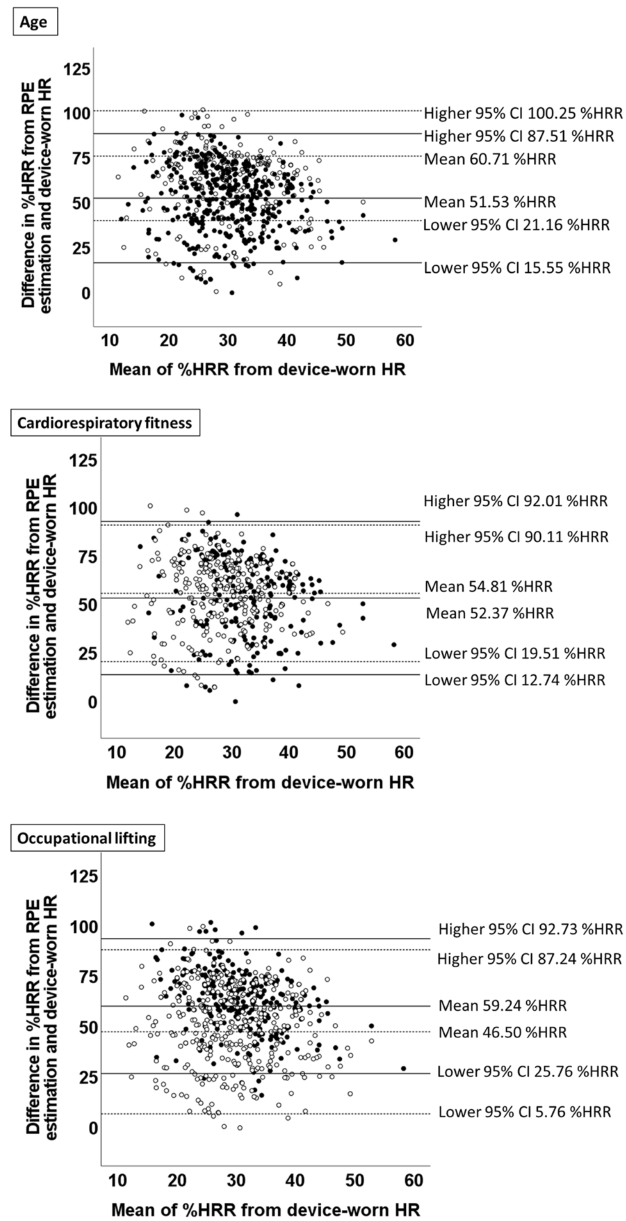

Fig. 3 Bland–Altman plot of the intensity of occupational physical activity, estimated by conversion of rate of perceived exertion and device-worn measures of heart rate to percentage of heart rate reserve (%HRR), and plotted against mean level of %HRR from device-worn measures. Stratified by the significant bias factors, where black dots and solid lines represents low age (< 50 years, $n = 393$); low exposure to occupational lifting (self-reported exposure to occupational lifting < 50% of work hours, $n = 371$); low level of cardiorespiratory fitness (< 30 mlO_2/min/kg, $n = 225$), and open dots and punctuated lines represents high age (≥ 50 years old, $n = 230$); high exposure to occupational lifting (self-reported exposure to occupational lifting ≥ 50% of work hours, $n = 249$); high level of cardiorespiratory fitness (≥ 30 mLO_2/min/kg, $n = 251$)

a CRF < 30 mLO_2/min/kg. Among participants exposed to occupational lifting ≥ 50% of work hours the mean differences in %HRR estimated by RPE and device-worn HR were 12.75%HRR lower than among participants being exposed to occupational lifting < 50% of work hours.

Discussion

This study aimed to investigate the agreement between OPA intensity estimated in %HRR by conversion of RPE and device-worn HR during free-living work, and potential bias factors on this agreement. The findings showed a low agreement between the estimations of OPA intensity by conversion of RPE and device-worn HR, as well as RPE tended to overestimate OPA intensity when compared to device-worn HR (Fig. 2). Additionally, the investigation of the potential bias factors showed that age, self-reported exposure to occupational lifting and CRF significantly biased the agreement between OPA intensity estimated in %HRR by conversion of RPE and device-worn HR (Fig. 3).

Previous lab and field studies overall corroborates the findings that RPE overestimates the intensity of physical activity, when compared to device-worn HR (Foster et al. 2001; Scherr et al. 2013). However, these studies evaluated agreement of RPE and device-worn HR during leisure time physical activity, thus our study contributes to the knowledge by evaluating the agreement of OPA intensity in %HRR estimated by conversion of RPE and device-worn HR and additionally include an investigation of potential bias factors contributing to the understanding of why RPE seems to overestimate intensity of physical activity.

The investigation of the potential bias factors showed age, CRF and exposure to occupational lifting to significantly bias the agreement between OPA intensity estimated in %HRR by conversion of RPE and device-worn HR.

The stratified analysis showed the mean differences in %HRR estimated from conversion of RPE and device-worn HR to be higher among participants aged ≥ 50 years old than those aged < 50 years old. Hence, age might influence the perception of the OPA intensity to a higher degree than HR are increased, giving rise to greater disagreement among participants aged ≥ 50 years old. This discrepancy may be explained by a variety of factors; one being that combinations of mental load and physical activity are shown to increase RPE (DiDomenico and Nussbaum 2011). Older participants are likely to be more experienced and might be appointed higher responsibilities, resulting in greater mental loads than younger participants. On the other hand this could also be explained by older participants being more experienced and thus having a lower mental load, but also lower CRF and thus may be reporting a RPE higher than appointed by device-worn HR.

The analysis stratified by CRF level showed high fit participants (CRF ≥ 30 mLO_2/min/kg) to have greater mean differences in %HRR estimated from conversion of RPE and device-worn HR during work than low-fit participants (CRF < 30 mLO_2/min/kg). Age will gradually decline CRF and thereby cause a higher OPA intensity among older than younger than workers (Karvonen et al. 1957). However, in the agreement between %HRR estimated by conversion of RPE and device-worn HR, this age decline of CRF will only give rise to bias if the reported RPE do not also increase with age, not seemingly being the case in the working age (Groslambert and Mahon 2006). These age declines in CRF may be more pronounced among groups not affected by the healthy worker selection bias. The healthy worker selection bias describes the migration of workers not having sufficient resources to fulfill the work task from occupational groups with high OPA into occupational groups with lower OPA levels (Li and Sung 1999).

Among participants reporting low exposure to occupational lifting (< 50% of working hours) the disagreement between %HRR estimated from conversion of RPE and device-worn HR were higher than among participants highly exposed to occupational lifting (≥ 50% of work hours). The bias from exposure to occupational lifting (static muscle activity) is in line with the previously reported lower correlations, between RPE and device-worn HR, during performance of partially dynamic and static exercises. In a practical perspective, this indicates that the presence of occupational lifting weakens the agreement between RPE and device-worn HR estimations of OPA intensity.

Thus, future studies, aiming to investigate intensity of OPA, should consider estimating OPA intensity by other methods than RPE, especially among occupational groups exposed to occupational lifting.

Strengths and limitations

The extraction of the working hours and the high quality of the device-worn HR measures (Skotte et al. 2014; Barreira et al. 2009) is a strength of the study. Due to the missing data on CRF on 147 participants a sensitivity analysis was performed among participants without any missing data in the included variables. This sensitivity analysis showed similar numerical results as well as statistically significant bias factors. However, the study also holds some limitations; first, to the best of the authors' knowledge is the RPE CR-10 scale not feasibility tested among blue-collar workers specifically or for OPA. The lack of feasibility testing may affect the reliability of the RPE-based estimations negatively and thus feed into the explanation of why RPE seems to overestimate the OPA intensity. Also, the estimation of the HR_{max} may affect the estimated OPA intensity in %HRR due to the intra-individual variability of HR_{max}. Additionally, the time duration for the estimation of OPA intensity different for the investigated methods. The device-worn HR were measured during working hours across 1–4 workdays and the RPE were not estimated across a specific time duration, but the participants were asked to estimate the strenuousness of their everyday work tasks. This variance in time duration for estimation of OPA intensity may affect the agreement as no information on whether or not the days including device-worn HR measurement were representative for the individuals OPA. Moreover, the generalizability of the findings is limited to the included occupational groups of blue-collar workers and might, therefore, not be applicable to e.g. white-collar workers.

Practical implications

Individuals working at high OPA intensities are at potentially increased risk of impaired health such as cardiovascular diseases and mortality (Holtermann et al.2011, 2010; Clays et al. 2012; Krause et al. 2009) as well as development of MSD (Andersen et al. 2012a) and long-term sickness absence (Andersen et al. 2012b). In the presence of increasing retirement age, lack of workforce, and aging society across countries, we should strive to create safe work ensuring longer healthy and safe working life (Rechel et al. 2013). Hence, to ensure long health and safe work, work needs to be designed ensuring a balance between the capacity of workers (e.g. CRF) and physical activity needed to perform the work tasks (Armstrong 1996; Louhevaara 1999). To design such work, we are in need of tools that can accurately assess OPA intensity during normal working conditions on many workers. For that reason, there is a need for a valid, feasible, easy-to-use and low-cost tool for assessing OPA intensity. Thus, future studies or practitioners using RPE-CR10 for estimation of OPA intensity should be aware of the potential bias factors and thus use it with care according to level of age, CRF and exposure to occupational lifting.

Conclusion

This study showed low agreement between OPA intensity estimated by conversion of RPE and device-worn HR, when analyzed as %HRR. The RPE tended to overestimate OPA intensity when compared to %HRR estimations from device-worn HR. Age, CRF, and self-reported occupational lifting were found to bias the agreement between RPE and device-worn HR measured intensity of OPA. Thus guidelines, legislation and advice that rely on self-reported measures of OPA intensity, ought to take these limitations of RPE as a measure of OPA intensity into account, and preferably in the future be based on device-worn measures of OPA intensity.

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Author contributions MK: conceived the idea, analyzed the data and drafted the manuscript. MK and NG: designed the protocol for analysis and MK, NG, AH and OM: discussed the interpretation of the results. MK, AH and MJ: collaborated in the design and protocol for the DPhacto cohort. All authors read, commented and approved the manuscript for submission.

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Availability of data and material Data are available upon request to and approval by the steering committee of the DPhacto cohort. Information regarding data request can be sent to Andreas Holtermann (aho@nfa.dk).

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval Data are collected in accordance to the Declaration of Helsinki, and the local ethical committee approved the design and protocol initial to data collection (H-2-2012-011).

Consent to participate All participants signed an informed consent to participate initial to data collection.

Consent to publication All authors gave consent to submit the manuscript.

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