Promotion of sustainable employability

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Chapter 3

OBJECTIVE COMPARISON OF ENERGETIC WORKLOAD AND CAPACITY IN OLDER PRODUCTION WORKERS: A PILOT STUDY

Submitted

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ABSTRACT

Background: This pilot study examined energetic workload and energetic capacity by objective methods in older production workers, and examined differences in overloaded and normally loaded workers.

Methods: Dutch meat processing workers were eligible if they were 50 years or older. Heart rate measurements were performed to quantify energetic workload. Maximum acceptable working time was calculated based on heart rates. Energetic capacity was derived from a sub-maximal bicycle test. Several health-related characteristics were evaluated by questionnaire.

Results: Forty-one production workers participated in this study. The workers used 33% of their energetic capacity or 18% of their heart rate reserve during a workday. Seven workers were classified as overloaded. There were no significant differences on demographic and health-related characteristics compared to normally loaded workers.

Conclusion: Energetic work capacity was sufficient to handle the workload for the majority of older workers. Overloaded workers had significantly higher energetic workload, despite similar energetic capacity.

Key words: energy expenditure, need for recovery, heart rate

INTRODUCTION

The workforce is aging and with aging comes reduced physical capacity[1-3]. An industry which is mostly made up of physical work is the meat processing industry[4]. Although improvements have been made by automation of processes, work is still repetitive, monotonous, and highly physically demanding. The work requires substantial energetic capacity of the workers, which may even exceed acceptable workload limits[5]. According to the Compendium of Physical Activities the energetic workload of manual work ranges from 2.8-6.5 METs (Metabolic Equivalent of Task)[6]. If a worker has sufficient energetic capacity compared to energetic work demands this should not directly lead to health problems. But, if a worker has to deal with prolonged overload and does not recover sufficiently, this may lead to health problems and reduced work ability[1], which may eventually lead to work disability[7]. Therefore, it is of great importance to maintain a balance between energetic demands and energetic capacity[8].

Signs of imbalance may be need for recovery after work and fatigue[1,9]. Need for recovery is seen as a short-term reaction to work. Accumulation of insufficient recovery may lead to fatigue and to health problems[9-11]. To prevent energy-related health problems, it is essential to address imbalances by quantifying energetic workload and energetic capacity. Although studies have been performed into energetic workload[12,13] or energetic capacity of workers[14], only one study was identified that examined the balance between energetic workload and energetic capacity[15]. That study objectively quantified energetic capacity, but quantified energetic workload by interviewing workers. Several studies have demonstrated that self-report is less valid than objective measures[16]. Therefore, it is a necessity to quantify both energetic workload and energetic capacity by objective methods.

Energetic workload can be objectively estimated by various methods, such as direct calorimetry, breath gas analysis, and heart rate (HR) recording[17]. Direct calorimetry and breath gas analysis are considered the most valid and reliable measurements, but are not always feasible to perform in a working environment. A more feasible and generally accepted method for assessing energetic workload is measurement of HR[18,19]. Although it is not as accurate as direct calorimetry or breath gas analysis, this method is feasible to estimate energy expenditure during a workday[20]. In a sports setting this is already common practice. Energetic capacity can be predicted by performing a (sub-) maximal exercise test on a cycle ergometer[21] or treadmill[22], for which various reliable protocols are available. Submaximal exercise tests are more feasible than maximal intensity exercise tests. However, their validity is debatable[23,24].

Research questions

To objectively investigate energetic workload and energetic capacity in the meat processing industry, two primary research questions were addressed. Firstly, how does energetic workload compare to energetic capacity at the individual level? Secondly, is energetic workload within acceptable limits, and do overloaded workers differ from workers who worked within their limits on demographic and health-related characteristics? Because it is still unknown how to best match energetic workload and energetic capacity, several strategies were followed to address these questions.

METHODS

The STROBE statement was followed to report this pilot study[25]. This study was part of a larger trial[26], for which the Medical Ethics Board of the University Medical Center Groningen decided that formal approval of the study protocol was not necessary. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all participants for being included in the study.

Study design and participants

In June 2013 a workers' health surveillance (WHS) was organized in a Dutch meat processing company. All contracted production workers of 50 years and older (n=162) were invited to participate in the WHS of whom 57 participated. For the current study, those 57 workers were eligible. This cross-sectional pilot was carried out in April 2014.

Primary measures

Heart rate during work (HRwork) was measured by the Zephyr BioHarness™ 3.0 (Zephyr Technology Corp., Annapolis, MD, USA) at a sample frequency of 1 Hz. Workers wore the BioHarness™ during a full 8-hour shift. Resting heart rate (HRrest) was the lowest heart rate for a worker. Maximum heart rate (HRmax) was estimated by the following formula: HRmax = 211 – 0.64·age[27].

Energetic capacity was estimated during a sub-maximal exercise test on a cycle ergometer using the Åstrand protocol[21]. This test was part of the WHS. Participants cycled for 6-7 minutes on an electromagnetically braked cycle ergometer (Tunturi E80, Tunturi, Bergeijk, the Netherlands) with a target HR above 120 beats per minute (bpm). Based on power output, HR, age, sex, and body weight, the maximal aerobic capacity (VO2max in $ml \cdot min^{-1} \cdot kg^{-1}$) was estimated[28]. The VO2max value was converted to METs by dividing it by 3.5[6].

Secondary measures: demographic and health-related characteristics

Age and sex were retrieved from company administration. Body Mass Index (BMI) was calculated from body height and weight which were measured during the WHS. Perceived health and current diseases were evaluated in the WHS. Perceived health was measured on an 11-point numeric rating scale (NRS). The current presence of a disease was evaluated by 13 items from the Work Ability Index (WAI)[29]. Workers indicated whether they were diagnosed with a disease (yes/no) in any of the following categories: musculoskeletal, cardiovascular, respiratory, psychological, neurological, gastro-intestinal, urinary/sexual, skin, tumor, metabolic, hematologic, hereditary, and other. Need for recovery after work (NFR) and perceived fatigue were assessed concurrent with the HR measurements. NFR was assessed by a subscale from the Dutch Questionnaire on the Experience and Evaluation of Work[30]. This scale contains 11 items (yes/no), resulting in a scale score ranging from 0-100; higher scores indicating more NFR. Cronbach's alpha in this sample was 0.86. Fatigue at the end of a workday was measured on an 11-point NRS; higher score indicates more fatigue.

Data analysis

HR data collected from the BioHarness™ 3.0 were downloaded using OmniSense Analysis software version 3.7.15 (Zephyr Technology Corp., Annapolis, MD, USA) and exported to a Microsoft Excel file. Data were checked for face validity to ensure that measurement registrations appeared as they should do, i.e. without missing or erroneous registrations. HRs below 40 and above the estimated maximum HR were considered measurement errors since it is not realistic to find these HR values during work in this sample. In order to collect real work-related HR measurements the first and last five minutes of each record were filtered out, because workers had to walk some time to and from their workplace. Deleted data were not replaced. Rest breaks during a workday were included in the analyses, because it was not clear for every participant when they had a rest break. Subsequently, one-minute averages were calculated, which were used for further analyses (HRwork).

Research question 1

To answer the first research question, two approaches were followed to compare energetic workload with energetic capacity:

1. In the first strategy, energetic workload was operationally defined as percentage of the heart rate reserve (%HRR). %HRR was calculated with the Karvonen formula[31]: %HRR = 100·(HRwork – HRrest)/(HRmax – HRrest), to indicate at what percentage of one's energetic capacity work is being performed.
2. In the second strategy, energetic workload was defined as HRindex which was calculated by the following formula[32]: HRindex = HRwork/HRrest. HRindex was converted to METs by the formula: METs = 6·HRindex – 5. This value was compared to the METs value derived from VO2max. Subsequently, the energetic ratio was calculated by dividing energetic workload by energetic capacity: energetic ratio = 100·(6·HRindex – 5)/(VO2max/3.5). The energetic ratio provides an estimate of how much of the energetic capacity is consumed by the energetic workload.

Research question 2

To answer the second research question, the %HRR was compared to existing guidelines for working time 5, and workers were classified into overloaded and normally loaded workers based on maximum acceptable working time (MAWT). For an 8h workday the average %HRR should not exceed 25%. MAWT was derived from the %HRR and was calculated according to the formula: MAWT = 26.12·($e^{-4.81}$(%HRR)/100), where 'e' is the natural logarithm. If actual working time was greater than MAWT, this was considered as overload. Overloaded workers were compared with normally loaded workers on demographic and health-related characteristics. The diagnosed diseases were included in the analysis. The workers were compared on energetic workload, energetic capacity, and energetic ratio as well. Mann-Whitney U tests were performed to detect group differences. All analyses were performed with the Statistical Package for the Social Sciences (version 22.0; IBM inc., Chicago, IL, USA) and tests were considered statistically significant if p<0.05.

RESULTS

From the 57 invited workers 41 provided written informed consent and participated in the HR measurements. The 16 WHS participants who did not participate in the HR measurements either refused to participate or were sick during the measurement days. The non-participants were older (57.6 vs. 55.5 p=.07), had higher affiliation age (29.2 vs. 23.0 p=.07), and had higher BMI (29.3 vs. 26.7 p=.01). Sex distribution was similar (38/3 vs. 15/1 p=.89). On average the participating workers wore the BioHarness™ 7.6 hours (range 3.9-9.6) on an 8-hour workday. Thirty-two participants provided information on fatigue, 35 filled out the NFR scale, and 33 filled out the current diseases list. No skin, hematologic or hereditary conditions were reported. Baseline sample characteristics are displayed in Table 1.

Table 1 Sample characteristics of N=41 older production workers.

Outcome	n (%)	Mean (SD)	Range (min-max)
Age, yr	41 (100%)	55.1 (3.7)	50 – 63
Sex	38 ♂, 3 ♀		
BMI, kg/m^2	41 (100%)	26.7 (3.3)	19.8 – 35.1
Need for Recovery (0-100)	35 (85%)	26.6 (27.0)	0.0 – 90.9

Outcome	n (%)	Mean (SD)	Range (min-max)
Fatigue (0-10)	32 (78%)	4.8 (2.6)	0 – 9
Perceived health (0-10)	35 (85%)	7.5 (1.7)	2 – 10
Currently having disease (yes)	20/33 (61%)		
• Musculoskeletal	16 (49%)		
• Cardiovascular	9 (27%)		
• Respiratory	3 (9%)		
• Psychological	4 (12%)		
• Neurological	12 (36%)		
• Gastro-intestinal	7 (21%)		
• Urinary/Sexual	3 (9%)		
• Tumor	2 (6%)		
• Metabolic	5 (15%)		
• Other	1 (3%)		

BMI = Body Mass Index.

Table 2 Means (SD) and range for heart rate measurement outcomes of older production workers. Correlations of energetic workload with fatigue and need for recovery.

Outcome	n	Mean (SD)	min-max
HRrest, bpm	41	70.6 (10.1)	47 – 94
Estimated HRmax, bpm	41	175.7 (2.4)	171 – 179
HRwork, bpm	41	88.9 (12.2)	64.8 – 113.6
Max. HRwork, bpm	41	118.3 (14.8)	88.8 – 145.1
%HRR, %	41	17.6 (6.0)	8.5 – 33.6
HRindex	41	1.3 (0.1)	1.1 – 1.6
Energetic workload, METs	41	2.6 (0.6)	1.7 – 4.9
Energetic capacity, METs	39	8.0 (1.7)	5.1 – 11.4
Energetic ratio[#], %	39	33.3 (8.1)	19.7 – 50.4
MAWT, hr	41	11h38 (3h06)	5h12 – 17h25

Ratio of energetic workload to energetic capacity. %HRR = % Heart Rate Reserve; HRindex = Heart Rate index; MET = Metabolic Equivalents of Task; MAWT = Maximum Acceptable Working Time.

In Table 2 the means, SD and ranges for HR measurement data are presented. The average energetic workload amounted to 33% of the energetic capacity. The production workers had a mean MAWT of 11.6 (SD 3.1) hours, compared to a mean of 8.4 (SD 0.5) actually worked hours, implying that the mean working time is within acceptable limits.

Seven production workers exceeded the MAWT by 1.2 hours on average. Their energetic workload and energetic ratio were significantly higher than that of their normally loaded counterparts. Results from the comparison are presented in Table 3.

Table 3 Group differences between overloaded and normally loaded older production workers.

	Overload (N=7)	**Normal load (N=34)**	
Outcome	**Mean (SD)**	**Mean (SD)**	**p**
Age, years	53.7 (3.1); n=7	55.5 (3.8); n=34	.29
Sex	7 ♂, 0 ♀	31 ♂, 3 ♀	.63
BMI, kg/m^2	25.7 (3.3); n=7	26.9 (3.3); n=34	.42
Energetic workload, METs	3.3 (0.8); n=7	2.4 (0.4); n=34	.00
Energetic capacity, METs	8.3 (1.6); n=7	8.0 (1.8); n=32	.56
Energetic ratio*	40.7 (7.9); n=7	31.6 (7.3); n=32	.01
Fatigue (0-10)	5.7 (1.8); n=6	4.7 (2.7); n=26	.48
Need for recovery (0-100)	28.0 (30.8); n=6	26.2 (26.8); n=29	.96
Perceived health (0-10)	6.6 (2.4); n=7	7.6 (1.4); n=28	.31
Current disease	n=4 (out of 7)	n=16 (out of 26)	1.00

* Ratio of energetic workload to energetic capacity. BMI = Body Mass Index; METs = Metabolic Equivalents of Task

DISCUSSION

This pilot study is the first to examine energetic workload in relation to energetic capacity in a working environment. It provides a novel method to quantify both measures objectively and is a practical tool for occupational health professionals.

On average, older production workers in the meat processing industry worked at one third of their energetic capacity. Average %HRR was lower than the guideline for an 8h workday (18% vs. 25%). Work time did not exceed acceptable limits in most, but not all workers (n=7 (17%) overloaded). They had significantly higher energetic workload and energetic ratio, but did not differ from 'normally loaded' workers regarding age, sex, fatigue, need for recovery, energetic capacity, perceived health status and current diseases. This study showed that energetic workload and energetic capacity can be quantified objectively and that they can be matched in most instances. This is in accordance with earlier studies on physical workload and capacity[8,33].

Perhaps a remarkable finding is the difference between %HRR and energetic ratio. Both measures are assumed to quantify energetic workload in relation to energetic capacity. As pointed out before it was not known which strategy works best in matching energetic workload and energetic capacity. This study was not designed to identify the best strategy, but it does show that the adopted strategies result in substantially different outcomes (18% and 33% of capacity utilized). Therefore, validity of %HRR and the energetic ratio may be questioned. This is underpinned by the fact that all overloaded participants still worked, despite being classified as energetically overloaded. It is recommended that further studies are performed to identify the 'best' strategy. Within our sample there was no difference in energetic capacity comparing overloaded and normally loaded workers. The overload in a few older workers was most probably caused by energetic workload itself as calculated from the HR response. Because energetic workload, in its turn, may be influenced by internal and external factors, such as body composition, natural variation, stress, task rotation, etc. But these factors go beyond the scope of this study. Notwithstanding, the workers who were classified as overloaded still performed their work, so it is assumed that they had sufficient energetic capacity. Therefore, it appears that energetic workload should be addressed, i.e. lowered. Although this may not be desirable from a short term business perspective, because it may reduce productivity, it may be more urgent from a health and longer term business perspective. Furthermore, the work itself does not form a training stimulus that is large enough to enhance energetic capacity[11]. Other studies have demonstrated the maintaining and improving effect of structured exercise programs on physical capacity[11]. It therefore seems logical to address energetic capacity, by training workers to the required level. To what results this leads in our sample remains to be investigated. Furthermore, ergonomic changes to the workplace could be considered. Another option is to educate overloaded workers and support them in a transfer to less demanding functions within or outside their current environment to prevent early exit from the labor market.

Strengths and limitations

In this study objective measures were used to quantify energetic workload and energetic capacity which allowed matching at the individual level. This is a major strength over studies in which group norms were used to evaluate workload. It provides insight in the group and individual balance between capacity and workload, and illustrates that both measures can be quantified relatively easily. Although no gold standards were used, this approach is feasible in practice. Another strong aspect of this study is the use of BioHarness™. Its accuracy is similar to other validated methods[34]. The BioHarness™ depends on conduction of electric signals from the heart. Conduction might be disturbed by movement of the BioHarness™ and body composition and result in erroneous HR data, being either missing values or values outside biologically normal ranges. Nevertheless, all measurements had between zero and 1% erroneous data which demonstrates that measurement data were valid. Furthermore, the deletion of missing and erroneous data did not disturb the general image of the measurements; neither did the averaging of HRs to one-minute values.

HR measurements comprised one day per person. Measurement of multiple days might provide a more accurate estimate of the workload, because workload may vary across days and depend on the day of the week. More accurate results might be obtained if a longitudinal design is used. In that way, intra-individual variation and time effects would be accounted for. It might be that more workers display signs of overload, but not continuously. Errors in the measurement or estimation of variables may have influenced the final results. For instance, some variables (HRmax, energetic workload) were indirectly assessed. Furthermore, it is not known whether true HRrest was measured. Therefore, the measured HRrest might be overrated. A lower HRrest and lower HRmax will result in a higher HRindex and %HRR which will result in higher energetic workload. The opposite can happen as well. In our study it seems more likely that HRrest was overrated, so the number of overloaded workers might be an underestimation. The used methods have proven valid and reliable on a group level[27,32] and were good methods to use at the workplace. More accurate determination of HRrest and HRmax should improve the validity and reliability of our results.

A factor that might have influenced the results of this study is the prevalence of various chronic diseases at baseline. Among participants with a cardiovascular disease, medication use (e.g. beta blockers) might have caused HR to remain low. It is known that the use of beta-blockers has a negative chronotope effect on the absolute maximum HR and the HR variability[35]. Because 30% of the subjects is known with a cardiovascular disease it is possible that these participants could have used a beta-blocker during the HR measurements which therefore could have influenced the results. However, assessment of energetic capacity would not have happened in case of HR medication use or presence of a cardiovascular condition. Another limitation is the measurement of VO2max. Firstly, it was measured nine months before the HR measurements. In that period, various things could have happened that affected VO2max at the time of the HR measurements. However, analysis of BMI revealed no difference over time ($t=-0.941$; $p=0.359$), indicating that VO2max was not affected by changing body weight. Secondly, ideally a maximal intensity exercise test is performed to measure VO2max. However, this was not practical and clinically relevant for a workplace setting. Therefore, the best alternative, a sub-maximal exercise test, was used to estimate energetic capacity. The relation between sub-maximal HR and VO2 does not seem to be linear and depends on various internal and external factors[36,37]. Depending on the prediction formula used, this may result in considerable estimation errors of VO2max[23]. How this affected our results is not known. The standard conversion factor from VO2max to METs is 3.5. However, studies among well-trained athletes indicated that conversion factors differ depending on training status. Higher conversion factors were found among elite-class athletes, on average 4.3[38]. Considering the training status in our sample, i.e. VO2max, it is safe to apply a conversion factor of 3.5.

Implications for practice and research

As demonstrated in this study, 1 out of 6 older workers was overloaded. This may lead to long term health changes and higher chances of early exit from the labor market which can be dealt with in different manners. First, energetic workload can be lowered by adjusting the workplace to the fitness level of the workers. Second, workers' energetic capacity can be elevated to the required capacity by means of physical training. It is up to occupational health professionals and ergonomists to decide which approach to take and to find an optimal balance[11]. In this study, in line with its purpose, gold standard instruments for the assessment of energetic workload and energetic capacity were not used, due to their practical limitations. Future research should use gold standard methods which measure workload and capacity directly. For energetic workload this implies that it should be measured by direct calorimetry or breath gas analysis. For energetic capacity a maximal intensity exercise test with breath gas analysis should be deployed. Only then can workload and capacity be compared reliably. As indicated before these methods can be used in workplace settings, but are not really practical. Therefore, new measurement equipment should be developed which can be easily used at the workplace.

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