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Impact of work pace on cardiorespiratory outcomes, perceived effort and carried load in industrial workers: a randomised cross-over trial

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ABSTRACT

Objectives This study investigates the impact of different work paces on cardiorespiratory outcomes, perceived effort and carried load (CL) in industrial workers.

Methods A randomised cross-over trial was conducted at a mid-sized steel company. We included 12 healthy industrial workers (8 females, age: mean 44±SD 9 years, height: 1.70±0.08 m, body mass: 79.5±13.4 kg) with at least 6 months of working experience. All participants performed 5 min of piece work at 100% (P100), 115% (P115) and 130% (P130) of the company's internal target yielded in a randomised order, separated by 5 min familiarisation breaks. The primary outcome was energy expenditure (EE), calculated from a respiratory gas exchange using a metabolic analyser. Secondary outcomes were total ventilation, oxygen uptake, carbon dioxide release, respiratory exchange ratio, heart rate and rating of perceived effort (0–10). Furthermore, the metabolic equivalent and the CL were calculated. Data were analysed with repeated measure analyses of variance.

Results For EE, a large 'pace' effect with a small difference between P100 and P130 (165.9±33.4 vs 178.8±40.1 kcal/hour^{-1}, p=0.008, standard mean difference, SMD=0.35) was revealed. Additionally, a large difference in CL between all paces (p<0.001, SMD≥1.10) was revealed. No adverse events occurred.

Conclusions Cardiorespiratory outcomes rise with increased work pace, but the practical relevance of these differences still needs to be specified. However, the CL will add up over time and may impact musculoskeletal health in the long term.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Industrial workers face physical and mental loads including repetitive tasks and a high pace of work. Conflicting results exist regarding the impact of work pace on various factors, such as error rate, biomechanical exposure, muscular load, musculoskeletal disorders and subjective experiences, such as perceived exertion and perceived fatigue.

WHAT THIS STUDY ADDS

⇒ Higher work pace increases cardiorespiratory factors and carried load among industrial workers but does not affect perceived effort and heart rate. Carried load should be highlighted because of potential long-term musculoskeletal health implications and emphasising the need to prioritise workplace health and productivity.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Work pace needs to be included in future research or interventions to enhance occupational health and safety through organisational changes, such as job rotation or a worker-specific change. This study emphasises the significant impact of work pace on workers' physiological responses and musculoskeletal health.

INTRODUCTION

Industrial workers are exposed to physical hazards during work, including heavy lifting, awkward positions, vibrations, high temperatures, precision, noise, excessive work pace and repetitive work.[1 2] In this context, more than 60% of industrial workers perform repetitive movements in standard tasks with cycle times of less than 30 s and minimal variation.[3]

Although a high work pace may not necessarily lead to greater profitability,[4 5] it is considered the standard practice within the industry. During repetitive tasks, work pace can affect performance[6 7] and impact the well-being and productivity of workers.[8] Beyond that, a high work pace increases the error rate[6 7] and perceived exertion.[9] Overall, the effect of work pace on biomechanical exposure is conflicting,[9] revealing a higher muscular load[3] and a potential increased risk of musculoskeletal disorders.[8] While work pace does not affect upper extremity kinematics,[10] an increased work pace can add time spent in awkward postures[11] and may lead to fatiguing effects.[6]

To better understand the link between occupational risks and work-related diseases, workplace-specific assessments of physical load on the cardiovascular system are warranted.[2] Determining energy demand during work may be crucial for occupational health monitoring.[12] The influence of work pace on cardiorespiratory factors has not been fully considered yet. Based on such assessments, customised health promotion interventions can be developed to address industrial workers' specific

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needs and challenges on environmental and individual levels. This can improve the long-term success of workplace health promotion.[13] Therefore, this study investigated the impact of different work paces on cardiorespiratory factors, perceived effort and carried load (CL) in industrial workers. We hypothesised that the higher the work pace, the higher the perceived, cardiorespiratory and CL.

METHODS

Participants

We adopted a randomised cross-over study design. Assuming large effect sizes,[4] the power analysis (α=0.05, study power (1−β error)=0.80, r=0.5, effect size η_p^2=0.14 (f=0.40)), with G*Power (V.3.1.9.7, University of Düsseldorf, Germany), revealed a required sample size of n=12 participants.

Factory workers from a mid-size steel company in Germany were enrolled in this acute intervention study. Prior to the study, 26 factory workers (16 females) were asked to participate in an informational event voluntarily. Consequently, 12 (8 females) respondents who met the selection criteria were recruited. The inclusion criteria were as follows: (1) age >17 years, (2) working experience at the respective workstation for at least 6 months. Exclusion criteria included (3) no cardiovascular or metabolic diseases (eg, diabetes mellitus) and (4) no acute or chronic skin diseases or injuries. Participants were instructed to avoid strenuous physical exercise 24 hours before their study attendance.

Randomisation

Eligible participants were randomly assigned to three different work paces. The randomisation process was simple non-restricted and was performed by SJ using the sample function in R (V.4.0.5) and RStudio (V.1.4.1106). All participants were blinded against the randomisation sequence.

Interventions

All participants performed repetitive tasks sitting at one of three similar working stations in the production process of pliers, which involved inserting pliers into a station to process the tongs and then removing them. A comparable amount of product was processed at each of the three working stations, with individual pieces of material weighing 200 g per piece. For 10 min each, participants processed a predetermined predefined number of products at rates corresponding to 100% (P100), 115% (P115) and 130% (P130) of the normative piece rate based on internal company calculations. Five of the 10 min were dedicated to familiarisation while the remaining 5 min were used for data collection. Participants were given feedback every minute on the number of workpieces handled in the previous minute and instructed to maintain, increase or decrease their work pace to match the predefined rate (table 1). Throughout the whole test, heart rate (HR) (H9, Polar Electro, Kempele, Finnland) and respiratory gas exchange were continuously reported. Respiratory gas exchange was spirometrically assessed breath-by-breath using a validated metabolic analyser (Metamax 3b, Cosmed, Germany). Before each measurement, the spirometric system was calibrated according to the manufacturer's recommendations.

Primary outcome

The primary outcome measurement was energy expenditure (EE; in kcal/hour^{-1}). To determine EE, carbon dioxide output ($\dot{V}CO_2$) and oxygen uptake (VO_2) were used, according to the equation of Weir[14] as the total heat output in a given time (kcal)=3.941 VO_2 (L)+1.106 $\dot{V}CO_2$ (L).

Secondary outcomes

The secondary outcomes were HR, total ventilation volume ($\dot{V}E$; in L/min^{-1}), carbon dioxide output ($\dot{V}CO_2$; in L/min^{-1}), VO_2 ($\dot{V}O_2$; in L/min^{-1}), respiratory exchange ratio (RER; calculated by dividing $\dot{V}CO_2$ by VO_2), averaged over the last 5 min for each of the three working paces. Furthermore, VO_2 related to the body weight and divided by 3.5 was used to estimate the metabolic equivalent (MET) of the performed tasks.[15] Moreover, the CL (CL; in kg) was assessed by counting the products' total number and rate (pieces per minute). After completing each bout, the participants were asked to rate their rating of perceived effort (RPE) from 0 (lowest) to 10 (highest).[16] No changes were undertaken after the trial commenced.

Statistics

All data are presented as mean±SD. Normal distribution was verified via the Shapiro-Wilk test (p≥0.1), and residuals were investigated using Q–Q plots. Variance homogeneity was verified using Levene tests (p≥0.1). To examine 'pace' differences (P100 vs P115 vs P130), repeated measure analyses of variance (rANOVA) were conducted for all respective outcome measures (EE, VO_2, $\dot{V}CO_2$, $\dot{V}E$, RER, MET, HR, RPE and CL). Mauchly's test for sphericity was performed, and Greenhouse-Geisser corrections were applied if necessary (p≥0.05). The rANOVA effect sizes are given as partial eta squared (η_p^2), with ≥0.01, ≥0.06 and≥0.14, indicating small, moderate and large effects, respectively.[17] In the case of significant 'pace' effects, Bonferroni-corrected post hoc tests were subsequently computed. For pairwise effect size comparison, standard mean differences (SMDs) were calculated, with <0.2, ≤0.2 to <0.5, ≤0.5 to <0.8 and ≥0.8, indicating small, moderate and large effects, respectively.[17] All statistical analyses were conducted using R (V.4.0.5) and RStudio (V.1.4.1106) software.

RESULTS

12 participants were enrolled in August 2023 (8 females and 4 males, age: 44±9 years, height: 1.70±0.08 m, body mass: 79.5±13.4 kg). No participant withdrew consent; none had to be excluded. Due to technical problems, the HR of two participants could not be recorded. For each additional outcome and condition, the data of all 12 participants could be used. During study conduction, no adverse or serious adverse event occurred.

The analysis revealed a large and significant 'pace' effect in EE ($F(2, 22)=5.78$, $p=0.010$, $\eta_p^2=0.34$). Post hoc testing indicated

Table 1 Target and reached work productivity at the three different levels of production standard time (P100, P115, P130)

Condition	Work productivity target (%)	Work productivity reached (%)	Work productivity target (Quantity/min)	Work productivity reached (Quantity/min)
P100	100	101.2±3.8	14.4±1.4	14.5±1.4
P115	115	113.0±4.0	16.5±1.7	16.2±1.7
P130	130	128.6±3.5	18.7±1.9	18.5±1.8

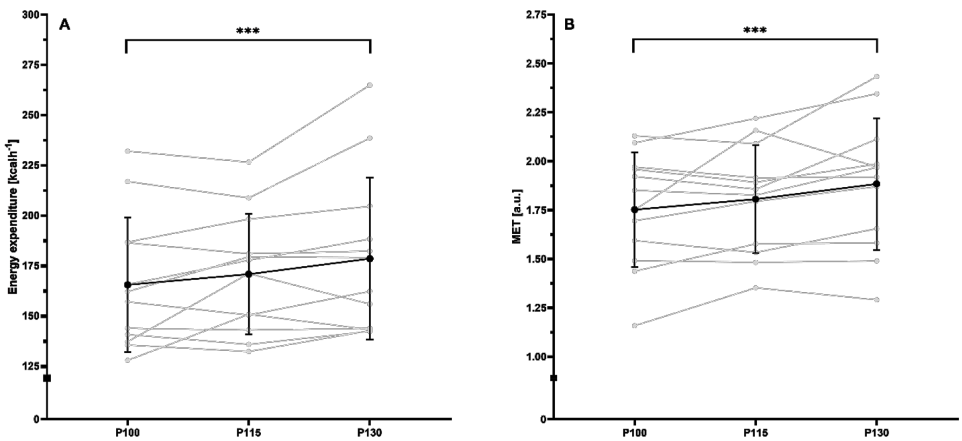

Figure 1 Mean values (black dots)±SD (error bars) for (A) energy expenditure and (B) metabolic equivalent of task (MET) during three different levels of production standard time (P100, P115, P130). Furthermore, individual values are indicated in grey. ***Significantly different from one another (p<0.001).

a significant difference between P100 and P130 (165.9±33.4 vs 178.8±40.1 kcal/hour^{-1}, p=0.008, SMD=0.35). In addition, a large and significant 'pace' effect occurred for MET (F(2, 22) = 6.03, p=0.008, η_p^2=0.35) with post hoc significant difference between P100 and P130 (1.75±0.39 vs 1.89±0.34 METs, p=0.007, SMD=0.38). The values are depicted in figure 1.

Furthermore, a large and significant 'pace' effect for VE (F(2, 22)=3.68, p=0.042, η_p^2=0.25), VO_2 (F(2, 22)=6.21, p=0.007, η_p^2=0.36), VCO_2 (F(2, 22)=4.32, p=0.026, η_p^2=0.28). The results of post hoc testing revealed a significant difference between P100 and P130 in VE (15.95±2.80 vs 17.12±3.29 L/min^{-1}, p=0.041, SMD=0.38), VO_2 (0.48±0.10 vs 0.52±0.12 L/min^{-1}, p=0.006, SMD=0,35) and VCO_2 (0.43±0.09 vs 0.46±0.11 L/min^{-1}, p=0.023, SMD=0.19) but not between P115 and any of the other paces. For RER (F(2, 22)=0.41, p=0.669, η_p^2=0.04), HR (F(2, 18)=1.15, p=0.340, η_p^2=0.11) and RPE (F(2, 22)=0.42, p=0.660, η_p^2=0.04), no significant 'pace' effect was detected. All underlying values are descriptively displayed in table 2.

Lastly, we found a large 'pace' effect for the CL (F(2, 22)=145.02, p<0.001, η_p^2=0.93). Post hoc revealed lower CL for P100 compared with P115 with a significantly large difference (174.2±16.7 vs 194.6±20.5 kg/hour^{-1}, p<0.001, SMD=1.10), for P100 compared with P130 (174.2±16.7 vs 221.4±22.1 kg/hour^{-1}, p<0.001, SMD=2.43), as well as a lower CL for P115 compared with P130 (194.6±20.5 vs 221.4±22.1 kg/hour^{-1}, p<0.001, SMD=1.26.). The values are depicted in figure 2.

DISCUSSION

Main findings and hypothesis verification

This randomised cross-over study elucidated the effect of different work paces on cardiorespiratory outcomes. In addition, the impact on CL and subjective exertion was also assessed. The primary findings of this study were as follows: (1) EE, MET, VE, VO_2 and VCO_2 increase with a higher work pace. (2) RPE did not change with different workpaces. (3) The CL increases with a higher work pace. The hypothesis could thus be confirmed for the cardiorespiratory and CL outcomes but not for perceived loads.

Energy expenditure

The literature specifies an average EE of approximately 228 kcal/hour^{-1} for manufacturing workers, which is much higher than our measured EE. Our measurements are comparable to data from 1963, where the same amount of work was classified as light to moderate work grades with a range of 110–180 kcal/hour^{-1}.[18]

We found a difference in EE between P100 and P130 of about 8%. This suggests that EE increases with higher work paces, which generally aligns with other studies.[4 19] A study observed an increase of over 30% at a 29% higher work rate compared with a normal pace and about a 15% increase for a higher pace rate of 23%, measured with wearables.[4] In this study, 20 workers performed repetitive tasks connecting two components at a

Table 2 Comparison of cardiorespiratory performance parameters and perceived effort during three different levels of production standard time (P100, P115, P130)

Parameter	P100	P115	P130	P value	η_p^2
VE (L/min^{-1})	15.95±2.80	16.69±2.53	17.12±3.29*	0.042	0.25
VO_2 (L/min^{-1})	0.48±0.10	0.50±0.09	0.52±0.12**	0.007	0.36
VCO_2 (L/min^{-1})	0.43±0.09	0.45±0.08	0.46±0.11*	0.026	0.28
RER (a.u.)	0.89±0.04	0.89±0.03	0.89±0.04	0.669	0.04
HR (min^{-1})	78.0±10.6	81.9±9.5	77.5±14.2	0.340	0.11
RPE (a.u.)	3.6±2.7	4.3±2.1	3.9±2.6	0.660	0.04

*Significantly higher than P100 (p<0.05).
**Significantly higher than P100 (p<0.01).
Furthermore, F-test p values (1×3-rANOVA) and effect sizes (η_p^2, partial eta squared) are also provided.
HR, heart rate; rANOVA, repeated measure analyses of variance; RER, respiratory exchange ratio; RPE, rating of perceived effort; VCO_2, acute carbon dioxide release; VE, total ventilation; VO_2, acute oxygen uptake.

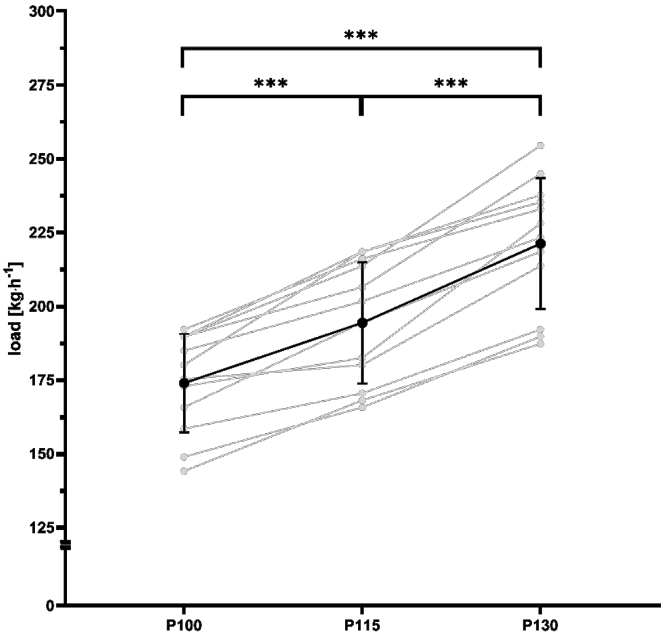

Figure 2 Mean values (black dots)±SD (error bars) for the carried load during the three different levels of production standard time (P100, P115 and P130). Furthermore, individual values are indicated in grey. ***Significantly different from one another (p<0.001).

work pace of about 140%. Li *et al*[19] investigated eight construction workers and found that an increased work pace resulted in higher EE when performing repetitive box handling at double their usual work pace (165.9 vs 178.8 kcal/hour^{-1}).[19] This intake is lower than that observed in cleaners, averaging over all tasks about 213 kcal/hour^{-1}.[11] However, comparisons between the studies and our own should be approached cautiously, considering their respective job profiles. Undertaking repetitive tasks is associated with a high cognitive load, which impacts cycle times.[20] In addition, working in a sitting position may lead to reduced overall physical activity.[21]

Workload

The workload classification must be considered when considering health promotion treatments for physical activity.[22] Thus, we determined that both P100 and P130 had MET values ranging from 1.75 to 1.89. This implies that the tasks are comparable to sedentary activities, such as hand sewing and inactivity.[23] It is important to note that the MET value is considerably lower than that of activities requiring light or moderate exertion using machine tools, with a MET value of 3.0.[23] Thus, based on these results and further research on health-related physical activity, engaging in leisure-time physical activity could benefit workers operating on these workstations to maintain their health.[24]

Cardiorespiratory outcomes

Previous research has demonstrated an impact of performance intensity on HR.[25] We found no significant difference in HR across the different work paces. Looking only at the average HR values, the physical workload of all three conditions may be classified as light work.[2] Working in a sitting position can theoretically increase upper body activation without significantly raising HR. However, this remains uncertain as we have not conducted any biomechanical assessment in our study. Nevertheless, in contrast to our findings, one study observed an increased HR at a higher work pace.[4] Despite the target work pace being set at approximately 140%, workers achieved a pace of approximately 129%.[4] In our study, every worker achieved a pace of 130% without difficulty. These findings suggest that our repetitive work was not metabolically demanding and did not consistently increase the HR. Furthermore, Nur *et al*[4] used an ActiHeart monitoring device, whereas we used an HR monitor fitted with a chest strap. Although the AcitHeart device showed good validity in measuring HR, it had poor to moderate validity for EE. In fact, when compared with the spirometry system of our study, the ActiHeart device overestimated EE.[26] Therefore, it is crucial to consider the measuring instrument being used carefully.

Perceived effort

Although a positive effect between higher work pace and increased RPE ratings has been reported earlier,[19] we did not find a significant difference between RPE at the three work paces. Specifically, we identified the highest RPE rating at 115%, diverging from the anticipated trend. Therefore, we could not rule out any bias. Our observed RPE rating remained consistently low, ranging between 3.6 and 4.3 on average, at different work paces. This is noteworthy compared with previous research reporting an RPE rating of 8–11.5 among cleaners with different tasks on a scale from 6 to 20.[22] In this term, measuring an individual's RPE and well-being determines the internal load one experiences while dealing with external load demands.[27] Notably, an increased perceived exertion despite an improved physical condition may lead to a higher risk of musculoskeletal disorders.[28]

Various exposure assessments are available to measure health-related outcomes using objective and subjective metrics like perceived effort.[1 2] Self-reports are more accessible, less costly and have shown to be a valid source of risk identification.[1 2] Self-reports offer practical and economic advantages, and a large number of workers can participate.[1] Still, they are prone to bias through individual factors like pain affecting the perceived workload,[29] undermining the reliability of this method in comparison to objective measurement and advanced techniques like sensors.[1 2] However, significant associations between high perceived exertion assessed and cardiovascular parameters like $VO2_{max}$ or muscle load were demonstrated in lifting tasks.[29] Additionally, the frequency of the measurements varies between objective and subjective measurements potentially leading to bias.[29] In our study, we conducted breath-by-breath measurements for objective data and utilised subjective measurements covering a longer period of time.

Carried load

For the CL, we found large effects between the three different work paces. Although the load with 200 g is relatively low, the difference between P100 and P130 extrapolated to a 40-hour workweek can amount to over 1.8 tons per week. When repeated over time, this can increase the risk of musculoskeletal disorders, which are common and are one of the main health risks for industrial workers.[3 10] Nevertheless, in our considerations, we assumed a constant speed throughout the day. Yet, it has already been shown that in many industries where employees are paid piece-work, employees are often working very fast in the morning and the work speed decreases during the day.[30] Therefore, developing strategies for identifying musculoskeletal issues and providing feasible solutions is essential. These may include well-organised duty schedules, modified working postures, job rotation and preliminary training to manage these issues effectively.[31] However, it is essential to thoroughly evaluate potential solutions before implementing them, as they may not always be effective.[32] Research suggests that including workers' characteristics in solutions, such as flexible time constraints, can reduce hazardous effects on older workers.[33] Another solution might be an educational approach, as previous research has shown decreased muscle activity through ergonomic instructions.[34] Notably, psychosocial factors need to be considered as factors for musculoskeletal disorders[35] and workability.[36]

Practical relevance

This study offers valuable insights for practical applications and suggests directions for future research. Research demonstrates that work pace varies throughout the day.[6] Although our study measured work pace for only a short period of time, the data indicate that work pace is a crucial factor to consider as an additional environmental factor in a human-centred approach to workplace health promotion initiatives. This aligns with principles such as the Goldilocks principle,[37] which addresses the need for adequate recovery and highlights the balance between work capacity and the promotion and maintenance of health.

Strengths and limitations

In our research, a strength was that we used a randomised crossover as the study design. Thus, the workplace posture does not greatly impact the results. This is important because a higher workspace may result in different postures,[7] thus affecting EE.[38] In addition, studies have assumed that exposure to awkward posture leads to a high risk of musculoskeletal disorders.[11] In addition, our study relies predominantly on physically demanding tasks, and factors such as training status do not greatly impact our results, which can influence the measurement.[2] A limitation of the study was the lack of analysis of demographic factors or mental aspects and experience due to the limited number of participants. However, it is important to note that mental aspects might be a factor,[2 35] and that age and sex affect EE,[2] with female workers showing higher rates, indicating a higher relative intensity.[22] Consequently, this leads to a higher health-related risk.[39] Furthermore, our study assumed a consistent work pace, which may not be representative throughout an entire workday and is an important factor to consider.[29] Additionally, there is a possibility of measurement bias as the technical error of the device used was reported to be $<2\%$.[40] When interpreting the data, it is important to consider these factors.

CONCLUSION

In conclusion, this randomised controlled study provides insights into the effects of different work paces on the cardiorespiratory outcomes of industrial workers and assesses their perceived effort and CL. The results indicate that a higher work pace increases EE and the cardiorespiratory outcomes VE, VO_2 and VCO_2. However, perceived exertion did not differ significantly across different work paces. Furthermore, the study revealed a substantial impact of work pace on CL, highlighting potential long-term implications for musculoskeletal health among industrial workers. Nonetheless, the practical relevance of the measured differences still needs to be investigated; the CL and the higher load with increased work pace should be considered in health-related interventions, along with other factors, such as training status. Taken together, these findings highlight the importance of workplace health promotion in addressing workers' health according to their working conditions. Further research is required to explore the implications of the data on work pace and identify effective interventions. Such efforts will contribute to a better understanding of the complex relationship between workplace and health among industrial workers, ultimately informing more effective interventions to promote occupational health and safety.

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Competing interests None declared.

Patient consent for publication Not applicable.

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Provenance and peer review Not commissioned; internally peer reviewed.

Data availability statement Data are available on reasonable request. The datasets used and analysed are available from the corresponding author on reasonable quest.

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