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Original Article

# Fatigue, Stress, and Performance during Alternating Physical and Cognitive Tasks – Effects of the Temporal Pattern of Alternations

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## Abstract

In occupational life, performing cognitive work tasks in between fatiguing physical work tasks may allow recovery and reduce stress without losing productive working time. The temporal pattern of such alternations is likely a determinant of the recovery effect, influencing both stress and fatigue; the difficulty of the cognitive task (CT) would also be a likely determinant. The aim of this study was to determine to what extent the temporal pattern of alternations between a repetitive physical task and a CT of different difficulties influenced perceived fatigability, performance fatigability, stress-related outcomes, and performance. Fifteen women performed four work sessions comprising 110 min of repeated bouts of a repetitive physical task (pipetting), alternating with a CT (*n*-back). Sessions differed in bout cycle time (short: 7 + 3 min versus long: 14 + 6 min) and CT difficulty (CTdiff; easy versus difficult). Fatigue was assessed from recordings of maximal voluntary contraction force in shoulder elevations and handgrip pre- and post-work, electromyography (EMG) from the right *trapezius* and right forearm extensors during work, and repeated self-ratings of fatigue and pain throughout the session. Stress was assessed using electrocardiography (heart rate variability), salivary alpha-amylase, and self-reports. Perceived fatigue increased significantly over time for all protocols and more in long-cycle than short-cycle conditions. EMG activity did not increase markedly over time in any condition. Neither objective nor subjective indicators suggested that stress increased over time, regardless of the temporal pattern. Pipetting performance remained stable in all conditions. Cognitive performance, measured by the proportions of correct positive and false positive answers, differed between CTdiff levels but remained stable over time, with no significant difference between temporal patterns. In summary, temporal patterns of alternating tasks influenced fatigue to some extent but had no obvious influence on stress indicators or performance. Thus, designing job rotation with alternating physical and cognitive work should consider the temporal patterns of alternations to minimize fatigue.

**Keywords:** fatigability; job rotation; mental work; recovery; repetitive work

### What's Important About This Paper

Alternations between physical and cognitive work tasks may be a feasible alternative to job rotation between physical tasks only, in providing recovery from physical work without losing productive time. We investigated to what extent the temporal pattern of alternations between a physical and a cognitive task (CT) affected fatigue, stress, and performance. We found that fatigue differed, to some extent, between short- and long-cycle alternations, but that both physical and cognitive performance was maintained in both cases. This may contribute to recommendations regarding the proper organization of job rotation schemes that include both physical task and CT.

## Introduction

More variation, defined as the change in exposure over time (Mathiassen, 2006), is often suggested as a remedy against fatigue, stress, and musculoskeletal disorders (MSD) in repetitive and monotonous work, by researchers (Kilbom, 1994; Liao and Drury, 2000; Mathiassen, 2006), authorities (European Committee for Standardization, 2008; The Swedish Work Environment Authority, 2012), and occupational health practitioners. A common approach to increase variation is to act on the duration or distribution of rest breaks, mainly for the purpose of providing recovery from physical work (Dababneh *et al.*, 2001; Luger *et al.*, 2019). However, breaks cannot be extended beyond a certain total duration, without interfering too much with productive work (Konz, 1998).

Overall, frequent yet short rest breaks ('micro-breaks') have been shown to result in less perceived discomfort and lower levels of electromyography (EMG) activity than longer but less frequent breaks (McClean *et al.*, 2001; Balci and Aghazadeh, 2003, 2004). The notion of micro-breaks being more effective in providing recovery than longer but less frequent breaks is supported by findings in controlled experiments on isometric, isotonic (static) contractions, showing that longer bouts of activity need to be followed by disproportionately longer rest breaks to obtain the same recovery effect after physical fatigue (Rohmert, 1973; Mathiassen, 1993). However, few studies have addressed the effect of temporal patterns of breaks on stress-related outcomes, and results are inconclusive. A field study (Boucsein and Thum, 1997) comparing long but infrequent rest breaks in office work with shorter but more frequent breaks found that the shorter breaks resulted in a lower overall stress response in the morning, while stress effects were less clear in the afternoon. Also for performance, the effects of the temporal structure of breaks are inconclusive. Some studies suggest that alternations with more frequent and shorter breaks may be preferable to longer and less frequent breaks (McClean *et al.*, 2001; Balci and

Aghazadeh, 2003, 2004), whereas others report the opposite (Horton *et al.*, 2012). Notably, effects on performance may depend on task complexity (Kher *et al.*, 1999; Allwood and Lee, 2004).

An alternative to manipulating passive rest breaks in occupational settings is to introduce productive cognitive tasks (CTs) with little physical load in between physical work tasks, in order to obtain the desired recovery effect without losing productive time. This can be viewed as a special case of job rotation, diverging from the more common idea of alternating between physical tasks only, which may not be effective in reducing fatigue and discomfort (Leider *et al.*, 2015; Padula *et al.*, 2017), perhaps due to these tasks not being sufficiently diverse (Mathiassen, 2006). An example of alternating between physical task and CT is to have industrial assembly workers occasionally performing administrative tasks (Christmansson *et al.*, 1999). Several experimental studies suggest that a 'break' comprising a CT, as opposed to passive rest, can, indeed, be effective in providing recovery after a physical task (Asmussen and Mazin, 1978; Davis *et al.*, 2002; Stock *et al.*, 2011), even if the CT is difficult (Mathiassen *et al.*, 2014; Mixer *et al.*, 2019). Stress responses appear mild, regardless of the cognitive load, at least for quite frequent alternations (Mathiassen *et al.*, 2014; Mixer *et al.*, 2019, 2020). The influence of the temporal pattern of alternations on outcomes reflecting fatigue, stress, and performance remains, however, to be established. This may be particularly relevant for women, since they suffer to a larger extent than men from MSD in occupations characterized by repetitive work (Nordander *et al.*, 2016). Moreover, women may adopt a different, and perhaps more harmful, motor control strategy in low-intensity, repetitive tasks than men (Johansen *et al.*, 2013; Srinivasan *et al.*, 2016b). Also, women may respond differently to stress (Krantz *et al.*, 2004).

Thus, the aim of this experimental study was to determine to what extent the temporal pattern of alternations between a repetitive physical task and a CT of different difficulties influences perceived fatigability, performance

fatigability, stress-related outcomes, and performance in both the physical and CTs among healthy women. Following [Enoka and Duchateau \(2016\)](#), we consider fatigue to be a process including performance fatigability, i.e. a decline in performance over a discrete time period, and perceived fatigability, i.e. changes in the sensations of the performer. We consider stress to occur when stress regulatory systems respond by a change in sympathetic ([Nater and Rohleder, 2009](#)) or parasympathetic nervous activation ([Laborde et al., 2017](#)).

We hypothesized that:

1. Fatigue and stress will increase across a series of repeated physical work bouts (WBs) alternating with bouts of a CT; the increase will be less pronounced when equal time proportions of physical task and CT are partitioned into short alternation cycles than into long cycles.
2. Performance in a difficult CT will be superior for short-cycle conditions compared with long-cycle conditions, whereas performance in an easy CT will not differ between temporal patterns.

## Materials and methods

### Participants

Fifteen women [mean age: 24.8 years, SD 4.0; height: 1.68 m, SD 0.07; weight: 65.4 kg, SD 9.7; body mass index (BMI): 23.1 kg·m<sup>-2</sup>, SD 2.9] were recruited via announcements on University Campus in Gävle, Sweden. Inclusion criteria were woman, age 20–50 years, and right handedness (determined according to [Oldfield, 1971](#)). Exclusion criteria were pregnancy, previous neck or back trauma, and chronic pain or illness affecting locomotion or the nervous system. These criteria were checked during an initial telephone contact. Thirteen participants reported having previous pipetting experience, typically from education or previous/current work, while two were novices. All participants provided signed informed consent during the training day. The study was approved by the Regional Ethical Review Board in Uppsala, Sweden (2014/002).

### Study design

The study protocol included a training session (1 h) performed on a separate day, followed by four experimental sessions interspersed by at least 3 days. The four experimental sessions were devoted to controlled work differing in cycle time (CycTim; long and short) and CT difficulty (CTdiff; easy and difficult) ([Fig. 1](#)). The two conditions with long-cycle times consisted of five 14-min

pipetting WBs alternating with five WBs of a 6-min CT, which was easy (LongEasy) in one session and difficult (LongDifficult) in another. The two short-cycle conditions consisted of ten 7-min pipetting WBs alternating with ten 3-min WBs of the easy (ShortEasy) or difficult (ShortDifficult) CT. Thus, in all four sessions, the total work time was 110 min, including ratings ([Fig. 1](#)). The order of the four conditions was counterbalanced across participants to control for order effects. Each participant chose, with very few exceptions, to perform all sessions either in the morning (8–12 am) or in the afternoon (1.30–5.30 pm). Participants were instructed to avoid intense physical training and intake of tobacco 24 h prior to a session and to abstain from eating, drinking (besides water), and brushing their teeth (to avoid contamination of saliva samples) 30 min prior to the experiment.

### Physical task and CT

#### Physical task (pipetting)

The physical task, i.e. pipetting, was performed at a work station used in previous studies ([Srinivasan et al., 2015a,c](#); [Samani et al., 2017](#); [Sandlund et al., 2017](#); [Mixer et al., 2019](#)). The task involved aspirating liquid from a pickup tube (Ø 20 mm) to one of the four target tubes (Ø 6 mm), clockwise and sequentially, following the pace of a metronome ([Fig. 2](#)). The cycle time was 2.8 s, corresponding to 100 MTM (Methods Time-Measurement; [Maynard et al., 1948](#)). In previous studies using the same experimental model, this pipetting task has been shown to be associated with a mean *trapezius* muscle activity corresponding to ~9% maximal voluntary contraction (MVC) ([Srinivasan et al., 2016a](#)). Participants were seated in a rigid chair adjusted according to standard guidelines, i.e. the chair height fixed to give a knee angle of 90° and table height fixed at participants' elbow height. The distance between chair and table was set to have participants' ulnar styloid process right above the pickup tube when holding the arm straight toward the tube ([Fig. 2](#)). To prevent participants from leaning forward during pipetting, their torso was strapped to the chair.

#### Cognitive task (*n*-back)

*N*-back is a standardized working memory task ([Owen et al., 2005](#); [Kane et al., 2007](#)), which we selected because it reflects cognitive requirements occurring in occupational settings, i.e. processing, maintaining, and updating information in the working memory ([Colom et al., 2006](#)). In our *n*-back, one of the seven consonants was presented in black (font Microsoft Sans Serif, size 120) on a white background, on a 20-inch standard computer screen

placed in an upright position at eye level, ~100 cm from the participant. A consonant was shown for 2 s, followed by a blank screen for 0.5 s. We used two difficulty levels: easy (1-back) and difficult (3-back). In 1-back, participants were instructed to press a button when the letter on the screen matched the letter presented one step back; in the difficult 3-back, they were to react on letters three steps back. Performance was measured by the percentage of correct-positive and false-positive answers.

### Training session

During the 1-h training session prior to the experiments, participants trained on the pipetting task to ensure adequate proficiency. Participants reporting no previous pipetting experience trained for an additional hour. Five of the participants had participated in an earlier study involving the same tasks (Mixer *et al.*, 2019).

### Pre- and post-test battery

Each experimental session started with baseline self-ratings and saliva sampling (Fig. 1). This was followed by a 5-min rest period, a 5-min practice session of the CT, and a blood pressure (BP) measurement. Thereafter, a set of reference voluntary contractions (RVCs), MVCs, and additional self-ratings were performed (Fig. 1), followed by another BP measurement and saliva sampling.

### Ratings

At specific times during the pre- and post-tests (cf. Fig. 1), participants verbally rated perceived fatigue and pain in the right shoulder and the lower arm, as well as stress, on the Borg CR-10 scale, from 0 (none at all) to 10 (extremely strong). Any number between 0 and 10, including decimals, was allowed. The Borg CR-10 scale has good psychometric properties and can be used for a number of psychophysiological modalities (Borg, 1990, 1998; Borg and Granberg, 2010).

### Maximal voluntary contractions

In both pre- and post-test batteries, MVC for the right shoulder was determined as the largest of three 5-s maximal vertical shoulder elevations, interspersed by 60 s rest. Participants were seated in a chair with relaxed shoulders and straight arms alongside the body, grabbing handles attached to a dynamometer at each side of the chair, i.e. a modified shoulder shrug (Ng *et al.*, 2014).

Thereafter, MVC for the right forearm was measured in a maximal handgrip, repeated three times (Nordander *et al.*, 2004). The participant was instructed to grab and

press, with their right hand and the elbow 90° flexed, a handgrip force transducer fixed on the table on their right body side at elbow height.

### Reference voluntary contractions

For the shoulder RVC, participants were instructed to hold both arms straight with palms down, at 90° abduction in the frontal plane (Mathiassen *et al.*, 1995). For the forearm RVC, participants exerted a 15% MVC handgrip (determined using the MVC obtained as described above), with visual feedback of the force on a computer screen. In the pre-test battery, the RVCs were repeated twice for 15 s with 30 s rest in between, and then once for 60 s, preceded by 30 s of rest. In the post-test battery, only the 60 s RVCs were performed. The reference contraction used for *trapezius* corresponds to ~15% of maximal force (Mathiassen *et al.*, 2003). Thus, *trapezius* EMG results in % reference voluntary exertion (%RVE) may, tentatively, be translated to %MVC by using this as a conversion multiplier.

### Physiological and psychophysical measurements during the work period

#### Perceived fatigability

During the last minute of each pipetting WB, and after each CT bout, participants verbally rated perceived fatigue in the right shoulder and lower arm and pain in the right shoulder and lower arm using the Borg CR-10 scale (cf. Fig. 1; Borg, 1990, 1998).

#### Performance fatigability

To assess muscle activity and to detect possible changes in performance fatigability, EMG was collected from the right *trapezius* muscle and the right forearm extensors throughout the experiment. For *trapezius* muscle EMG, a pair of self-adhesive electrodes (Ambu Neuroline 720, Ambu, Malaysia) were placed at 20 mm inter-electrode distance, lateral to the midpoint between vertebrae C7 and acromion (Mathiassen *et al.*, 1995). For right forearm extensors, the electrode pair was placed on the muscle belly at one-third of the distance between elbow and the ulnar styloid process (Nordander *et al.*, 2004). A reference electrode (Ambu Neuroline Ground, Ambu, Malaysia) was placed on vertebra C7. Before electrode application, the skin was prepared through shaving, gentle rubbing with abrasive paper, and cleaning with alcohol.

EMG signals were pre-amplified at a gain of 500 using the Noraxon system (Noraxon, MyoSystem1400 A), band-pass filtered 10–1000 Hz, and sampled at

2000 Hz using a customary software (Platon version 8.1). Then, each file was imported to the Spike software (Spike 2, Cambridge Electronic Design, Cambridge, UK, 2015), and filtered using a finite impulse response high-pass filter with a cutoff frequency at 35 Hz to remove contamination by electrocardiographic signals. Then, it was visually inspected, cleaned from obvious artifacts, and root mean square (RMS) converted in consecutive 250 ms windows. These EMG RMS values were normalized in terms of percent of the mean %RVE during the 15 s RVCs in the pre-test battery (Mathiassen *et al.*, 1995). Submaximal exertions have been suggested to be more useful for normalization purposes than maximal exertions, in particular, if participants are unaccustomed to exerting maximal force (Mathiassen *et al.*, 1995).

## Stress indicators

### Cardiovascular measures

Electrocardiography was recorded throughout the experiment session using a standard two-led configuration of self-adhesive Ag/AgCl electrodes (Ambu Blue Sensor VLC, Malaysia). It was sampled at a frequency of 2000 Hz and with a gain of 5, using customary software (Platon version 8.1), amplified by Noraxon (Noraxon, MyoSystem 1400A), and band-pass filtered at 0.5–200 Hz. After off-line import to the Spike software (Spike 2, Cambridge Electronic Design, Cambridge, UK, 2015), each data file was processed to determine R–R intervals [heart rate (HR)] and calculate heart rate variability (HRV) variables. R–R intervals were visually inspected for artifacts and replaced using linear interpolation before HRV analysis.

HRV indices were analyzed in both time and frequency domains using non-overlapping 2-min windows to determine indices reflecting parasympathetic nervous activity (Bertsch *et al.*, 2012; Laborde *et al.*, 2017). Following recommendations (Malik *et al.*, 1996), HR and the RMS of successive differences between R–R intervals (RMSSD) were selected in the time domain and high frequency (HF) spectral power at 0.15–0.4 Hz in the frequency domain. These HRV indices are valid indicators of parasympathetic nervous activation (Malik *et al.*, 1996; Kleiger *et al.*, 2005) and reliable markers of autonomic activity during repetitive low-intensity work (Hallman *et al.*, 2015).

Systolic and diastolic arterial BP (mmHg) were measured as indicators of sympathetic nervous activation (Lundberg, 2002) once at each of four specific time points (cf. Fig. 1) using a noninvasive automatic BP monitor placed on the participants' upper non-dominant arm (Boso Medicus, Sohn GmbH, Germany).

## Alpha-amylase

As a noninvasive biomarker of sympathetic nervous activation, saliva alpha-amylase (sAA; Rohleder and Nater, 2009) was measured through passive drooling technique (Nagy *et al.*, 2015) at time points shown in Fig. 1. Participants were asked to first swallow, then allow saliva to pool passively in their mouths for 1 min and then spit in a plastic cup (this procedure was repeated immediately). After mixing and dispensing the saliva, samples were frozen (–18°C) until analyzed. sAA activity was determined (Pointe Scientific, Inc.; Liquid Amylase, CNPG3 reagent set; 2 min 1000× at room temperature) through duplicate analyses and expressed in U/ml saliva. Saliva/min and sAA U/min were also computed.

## Ratings

During the last minute of each pipetting WB, and just after each CT WB, participants provided verbal self-ratings on the Borg CR-10 scale of stress, fatigue, pain, mental fatigue, and mental effort (the latter only after CT WBs).

## Statistical analyses

### Data distributions

Data were checked for normality. No deviations in terms of skewness and kurtosis were found, except for HRV-variables RMSSD and HF. These variables were log-transformed before further statistical analysis.

### Baseline observations

To check for possible differences between protocols in pre-test indicators of fatigue, pain, and stress, a set of repeated measures Analysis of Variance (ANOVA) with CycTim (long/short) and CT difficulty (CTdiff; easy/difficult) as within-subject factors were performed. For descriptive statistics, variables were expressed as group means and standard deviations (SDs) between participants.

### Development of fatigue, stress, and performance during work

A series of repeated measures ANOVAs were conducted to analyze the effects of WB ( $n = 5$  and  $n = 10$  in the long- and short-cycle condition, respectively), CycTim (long/short) and CTdiff (easy and difficult), including two- and three-way interactions, on the following outcomes: perceived fatigue, mental fatigue, mental effort, pain, stress, EMG amplitude (one model for the first minute of each pipetting bout and one for last minute of each pipetting bout), HR, HRV, and CT performance (correct-positive and false-positive answers, in percent). The short- and long-cycle protocols comprised different numbers of WBs, and, therefore, the ANOVAs

were based on data from each WB for the long-cycle protocols (WB 1, 2, 3, 4, and 5) and every second WB for the short-cycle protocols (i.e. WB 2, 4, 6, 8, and 10 for ratings and EMG during the first minute of pipetting and WB 1, 3, 5, 7, and 9 for EMG in the last minute of pipetting, and HRV).

### Pre- and post-test differences

A series of repeated measures ANOVAs were conducted to analyze the effects of time (before and after), CycTim (long and short), and CTdiff (easy and difficult), including two- and three-way interactions, on the outcomes MVC, BP, and sAA. For sAA, percent of baseline values were used (i.e. no baseline levels were included in the model).

Statistical analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp). Results are reported in terms of  $F$ -statistics with corresponding  $P$ -values and partial eta-square effect sizes,  $\eta_p^2$  (Lakens, 2013). Effect sizes are a complement to  $P$ -values in providing an estimate of the magnitude of an effect rather than implying statistical significance only. Also, effect sizes are more (though not fully) independent of sample size (Richardson, 2011). Cohen (1988) suggested benchmark sizes for small, medium, and large  $\eta_p^2$  to be 0.01, 0.06, and 0.14, respectively.

## Results

### Pre-test outcomes

We found no significant differences between the four experimental conditions in any pre-test outcome variable (all  $P > 0.1$ ), except for perceived fatigue in the right shoulder, which was higher before the easy CT compared with the difficult CT in the short-cycle condition ( $F = 10.48$ ,  $P = 0.006$ ,  $\eta_p^2 = 0.43$ ).

Time of day (morning or afternoon session) was entered as a between-groups factor in the repeated measures ANOVA of sAA data but was not statistically significant ( $P = 0.108$  for values expressed as percent of baseline and  $P = 0.099$  for absolute values).

### Perceived fatigability

Perceived fatigue and pain in the right shoulder and lower arm during the last minute of pipetting WBs increased significantly with time, regardless of CycTim and CTdiff (Table 1; Fig. 3). We found a significant interaction CycTim  $\times$  WB on perceived fatigue in the right shoulder, with a steeper increase across WBs for long cycles compared with short cycles (Table 1; Fig. 3).

### Performance fatigability

EMG from three participants was discarded due to technical errors, and, thus, EMG recordings from 12 participants were included in the analysis.

We found no significant main effect of WB or CycTim on EMG in neither the right *trapezius* nor the right forearm extensors (Table 2, Fig. 4). However, for the forearm extensors, we found a significant interaction effect CycTim  $\times$  WB, with a slightly larger increase in first-minute EMG over long-cycle WBs than over short-cycle WBs.

### Stress

Perceived stress did not change significantly over WBs (Table 1). We found no main effect of CycTim or CTdiff on any rating. We did, however, find an interaction between CTdiff and WB on perceived stress (Table 1); stress ratings decreased over time for the easy CT but increased in protocols with the difficult CT.

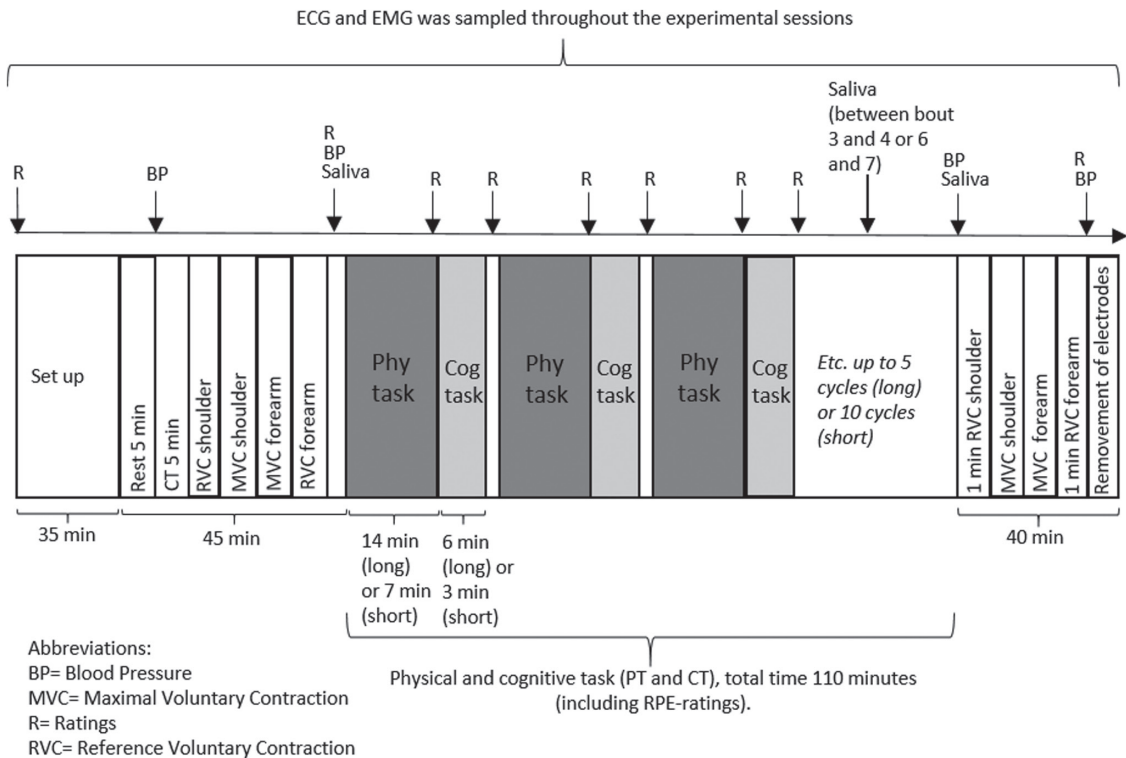
We found a significant main effect of WB for HR, which decreased with time (Table 2, Fig. 5). Interactions between CycTim and WB were found for HR and RMSSD (Table 2; Figs 5 and 6), with a larger decrease and a larger increase, respectively, in the long-cycle protocols (Table 2).

### Physical and CT performance

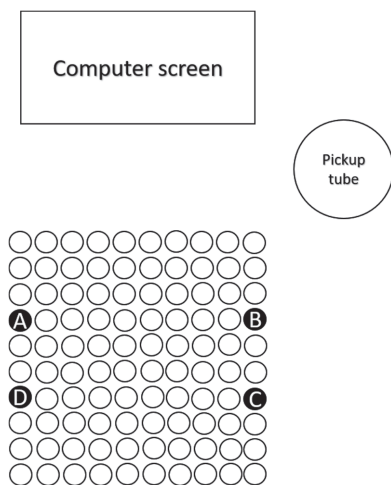
Performance in the physical task remained stable with only a few errors occurring throughout the 110 min of work in all four experimental conditions.

As expected, we found a significant main effect on cognitive performance for CTdiff (easy and difficult), with more errors occurring in the difficult CT, both in terms of less correct-positive answers and more false-positive answers (Table 3). We found no main effect for CycTim (Table 3); however, we found a significant interaction between WB and CTdiff on both correct-positive and false-positive answers, with performance decreasing slightly across WBs in protocols with the difficult task but not in those with the easy task (Table 3).

Ratings of mental fatigue just after having performed the CT increased significantly across WBs, while mental effort did not change significantly across WBs (Table 3). Both mental fatigue and mental effort were significantly higher for the difficult CT than for the easy. We found no main effect of CycTim on ratings of mental fatigue or mental effort, and we found no significant interaction between CycTim and CTdiff (Table 3).



**Figure 1.** Data collection flow chart for both long- and short-cycle conditions. The white zone immediately after a CT illustrates an ~1-min break for ratings.



**Figure 2.** The arrangement of pickup and target tubes and the computer screen used for the CT. One work cycle consisted of the participant aspiring liquid from the pickup tube and then dispensing it in one of the four target tubes (A–D), in a clockwise order.

### Pre versus post differences for MVC, amylase, and BP

MVC did not differ between pre- and post-tests (shoulder elevation  $F = 0.30$ ,  $P = 0.60$ ,  $\eta_p^2 = 0.05$ ;

handgrip  $F = 2.50$ ,  $P = 0.17$ ,  $\eta_p^2 = 0.29$ ). CycTim did not significantly influence MVC (CycTim shoulder elevation  $F = 0.80$ ,  $P = 0.41$ ,  $\eta_p^2 = 0.12$ ; CycTim handgrip  $F = 0.06$ ,  $P = 0.82$ ,  $\eta_p^2 = 0.01$ ). There were no significant interaction effects for MVC (all  $F \leq 0.62$ ,  $P \geq 0.46$ ).

sAA was higher post-test than before the work period ( $F = 6.91$ ,  $P = 0.02$ ,  $\eta_p^2 = 0.35$ ), but there was no significant effect of CycTim ( $F = 0.55$ ,  $P = 0.47$ ,  $\eta_p^2 = 0.04$ ) or CTdiff ( $F = 0.83$ ,  $P = 0.38$ ,  $\eta_p^2 = 0.06$ ). There were no significant interaction effects for sAA (all  $F \leq 3.6$ ,  $P \geq 0.08$ ).

Both systolic and diastolic BP were higher post-test than pre-test (systolic  $F = 28.6$ ,  $P < 0.001$ ,  $\eta_p^2 = 0.67$ ; diastolic  $F = 15.04$ ,  $P = 0.002$ ,  $\eta_p^2 = 0.52$ ) but BP was not significantly associated with CTdiff or with cycle time (all  $F \leq 1.7$ ,  $P \geq 0.20$ ). Neither systolic nor diastolic BP (all  $F \leq 3.3$ ,  $P \geq 0.07$ ) showed significant interaction effects.

## Discussion

In this controlled study, we aimed at determining to what extent the temporal pattern of alternations between a physical and a CT influenced perceived fatigability, performance fatigability, stress responses, and

**Table 1.** Repeated measures ANOVAs of ratings of perceived fatigue, pain, and stress, showing main effects of WBs, CycTim, and CTdiff as well as their interaction effects.

Measure	ANOVA			
	df	F	P	$\eta_p^2$
Fatigue right shoulder				
WB	4	13.14	<b>P &lt; 0.001</b>	0.48
CycTim	1	0.87	0.37	0.06
CTdiff	1	0.38	0.55	0.03
WB × CycTim	4	2.90	<b>0.03</b>	0.17
WB × CTdiff	4	0.44	0.78	0.03
WB × CycTim × CTdiff	4	1.41	0.24	0.09
Fatigue lower arm				
WB	4	9.19	<b>P &lt; 0.001</b>	0.40
CycTim	1	3.28	0.09	0.19
CTdiff	1	0.01	0.91	0.001
WB × CycTim	4	0.60	0.68	0.04
WB × CTdiff	4	0.54	0.71	0.04
WB × CycTim × CTdiff	4	1.01	0.41	0.07
Pain right shoulder				
WB	4	6.05	<b>P &lt; 0.001</b>	0.30
CycTim	1	0.69	0.42	0.05
CTdiff	1	0.78	0.39	0.05
WB × CycTim	4	0.96	0.44	0.06
WB × CTdiff	4	0.20	0.94	0.01
WB × CycTim × CTdiff	4	0.81	0.53	0.05
Pain lower arm				
WB	4	4.25	<b>0.004</b>	0.23
CycTim	1	0.67	0.62	0.05
CTdiff	1	0.35	0.56	0.03
WB × CycTim	4	0.67	0.62	0.05
WB × CTdiff	4	1.25	0.30	0.08
WB × CycTim × CTdiff	4	0.81	0.52	0.06
Stress				
WB	4	0.39	0.81	0.03
CycTim	1	1.84	0.20	0.12
CTdiff	1	1.43	0.25	0.09
WB × CycTim	4	2.28	0.07	0.14
WB × CTdiff	4	4.0	<b>0.007</b>	0.22
WB × CycTim × CTdiff	4	1.45	0.23	0.09

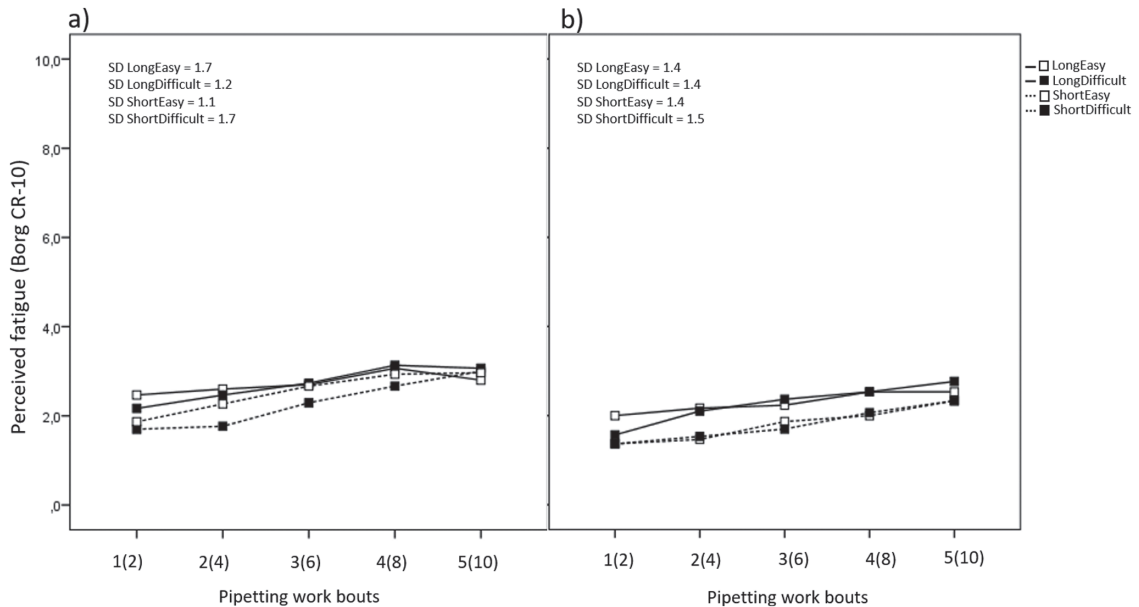
df, degrees of freedom;  $\eta_p^2$ , partial eta squared. *P*-values ≤ 0.05 are marked in bold.

performance, and whether CTdiff was important. To our best knowledge, no previous experimental study has addressed this. We found that the temporal pattern of alternations influenced performance fatigability and perceived fatigability to some extent, but that stress responses were, in essence, unaffected. CTdiff had no obvious effects on fatigue and stress, except for perceived stress, where ratings were slightly higher during the difficult than during the easy CT.

Pipetting performance was maintained throughout all four protocols. Cognitive performance was significantly lower during the difficult CTs compared with the easy but did not differ between long- and short-cycle conditions.

We hypothesized that performance fatigability and perceived fatigability would increase over physical WBs but be less pronounced in short alternation cycles than in long. We found that EMG activity in right forearm





**Figure 3.** Perceived fatigue (Borg CR-10) in (a) right shoulder and (b) right lower arm during the last minute of pipetting WBs 1–5 for long cycles (full-drawn lines) and bouts 2, 4, 6, 8, and 10 for short cycles (dashed lines). Mean values for the easy CT (black squares) and the difficult CT (white squares). SDs refer to all participants ( $n = 15$ ) across all time points.

extensors was higher during long-cycle conditions than during short-cycle conditions (Table 2, Fig. 4), while *trapezius* EMG levels did not differ between conditions. In a study by Mixer *et al.* (2019), where participants performed alternations between physical task and CT in the same temporal pattern as the short-cycle protocol in the present study, right *trapezius* EMG amplitude increased significantly both within and over WBs. However, this increase was modest, and other performance indicators of fatigability remained unchanged. We believe that the minor effects observed on performance fatigability may, at least partly, be due to the low intensity of the physical pipetting task with mean values for right trapezius and right forearm extensor EMG corresponding to ~9% MVC (Srinivasan *et al.*, 2016a) and 15% MVC (present study, cf. Fig. 4), respectively. Our findings showing no significant change in performance fatigability (EMG RMS amplitude and MVC) but increasing levels of perceived fatigability over WBs follow previous studies of low-force tasks (<15% MVC) performed for more than 1 h (de Looze *et al.*, 2009; Yung and Wells, 2017). We also found that perceived fatigue ratings in the right shoulder during the last minute of pipetting bouts were slightly higher during long- than short-cycle protocols, at least in the beginning of the work session (Table 1, Fig. 3). This suggests that cycles with frequent alternations between a low-force physical task and a CT result

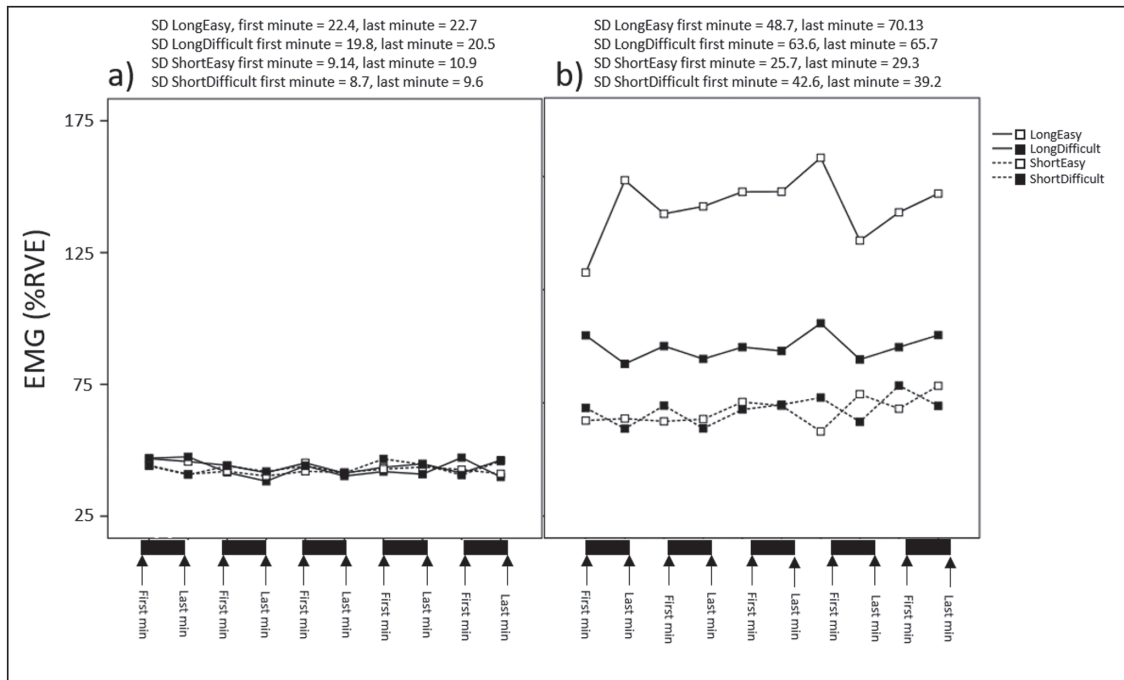
in less fatigue than long cycles with less frequent alternations, even if the total time with physical and cognitive work is the same. An effect of cycle time was reported even in previous studies, showing that micro-breaks every 15 min resulted in lower discomfort ratings in the upper extremity during computer work than did 5-min breaks every 30 min (Balci and Aghazadeh, 2003), and that protocols with 30 s breaks every 20 min resulted in less perceived discomfort than did 30 s breaks every 40 min (McClean *et al.*, 2001). Notably, all conditions investigated by Balci and Aghazadeh (2003) comprised the same total time in rest breaks (i.e. a similar design as ours), whereas the McClean *et al.* (2001) study did not.

To our knowledge, very few studies have assessed the effect of rest break schedules on stress responses. Contradicting our hypothesis of stress being more pronounced in protocols with longer cycles, we found a larger parasympathetic nervous activity (i.e. increased HRV) during long-cycle than during short-cycle conditions (Table 2; Figs 5 and 6). Sympathetic nervous activation increased, as indicated by sAA, between pre- and post-work measurements but was not affected by the pattern of alternations during work. In addition, parasympathetic activity increased to a larger extent in long-cycle protocols (i.e. decreased HR and increased RMSSD, Table 2; Figs 5 and 6), which does not support our hypothesis. It is possible that more frequent changes

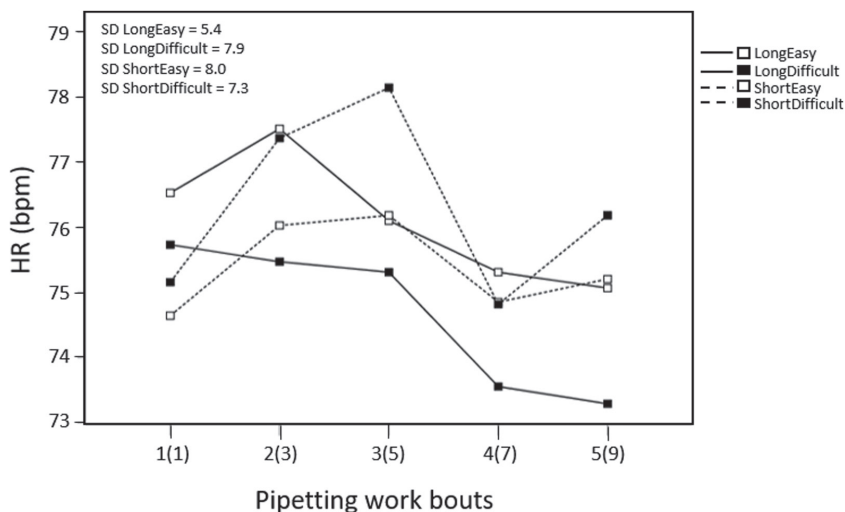
**Table 2.** Repeated measures ANOVAs for EMG, HR, and HRV variables, showing main effects of WBs, CycTim, and CTdiff as well as their interaction effects.

Measure	ANOVA			
	df	F	P	$\eta_p^2$
Performance fatigability				
EMG right <i>trapezius</i> , %RVE (all first minutes)				
WB	4	0.50	0.77	0.05
CycTim	1	0.08	0.79	0.01
CTdiff	1	0.06	0.82	0.01
WB × CycTim	4	1.03	0.41	0.11
WB × CTdiff	4	0.11	0.98	0.01
WB × CycTim × CTdiff	4	0.81	0.53	0.09
EMG right <i>trapezius</i> , %RVE (all last minutes)				
WB	4	1.86	0.14	0.19
CycTim	1	0.02	0.91	<0.01
CTdiff	1	0.03	0.86	<0.01
WB × CycTim	4	1.41	0.25	0.15
WB × CTdiff	4	0.12	0.96	0.02
WB × CycTim × CTdiff	4	0.77	0.56	0.09
EMG forearm extensors, %RVE (all first minutes)				
WB	4	2.60	0.06	0.24
CycTim	1	4.13	0.08	0.34
CTdiff	1	0.58	0.47	0.07
WB × CycTim	4	2.72	<b>0.05</b>	0.25
WB × CTdiff	4	1.16	0.35	0.13
WB × CycTim × CTdiff	4	1.63	0.19	0.17
EMG forearm extensors, %RVE (all last minutes)				
WB	4	1.42	0.25	0.51
CycTim	1	4.33	0.07	0.35
CTdiff	1	1.17	0.31	0.13
WB × CycTim	4	0.71	0.59	0.08
WB × CTdiff	4	0.32	0.86	0.04
WB × CycTim × CTdiff	4	0.62	0.65	0.07
HR and HRV				
HR, bpm				
WB	4	6.26	<b>P &lt; 0.001</b>	0.31
CycTim	1	0.37	0.55	0.03
CTdiff	1	0.01	0.91	0.001
WB × CycTim	4	2.87	<b>0.03</b>	0.17
WB × CTdiff	4	1.31	0.28	0.09
WB × CycTim × CTdiff	4	0.27	0.90	0.02
RMSSD, log ms				
WB	4	1.10	0.37	0.07
CycTim	1	1.45	0.25	0.09
CTdiff	1	0.01	0.94	0.00
WB × CycTim	4	2.52	<b>0.05</b>	0.15
WB × CTdiff	4	0.47	0.76	0.03
WB × CycTim × CTdiff	4	1.13	0.35	0.08
HF, log ms <sup>2</sup>				
WB	4	0.75	0.56	0.05
CycTim	1	1.50	0.24	0.10
CTdiff	1	0.07	0.80	0.01
WB × CycTim	4	1.33	0.27	0.10
WB × CTdiff	4	0.20	0.94	0.01
WB × CycTim × CTdiff	4	0.63	0.64	0.04

df, degrees of freedom;  $\eta_p^2$ , partial eta squared. P-values ≤ 0.05 are marked in bold.



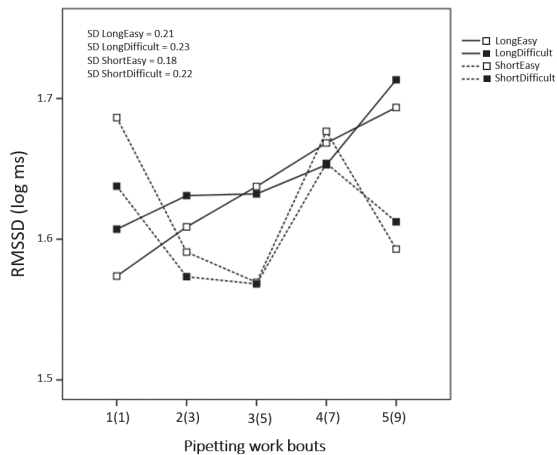
**Figure 4.** EMG activity (%RVE) in (a) the right *trapezius* and (b) the right forearm extensors during the first and last minutes of pipetting WBs 1–5 for long cycles (full-drawn lines) and, for short cycles (dashed lines), bouts 1, 3, 5, 7, and 9 for first-minute results and bouts 2, 4, 6, 8, and 10 for the last minute. The easy CT is illustrated by black squares, and the difficult CT by white squares. SDs refer to all participants ( $n = 12$ ) across all time points.



**Figure 5.** HR (bpm) during the first 7 min of pipetting bouts 1–5 for long cycles (full-drawn lines) and the first 3.5 min of pipetting bouts 1, 3, 5, 7, and 9 for short cycles (dashed lines). The easy CT is illustrated by black squares, and the difficult CT by white squares. SDs refer to all participants ( $n = 15$ ) across all time points.

between tasks increased autonomic activation, so that the HR decrease observed during the long-cycle protocol was counteracted in the short-cycle protocols. Bousein

and Thum (1997) compared psychophysiological recovery measures during a full workday between two rest break schedules: short but frequent breaks versus longer



**Figure 6.** RMSSD (log ms) during the first 7 min of pipetting bouts 1–5 for long cycles (full-drawn lines) and the first 3.5 min of pipetting bouts 1, 3, 5, 7, and 9 for short cycles (dashed lines). The easy CT is illustrated by black squares, and the difficult CT by white squares. SDs refer to all participants ( $n = 15$ ) across all time points.

but less frequent breaks. In the morning, the short rest break schedule resulted in increased HRV and decreased electrodermal activity, whereas, in the afternoon, the effect on HRV was less clear, but electrodermal activity increased as a result of the short rest break schedule. Thus, activation patterns and recovery patterns may change over time during a full workday as stress and fatigue accumulate. While [Boucsein and Thum \(1997\)](#) measured stress markers throughout the day, our work protocol (110 min of alternating work) was too short to disclose fluctuations between activation and recovery occurring during 8 h of work.

We also hypothesized that the difficult CT would lead to more errors in long-cycle alternations than in short cycles, due to accumulated mental fatigue during long cognitive bouts. This hypothesis was not supported since CT performance, measured by correct-positive and false-positive answers, did not differ significantly between the two temporal patterns. Also, mental fatigue and mental effort were almost unaffected by the temporal pattern, indicating that participants did not

**Table 3.** Repeated measures ANOVAs of CT performance. Mean (SD between participants) for the percentage correct-positive and false-positive answers in the four different conditions. Main effects for WB, CycTim, and CTdiff and their interaction effects.

Measure	Mean (SD)	df	F	P	$\eta_p^2$
Correct positive					
LongEasy	97.6 (2.5)				
LongDifficult	58.5 (18.9)				
ShortEasy	97.3 (3.2)				
ShortDifficult	61.0 (17.3)				
WB		4	1.78	0.15	0.11
CycTim		1	0.91	0.36	0.06
CTdiff		1	73.61	<b>&lt;0.001</b>	0.84
WB × CycTim		1	0.18	0.68	0.01
WB × CTdiff		4	3.53	0.01	0.20
WB × CycTim × CTdiff		4	1.47	0.23	0.10
False positive					
LongEasy	0.3 (0.4)				
LongDifficult	4.2 (3.3)				
ShortEasy	0.1 (0.1)				
ShortDifficult	4.1 (2.4)				
WB		4	0.45	0.77	0.03
CycTim		1	1.73	0.21	0.11
CTdiff		1	30.4	<b>&lt;0.001</b>	0.69
WB × CycTim		1	0.42	0.52	0.30
WB × CTdiff		4	0.55	0.70	0.04
WB × CycTim × CTdiff		4	0.61	0.66	0.04

df, degrees of freedom,  $\eta_p^2$ , partial eta squared. P-values  $\leq 0.05$  are marked in boldface.

'give in' during long cycles, being able to maintain focus throughout the 6-min CT. [Balci and Aghazadeh \(2003\)](#) found that a work–rest schedule with frequent micro-breaks resulted in higher speed, performance, and accuracy in both data entry and an arithmetic task, compared with longer but less frequent breaks.

### Methodological considerations

The strengths of this study include its design with strictly controlled alternations between physical task and CT. Another strength is the comprehensive set of methods to assess different aspects of performance fatigability, perceived fatigability, and stress, using both participant ratings and direct physiological and biomechanical measurements.

When planning the experiments, we performed power calculations showing that 15 participants were needed to statistically detect relevant differences between conditions. Since our final sample size of 15 women was the minimum required, we acknowledge a non-trivial risk that our results may suffer from type II errors.

Performance fatigability was assessed using EMG RMS amplitude and pre- and post-measurements of MVC. Changes in EMG RMS amplitude have been suggested to reflect fatigue-related changes in muscle recruitment ([Hägg et al., 2000](#)). We abstained from analyzing EMG frequency as an indicator of performance fatigue, since frequency data from low-intensity tasks are difficult to interpret in this respect ([Hägg, 1992](#); [Mathiassen, 1993](#)).

Changes in stress regulatory systems were measured using sAA and HRV indices reflecting different branches of the autonomic nervous system. We collected saliva through a passive drooling technique, which has the advantage of taking the whole saliva production into account ([Rohleder and Nater, 2009](#); [Nagy et al., 2015](#)), which absorbent materials will not do ([Salimetrics, 2009](#)).

Our study population included healthy, young women, and results may not be readily transferable to women of other age groups or to men. Studies suggest that motor control strategies, especially during low-intensity tasks, differ between women and men ([Johansen et al., 2013](#); [Srinivasan et al., 2016b](#)). Regarding age, some studies report that older individuals exhibit greater force fluctuations and greater decreases in cognitive and mental load in response to concurrent physical and mental activity compared with the younger ([Voelcker-Rehage et al., 2006](#); [Pereira et al., 2015](#)).

### Ecological validity

We argue that the physical task and CT investigated here have good ecological validity. Pipetting is performed by,

for instance, biomedical analysts ([Sadeghian et al., 2014](#)) and serves as a valid model of repetitive, low-force work engaging the upper extremity ([Björkstén et al., 1994](#); [Fredriksson, 1995](#); [Buczek et al., 2013](#)). Similar low-intensive, repetitive, and constrained tasks performed using the arms and hands also occur in other occupations, including light industrial assembly ([Bosch et al., 2007](#)) and retail ([Bonfiglioli et al., 2007](#)). This task has been used in several controlled studies investigating physiological responses and motor variability during low-force work ([Srinivasan et al., 2015a,b](#); [Samani et al., 2017](#); [Sandlund et al., 2017](#); [Mixer et al., 2019](#)). In striving to avoid a too cognitively demanding physical task, we had participants performing the pipetting task in a regular, sequential, clockwise pattern. We used a CT that could be manipulated in a controlled way to present different cognitive loads. In line with previous research showing significant differences in cognitive load between *n*-back difficulty levels ([Herff et al., 2014](#)), we found performance to differ significantly between the easy (1-back) and difficult (3-back) levels. *N*-back was also chosen for involving occupationally relevant requirements, i.e. executive functioning of the working memory, including maintaining, updating, and retrieving information ([Kane et al., 2007](#); [Diamond, 2013](#)). This complexity of demands may offer a more appropriate model of cognitive processes in occupational settings than, for instance, simple span tasks ([Colom et al., 2006](#)).

Obviously, real-life occupational settings include factors of relevance to fatigue and stress that cannot be evaluated using an experimental design, such as psychosocial factors associated with leadership and social support ([Bakker and Demerouti, 2007](#); [Jarczok et al., 2013](#)). Moreover, our results may not be readily transferable to occupations where repetitive work tasks are performed with a higher physical intensity than that required in pipetting, such as meat-cutting ([Christensen et al., 2000](#)) and flight baggage handling ([Wahlström et al., 2016](#)). Also, the strictly controlled, regular, and frequent alternations may not truly reflect a real occupational setting, where temporal patterns of alternations are likely to vary more. In a field study ([Jahncke et al., 2017](#)) of occupations where alternations between physical and mental tasks occurred as part of the work, workers reported to have 3.7 such alternations per day. Thus, even the long-cycle condition of our study (14 + 6 min of pipetting + CT) may not adequately mimic the fluctuations between fatigue and recovery of ordinary workdays. To this end, cycle times beyond 20 min might have led to a more pronounced physiologic response than that observed in the present study, even if the very weak effects of the temporal pattern on increase in

EMG amplitudes across WBs suggest that no major effects of longer cycle times would be expected. The experimental sessions investigated here totaled ~2 h, i.e. one-quarter of a standard workday. Although it would have been interesting to increase the time, practical reasons made it unfeasible to expand experimental sessions beyond 4 h.

Although the study design, including its strictly controlled and relatively frequent alternations, may not be readily transferable to an occupational practice, we argue that our study contributes to a useful understanding of the effects of temporal patterns in alternating tasks on fatigue and stress. Thus, future studies devoted to alternations between physical task and CT should address the development and implementation of job rotation schemes including such alternations in real occupational settings.

### Conclusions

This study showed that the temporal pattern of alternations between a low-force, repetitive physical task (pipetting) and a CT (*n*-back) only influenced indicators of perceived fatigue, performance fatigue, and stress to a small extent. Performance in both an easy and a difficult version of the CT was maintained throughout both long- and short-cycle protocols, and performance in the physical task did not decrease. These findings corroborate previous research (Mixer *et al.*, 2019, 2020) suggesting that alternating between physical and cognitive work tasks may represent an alternative to a ‘classic’ job rotation between physical tasks only, since it offers the opportunity to recover from physical fatigue, while also maintaining productivity.

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### Disclaimer

The authors declare no conflict of interest relating to the material presented in this article.

### Data availability

The data underlying this article cannot be shared publicly for the privacy of individuals participating in the study. The data

may be shared on reasonable request to the corresponding author.

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