Universiteit Leiden

Psychologie
Faculteit der Sociale Wetenschappen

Effects of physical load on cognitive performance in the military field

TNO innovation for life

Ministerie van Defensie

Name: L. M van Peppen, s1011952

Internal supervisor: Drs. W. L. G. Verschuur

External supervisor: Dr. M. H. P. H. van Beurden

Cognitive Psychology

Thesis Msci Applied Cognitive Psychology

Introduction

Defence aims to a successful and responsible use of the military. Therefore it is important to train the military and to gain insight into processes of performance. Soldiers often have to perform complex tasks in extreme conditions, sometimes approaching or exceeding the limits of their capabilities. These complex tasks are influenced by many (inter-)related factors (Valk, 2013; Valk & Veenstra, 2010). This study will focus on the effects of workload, and particular physical load, on cognitive performance.

Workload

Workload is the result of the achievement of a particular level of performance on a task with specific demands, depending on the capacities of the individual. The cost incurred by the individual is the workload (Hart & Staveland, 1988, as cited in DiDomenico & Nussbaum, 2008). As defined by DiDomenico and Nussbaum (2008), “workload is determined by the interaction of the task demands, the circumstances under which it is performed and the skills, behaviors and perceptions of the individual” (p. 1). The task demands may consists of physical and cognitive tasks.

There is significant inconsistency among researchers concerning overlapping aspects of stress and workload. Both concepts include the interaction between demands and resources. However, most researchers provide evidence that workload is believed to be much more than that (Staal, 2004). The majority of studies on workload and stress has shown that both workload and stress can result in reduction of attention, working memory, perceptual motor performance and judgment and decision making. The latter can result in hypervigilance, an enhanced state of sensory sensitivity (Staal, 2004). Reduction in attention is characterized by reduction of cue utilization and decrement of the functional visual field, known as the tunneling hypotheses (Easterbrook, 1959, as cited in Staal, 2004; Martens & van Winsum, 2000).

Cognitive workload

A component of workload is cognitive workload. Cognitive workload is determined by the ratio between the required and the available processing capacity of the task executor (Gaillard, 1996, as cited in Veltman & Neerincx, 2003). Influential aspects of cognitive workload are the task demands and the momentary processing capacity. High cognitive workload appears when task demands are approaching the limits of the processing capacity, which is called overload (Veltman & Neerincx, 2003). Mental effort is required to fulfill the task demands. Physiological reactions to this process are an increase in heart rate frequency, an increase in respiratory rate and a reduction in eye blinking (Veltman & Gaillard, 1998, as cited in Veltman & Neerincx, 2003).

TNO Human Factors has developed the ‘kubus model’ to predict cognitive workload, based on the cognitive load theory (CLT; Paas, Renkl & Sweller, 2004; Sweller, Ayres & Kalyuga, 2011;

Sweller, Van Merriënboer & Paas, 1998, as cited in Choi, Van Merriënboer & Paas, 2014). The ‘kubus model’ describes three factors in a cube: time occupied, task-set switching and level of information processing. Cognitive workload is determined by the combination of the three load factors (Neerincx & Van Besouw, 2000). As shown in figure 1, human activities can be projected in a 3-dimensional space with regions indicating underload and overload.

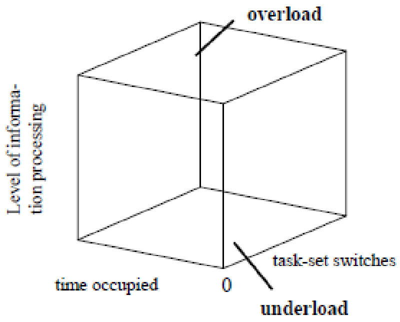

Figure 1. The ‘Kubus model’

Physical load

Workload is also determined by physical load, which depends on the degree and duration of exercise. Several studies have described a negative effect of physical activity on cognitive performance, possibly as a result of fatigue (Gutin, 1973, Isaacs & Pohlman, 1991, Hancock & McNaughton, 1986, McMorris & Keen, 1994, Salmela & Ndoye, 1986, Tomporowski, Ellis & Stephens, 1987, as cited in Hogervorst, Jeukendrup & Jolles, 1996). However not all studies found this negative effect. The various results are difficult to compare, because of differences in the studies with regard to the population and to the cognitive and physical tasks (Hogervorst, Jeukendrup & Jolles, 1996).

Different theories about physical load and the influence on general performance are developed. Yerkes and Dodson (1908) developed the inverted U-hypotheses, which suggested that as physical load increases, performance improves up to an optimal point and thereafter decreases with further increases in physical load (Tomporowski & Ellis, 1986). For many years, it has been argued that low intensity and high intensity exercise would result in poor cognitive performance while performance would be optimal during moderate intensity exersice (Draper, McMorris & Parker, 2010). However, there is little evidence for such an effect. The drive-theory hypotheses suggest that performance increases linearly with physical load (Spence & Spence, 1996, as cited in Tomporowski & Ellis, 1986).

Effects of physical load on cognitive performance depend on the intensity, type and duration of the performing exercise (Tomporowski & Ellis, 1986). It is difficult to compare results of the impact of a particularly intensity of exercise because there is no objective means to determine the intensity. However, most research has shown that steady-state aerobic exercise results in improvement of cognitive performance. It seems like intense aerobic exercise does not impair cognitive functioning (Tomporowski, 2003). In addition, it is shown that jogging results in higher workload than walking and standing (Perry, Sheik-Nainar, Segall, Ma & Kaber, 2006). The impact of exercise on performance is determined by the current level of physical activity and level of experience of the individual. Tomporowski (2003) has shown that physically fit individuals perform better on cognitive tasks than less physically fit individuals. Furthermore, the effect of physical load on cognitive performance depends on motivational factors and the dominant state brought by exercise: physical fatigue or arousal of the central nervous system (Tomporowski & Ellis, 2003).

Physical load and aspects of cognition

Effects of physical load on cognitive performance depend on the type of tasks, in which a difference can be made between simple cognitive tasks and complex cognitive tasks. Simple cognitive tasks includes detection, visual search and choice-responses. The speed of information processing in these tasks is likely to increase during physical load (Hogervorst, Jeukendrup & Jolles, 1996; Tomporowski, 2003). A distinction can be made between simple reaction time and choice reaction time. Draper, McMorris and Parker (2010) have shown that both are affected differently by differing exercise intensities. Simple reaction time was not significantly affected by increases in exercise while choice reaction time showed a significant linear decrease with increasing intensity. However, not all studies have found similar effects on simple reaction time (Guizani et al, 2006; Brisswalter et al, 1997, Davranche et al, 2006; McMorris & Keen, 1994; as cited in Draper, McMorris & Parker, 2010).

Dissimilar effects of physical load occur on complex tasks, which require a great deal of resources of the central nervous system, such as problem-solving and decision making (Hogervorst, Jeukendrup & Jolles, 1996; Mozrall & Drury, 1996, as cited in DiDomenico & Nussbaum, 2011; Murray & Russoniello, 2012; Tomporowski, 2003). It is hypothesized that this effect arise because fatigue mainly affects complex cognitive tasks (Fleury, Bard & Carriere, 1981, as cited in Hogervorst, Jeukendrup & Jolles, 1996). Furthermore, physical arousal results in facilitating the performance of well-learned tasks (Graydon, 2000, as cited in Tomporowski, 2003).

Assessment of workload

Cognitive workload is measured by subjective and objective assessment tools. There is inconsistency among researchers about the relationship between subjective and objective measures. Some demonstrated a strong relationship where others failed to find any significant correlation (Gopher and Braune, 1984, as cited in Staal, 2004). Subjective measurements, usually rating-scales, can provide detailed conclusions concerning the individuals' workload. The advantage of objective measurements is that they are suitable for practical applications in the field. Objective measurements for cognitive workload can be divided into brain-related measures, eye-related measures and heart-related measures (Ryu & Myung, 2005). It seems useful to obtain measurements of various elements of workload, as proposed by the multiple resources model (Wickens and Hollands, 2000, as cited in Ryu and Myung, 2005).

Physical load is also measured by subjective and objective assessment tools. Subjective measurements of physical load are self- or interviewer administered recall of physical load, obtained by questionnaires or interviews. Subjective measurements are easy to apply and offer a low cost per observation but have limitations in terms of recall and response bias (Kohl, Fulton & Caspersen, 2000; Prince et al., 2008). Most used subjective measurements are scales like the ratings of perceived exertion, developed by Borg in 1962. Heart rate and blood lactate concentration are examples of physiological measures that correlate with perceived exertion (Borg & Kaijser, 2006). Objective assessments tools consist of calorimetry, physiologic markers, motion sensors and monitors and direct observation. These measurements are more precise and accurate than subjective measurements (Prince et al., 2008). The different physical load assessment tools are not measuring identical components and therefore it could be useful to use various methods to obtain a more complete assessment of physical load (Kohl, Fulton & Caspersen, 2000).

There is a growing number of tasks that include both physical and mental aspects, particularly with the ongoing implementation of technology. Over the last few decades, several cognitive workload and physical load assessment tools are developed and validated. Although cognitive workload and physical load influences many similar processes, little attention is paid to this fact in the development of assessment tools. Little is known about the validity of the assessments tools during situations that require concurrent physical and mental demands.

Research Questions & Hypotheses

A decrease in cognitive performance can have great impact and it is therefore important to gain more insight into influencing factors of cognitive performance. Preventive action and early recognizing of decrements in cognitive performance are important to optimize the employment of Defence staff. Scientific research has shown that physical load can affect cognitive performance. However, there are conflicting findings concerning the exact relationship between physical load and cognitive performance. Furthermore, little is known about the effect and assessment of physical load on specific aspects of cognition.

In this study the following questions will be examined: *'What is the effect of physical load on cognitive performance and does the degree of physical load plays a role?* and *'Is the effect of physical load on cognitive performance similar in different aspects of cognition?'* and if there is an effect of physical load on (aspects of) cognitive performance '*Does the participants' level of cognitive* *performance and experienced physical load plays a role?'* The corresponding hypotheses, based on results from earlier research, are:

1. Physical load improves overall cognitive performance.
2. Physical load increases attention.
3. Physical load increases memory.
4. Physical load decreases set shifting.
5. Physical load decreases problem-solving.
6. Participants' level of cognitive performance affects an effect of physical load on cognitive performance.
7. Participants' level of experienced physical load affects an effect of physical load on cognitive performance.

Methods

Participants

The purpose is to recruit 24 physical fit individuals to participate in this study. Participants will be recruited by TNO Human Factors. A maximum of 24 participants was necessary due to material and money restrictions. Participants have to sign an informed consent form describing the study protocol and have to be approved by the ethical committee of TNO Human Factors.

Experimental Design

A crossover design is used with one independent variable: level of physical load. Three conditions are created, based on the levels of physical load. Furthermore, a baseline condition is presented. A pilot study is done to choose the physical load levels. All participants first complete the baseline condition to familiarize themselves with the cognitive tasks. Thereafter, participants complete the three physical load conditions, differing in level of physical load. They are assigned to this conditions in a randomly assigned order. As a result, six groups exist, differing in the sequence of the conditions (figure 1). Each condition includes five cognitive tasks performed at a different level of physical load.

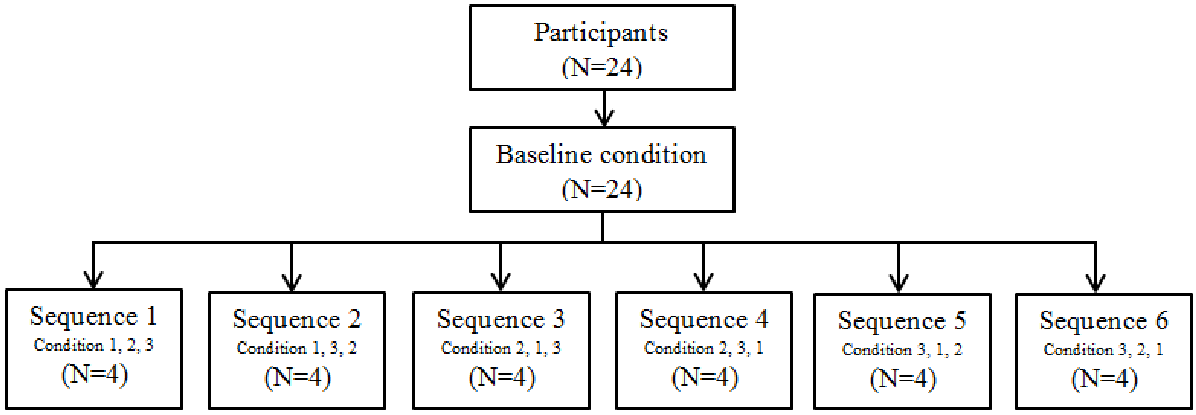

Figure 1. The experimental design

Physical load is controlled at three levels: no physical load, low physical load and high physical load. These levels are created by adjusting the weight of physical load on a bicycle ergometer. Therefore a formula, developed by TNO Human Factors, based on participants' body weight is used: $body\ weight \times n$. The n can vary between 0.8 (very light) and 1.5 (extremely high). The first level has no addition of physical load. The low physical load level is determined by $body\ weight \times 1$. The high physical load level is determined by $body\ weight \times 1.4$.

Procedure

The experiment lasts from 9.00 a.m. until 18.00 p.m. over two weeks and starts in week 7 of 2015. Experimental trials are conducted at TNO Soesterberg. The room is completely adapted in order to create a decent atmosphere. All participants are encouraged by the same supervisor during all stages of the test. They are given written instructions describing all procedures related to the study but are naïve of its aims and hypotheses. Participants' body weights and other important subject characteristics are measured and collected.

The experiment lasts approximately 2,5 hours per participant. Before they start with the experiment, the participants have to relax to ensure they have reached a heart rate close to their resting heart rate. Every condition lasts approximately 30 minutes and a minimum of 5 minutes rest between the conditions is provided to return to the resting heart rate (DiDomenico & Nussbaum, 2008). Participants are listening to music during this heart rate recovery time, to enhance recovery from the intense exercise (Eliakim, Bodner, Meckel, Nemet and Eliakim, 2013). Participants have to complete five different cognitive tasks in every condition: the *n*-back task (working-memory), the Stroop color-word task (attention), Wisconsin Card Sorting task (set shifting) the Tower of London task (problem-solving), the Psychomotor vigilance task (vigilance) and the Peripheral Detection task (detection). These tasks are presented on a computer screen and are performed by using large buttons which were attached to the bicycle ergometer and a small button on the index finger. The order of the cognitive tasks is randomly presented within the conditions to minimize confounding influences.

During each condition, participants are asked to assess their cognitive workload (NASA-TLX), their physical workload (Ratings of Perceived Exertion scale) and their estimated stress (Stress Appraisal Measure). These assessments are provided and filled in by the supervisor. After completing the four conditions, participants have the opportunity to shower and to change clothes. At the end of the study, participants will be debriefed, thanked for their participation and asked not to discuss the study with other participants.

Tasks and measures

In the *n*-back task, a sequence of stimuli is provided on the computer screen. Participants are asked to press the button only when the current stimulus matches a stimulus that was presented *n* items previously. In this experiment, the 2-back version of the task is used. Cognitive performance is measured based on accuracy and reaction time. The *n*-back task requires both the maintenance and manipulation of information in working memory (Gazzaniga, Ivry, Mangun, 2009).

In the Wisconsin Card Sorting Task (WCST), participants are presented with four cards which can vary along three dimensions: number, color and shape. The task is to sort a stack of cards according to a rule of classification. Feedback (‘right’ or ‘wrong’) is provided after each match, enabling the participants to determine the correct rule. This rule is changed without warning after six correct matches. Subsequently, the participants have to shift to a new mode of classification. Cognitive performance, based on set shifting, is measured by the proportion of correct matches (Groome, 2006; Monchi, Petrides, Petre, Worsley & Dagher, 2001).

In the Tower of London task (TLT), two displays with three beads and three pegs of varying heights are presented on the computer screen. Participants are asked to move the beads to copy the pattern shown in the upper display. These beads can only be moved one at a time and can only be moved to a different peg (Shallice, 1982, as cited in Groome, 2006). The number of moves required is used as measure of cognitive performance.

The psychomotor vigilance task (PVT) requires the participants to detect rare occurrences such as an encroaching enemy aircraft (Groome, 2006). To perform the PVT, participants are given a joystick and have to press the button as soon as the signal is detected. The main measurement of cognitive performance in the PVT is the number of missed signals.

The head-mounted Peripheral Detection Task is a visual secondary task that measures effects of workload on the process of selective attention, based on the cognitive tunneling paradigm (Horst & Martens, 2009). These effects are measured by the detection of stimuli at the same height relative to the eye. Participants have to respond as fast as possible to the peripherally presented visual stimulus (red square) by pressing a finger switch. After two seconds, the stimulus disappear. If a response is not detected within these two seconds, this is coded as a missed signal. Higher reaction time (RT) and higher amount of missed signals can be interpreted as the result of higher workload. The PDT can be performed without rotating the head to the direction of the stimulus. Furthermore, little conscious attention is required (Martens & van Winsum, 2000).

Participants provide both objective and subjective assessments of cognitive workload. Objective assessments of cognitive workload are obtained using the head-mounted Peripheral Detection Task (PDT). Subjective assessments of cognitive workload are obtained using the National Aeronautical and Space Administration Task Load Index (NASA-TLX). The NASA Task Load index is a multi-dimensional rating procedure that provides an overall workload score based on six subscales: mental demands, physical demands, temporal demands, performance, effort and frustration (Hart and Staveland, 1988, as cited in DiDomeinco & Nussbaum, 2008). Descriptions are included for each of the subscale. The NASA-TLX is a numerical scale ranging from 0 to 100 with 5-point steps. The overall workload score is based on a weighted average of the subscale. In this experiment, the rating scales are adapted to the military context in order to establish confidence.

Similar to assessment of cognitive workload, participants provide both objective and subjective assessment of physical load. A LifeMonitor (Hidalgo) is used to obtain objective physical load scores. This wearable technology senses, records and processes data measured from the participants. Physiological signs measured by Hidalgo includes heart rate, body position, skin and body temperature, movement and respiration. In this experiment, heart rate is used for further analysis. Subjective assessments of physical workload are obtained using the 6-10 Ratings of Perceived Exertion scale (RPE; Borg, 1970, 1985, 1998, as cited in Borg & Kaijser, 2006) which is widely used in sports and exercise testing. The RPE scale is a numerical scale ranging from 6 (no exertion at all) to 20 (maximal exertion). The range of 6 to 20 follows the general hearth rate of healthy adults by multiplying by 10. Several studies have shown that there is a linear relationship between RPE data and stimulus intensity, heart rates and oxygen consumption during physical activity on a bicycle ergometer (Hassmén, 1991; Noble & Roberts, 1996; Borg, 1998, as cited in Borg & Kaijser, 2006).

Data analysis

The data will be analyzed with SPSS 22.0 statistical software. To describe the demographical variables, descriptive statistics will be used. Frequency tables and histograms will be inspected to investigate the distribution of age and gender. An independent t-test will be conducted to investigate whether the average ages of the groups are similar. This test is suitable for the comparison of the distribution of an interval variable, as age. The chi-square test will be used for the distribution of the nominal variable sex. A confidence level of 95% ($\alpha = 0.05$) will be used in all tests.

A repeated measures ANOVA will be used to test the hypotheses. For the first hypothesis, a 4 (activity) x 6 (sequence) design is used. The within-subjects factor in this analysis is the change between the activity levels. This is the change in cognitive performance for every participant, regardless of the group in which the participant is classified. The between-subjects factor in this analysis is sequence and makes a distinction between ... In order to confirm the first hypothesis, the interaction effect ‘period x condition’ should be significant. If this turns out, the univariate F-tests will be examined to determine which condition reports the greatest reduction in cognitive performance.

The same design will be used to test hypothesis 2 - 5. However, overall cognitive is not the outcome measure in these analyses. The results on the Stroop color-word task, the Psychomotor vigilance task and the Peripheral Detection Task will be used as outcome measure for hypothesis 2. The results on the *n*-back task, the Wisconsin Card Sorting task and the Tower of London will be used respectively as the outcome measures of hypotheses 3, 4 and 5.

Results

Demographic variables

Eleven men and thirteen women participated in this study. The average age of the total group is 27,21 years (*SD* = 5.49) and varies from 18 years to 39 years. One participant only finished high school. The remaining participants finished or study tertiary education program, namely intermediate vocational education (2 participants), higher professional education (7 participants) and university education (fourteen participants).

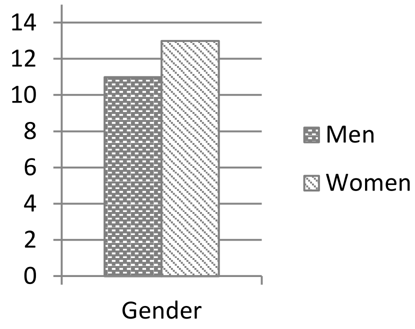

Figure 1. Frequency distribution of gender in the total group.

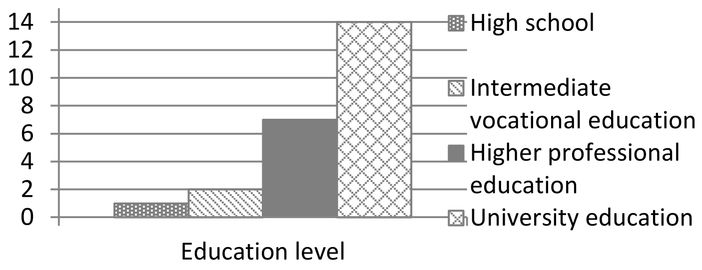

Figure 2. Frequency distribution of education level in the total group.

Outcomes

Repeated measures ANOVAs are conducted with WS-factor 'physical load', five measures of cognitive performance (conscious and selective attention, problem solving, set shifting, working memory) and measures of perceived cognitive workload, perceived physical workload, threat appraisal and the feeling of control. A repeated measures ANOVA including BS-factor 'order' shows that there is no interaction effect of 'physical load x order', $F(15, 48) = .56$, $p = .815$. This implies that differences in change of cognitive performance were not significantly associated with the order of the physical load conditions. Outlier's scores are recoded into the score of the closest non-outlier.

Perceived cognitive workload (NASA-TLX)

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(5) = 19.26$, $p = .002$, therefore Greenhouse-Geisser corrected tests are reported. The results show that perceived cognitive workload was not significantly affected by the level of physical load, $F(3, 63) = 1.55$, $p = .226$.

Four analyses are conducted to discover whether physical load affects perceived cognitive workload on the four cognitive tasks separately. Mauchly's test indicated that the assumption of sphericity had been violated in the analyses of working memory ($p = .006$), set shifting ($p = .012$) and problem solving ($p = .013$), therefore the Greenhouse-Geisser corrected tests are reported. The results show that perceived cognitive workload was not significantly affected by the level of physical load while performing a task based on conscious attention, $F(3, 63) = .90$, $p = .445$, based on working memory, $F(3, 63) = 2.19$, $p = .127$, based on set shifting, $F(3, 63) = 1.04$, $p = .366$, and based on problem-solving, $F(3, 63) = 1.09$, $p = .347$.

Threat appraisal (SAM - threat)

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2 (5) = 17.74$, $p = .003$, therefore the Greenhouse-Geisser corrected tests are reported. The results show that threat appraisal was significantly affected by the level of physical load, $F(3, 63) = 6.54$, $p = .004$. Post-hoc tests and means revealed that threat appraisal is significantly lower while no physical load was present (M = 1.60) compared to threat appraisal during low physical load ($M = 1.80$, $p = .009$) and high physical load ($M = 1.81$, $p = .027$). There was no significant difference in threat appraisal between the low physical load level and the high physical load ($p < .001$).

Four analyses are conducted to discover whether physical load affects threat appraisal for the four cognitive tasks separately. Mauchly's test indicated that the assumption of sphericity had been violated in the analyses of conscious attention ($p < .001$), set shifting ($p = .020$), and problem solving ($p = .019$), therefore Greenhouse-Geisser corrected tests are reported. The results show that threat appraisal was not significantly affected by the level of physical load while performing a task based on conscious attention, $F(3, 63) = 1.397$, $p = .259$, and based on set shifting $F(3, 63) = 2.634$, $p = .077$. However, the results show that threat appraisal was significantly affected by the level of physical load while performing a task based on working memory , $F(3, 63) = 3.603$, $p = .018$. Post-hoc tests and means revealed that threat appraisal was highest when physical load was high ($M = 2.32$), followed by low physical load ($M = 2.30$), no physical load ($M = 2.11$) and the baseline condition ($M = 2.03$). Furthermore, threat appraisal was significantly affected by the level of physical load while performing a tasks based on problem solving, $F(3, 63) = 3.472$, $p = .035$. Post-hoc tests and means revealed that threat appraisal was highest when physical load was high ($M = 1.80$), followed by low physical load ($M = 1.73$), no physical load ($M = 1.60$) and the baseline condition ($M = 1.46$).

Feelings of control (SAM - control)

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2 (5) = 15.73$, $p = .008$. therefore Greenhouse-Geisser corrected tests are reported. The results show that feelings of control were not significantly affected by the level of physical load, $F(3, 63) = .97$, $p = .388$.

Four analyses are conducted to discover whether physical load affects the feeling of control perceived cognitive workload for the four cognitive tasks separately. Mauchly's test indicated that the assumption of sphericity had been violated in the analyses of conscious attention ($p = .007$), and problem solving ($p = .002$), therefore Greenhouse-Geisser corrected tests are reported. The results show that the feeling of control were not significantly affected by the level of physical load while performing a task based on conscious attention, $F(3, 63) = .39$, $p = .687$, based on working memory, $F(3, 63) = 1.35$, $p = .269$, based on set shifting, $F(3, 63) = .06$, $p = .967$, and based on problem solving, $F(3, 63) = 1.14$, $p = .341$.

Perceived Exertion (RPE scale)

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(5) = 23.97$, $p < .001$, therefore Greenhouse-Geisser corrected tests are reported. The results show that the Borg Ratings of Perceived Exertion were significantly affected by the level of physical load, $F(3, 63) = 168.57$, $p < .001$. Post-hoc tests and means revealed that perceived exertion was significantly lower while no physical load was present ($M = 6.42$) compared to low physical load ($M = 10.89$, $p < .001$) and high physical load ($M = 13.04$, $p < .001$). Furthermore, perceived exertion during high physical load was significantly higher compared to low physical load ($p < .001$).

Table 1. Difference in perceived exertion between the physical load conditions considered by the specific cognitive aspects (evaluated with RPE scale).

	Baseline		**No physical load**		**Low physical load**		**High physical load**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Borg RPE scale								
Conscious attention	6.55	1.10	6.27	.70	11.00	1.90	12.91	2.16
Working memory	6.59	1.10	6.45	.86	10.55	1.85	13.00	2.14
Set shifting	6.64	1.14	6.59	1.22	10.41	1.37	12.82	2.09
Problem solving	6.55	1.10	6.41	.80	10.77	1.41	12.64	2.04

The effect of physical load on attention

Repeated measures ANOVAs are conducted to test the hypothesis that physical load increases conscious and selective attention. Mauchly's test indicated that the assumption of sphericity in the analysis of conscious attention had not been violated, $\chi^2(5) = 2.70$, $p = .747$. The results show that conscious attention was significantly affected by the level of physical load, $F(3, 63) = 4.61$, $p = .006$. Post-hoc tests and means revealed that reaction time of conscious attention was significantly lower while physical load was high (*M* = 382.47) compared to no physical load (*M* = 416.38, $p < .001$) and the baseline condition (*M* = 419.13, $p < .001$). Despite the fact that differences between the other conditions were not significant, there was a minor trend observable. Reaction time of conscious attention was lowest during high physical load (*M* = 382.47), followed by low physical load (*M* = 400.78), no physical load (*M* = 416.38) and the baseline condition (*M* = 419.13).

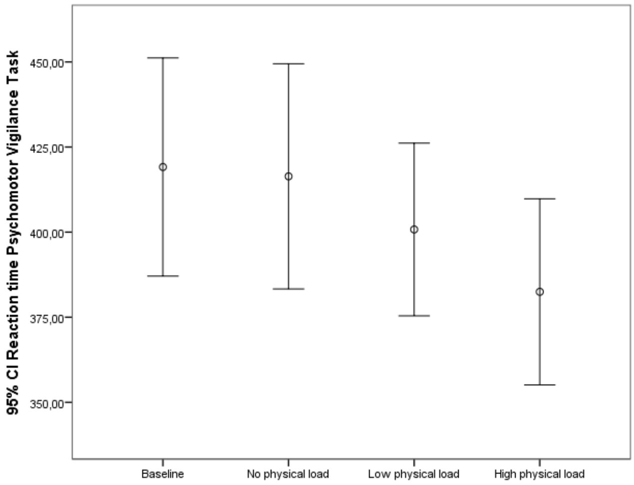

Figure 3. 95% confidence interval of reaction time of conscious attention.

Mauchly's test in the analysis of selective attention indicated that the assumption of sphericity had not been violated, $\chi^2(5) = 6.29$, $p = .279$. The results show that selective attention was significantly affected by the level of physical load, $F(3, 63) = 17.70$, $p < .001$. Post-hoc tests and means revealed that participants missed significantly more cues at the baseline condition ($M = 23.77$) compared to the no physical load condition ($M = 17.48$, $p < .001$) and the low physical load condition ($M = 16.54$, $p = .002$). Despite the fact that differences between the other conditions were not significant, there was a minor trend observable. As physical load increased, selective attention improved up until physical load was low ($M = 16.54$) and thereafter decreased ($M = 19.51$).

In addition to the analysis of the accuracy of selective attention, the speed of selective attention is analyzed. Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(5) = 6.29$, $p = .279$. The results show that the speed of selective attention was significantly affected by the level of physical load, $F(3, 63) = 17.70$, $p < .001$. Post-hoc tests and means revealed that participants had significantly higher reaction times at the baseline condition ($M = 639.77$) compared to the no physical load condition ($M = 561.95$, $p < .001$), the low physical load condition ($M = 568.50$, $p < .001$) and the high physical load condition ($M = 568.68$, $p = 000$). Despite the fact that differences between the other conditions were not significant, there was again a minor trend observable. Reaction times were lowest when there was no physical load and higher – but comparable to each other – when physical load was low or high.

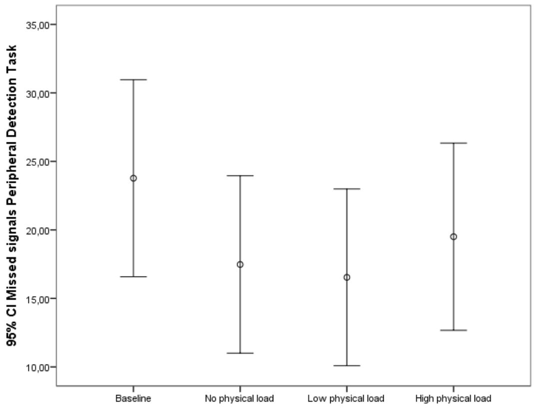

Figure 4. 95% confidence interval of percentage missed signals of selective attention

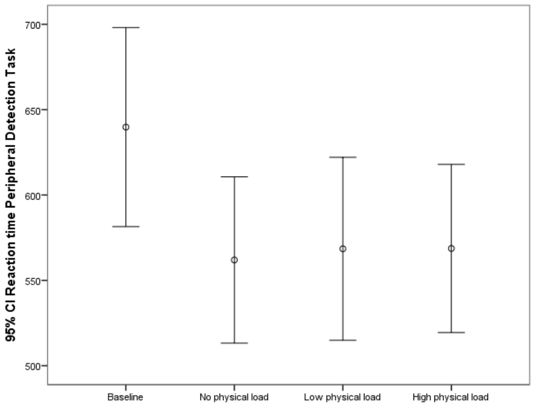

Figure 5. 95% confidence interval of reaction time of selective attention.

The effect of physical load on working memory

Repeated measures ANOVAs are conducted to test the hypothesis that physical load increases working memory. Both accuracy and speed of working memory are included in the analyses. Mauchly's test in the analysis of accuracy of working memory indicated that the assumption of sphericity had not been violated, $\chi^2(5) = 6.63$, $p = .250$. The results show that the accuracy of working memory was significantly affected by the level of physical load, $F(3, 63) = 3.35$, $p = .024$. Post-hoc tests and means revealed that participants were most accurate when physical load was high (M = 55.73). Thereafter, accuracy was highest when there was no physical load (M = 55.45) followed by low physical load (M = 54.59) and the baseline condition (M = 53.32).

Mauchly's test in the analysis of the speed of working memory indicated that the assumption of sphericity had not been violated, $\chi^2(5) = 3.47$, $p = .629$. The results show that the speed of working memory performance was significantly affected by the level of physical load, $F(3, 63) = 5.073$, $p = .003$. Post-hoc tests and means revealed that participants had significantly lower reaction times when physical load was high (M = 621.91) compared to low physical load (M = 692.50, $p = .006$). Furthermore, reaction times were significantly lower when physical load was high (M = 626.09) compared to the baseline condition (M = 684.45, $p = .030$). Despite the fact that differences between the other conditions were not significant, there was a minor trend observable. The results show that the speed of working memory was highest in the high physical load condition (M = 621.91), followed by the no physical load condition (M = 661.82). The speed of working memory was lowest when physical load was low (M = 692.50), followed by the baseline condition (M = 684.46).

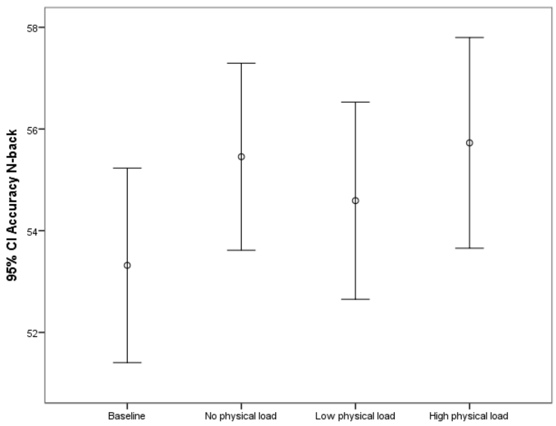

Figure 6. 95% confidence interval of accuracy of working memory.

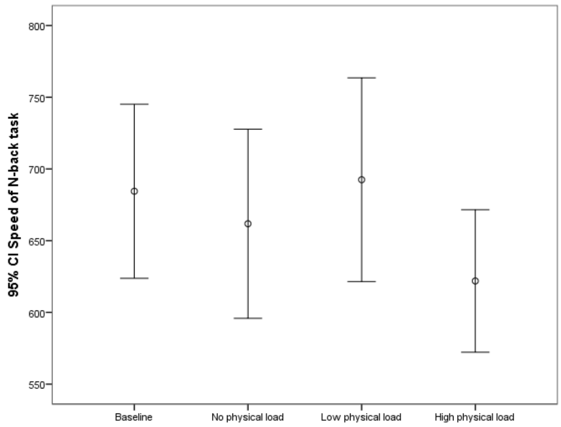

Figure 7. 95% confidence interval of speed of working memory

The effect of physical load on set shifting

A repeated measures ANOVA is conducted to test the hypothesis that physical load decreases set shifting. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(5) = 12.71$, $p = .026$, therefore the Greenhouse-Geisser corrected tests are reported. The results show that set shifting is not significantly affected by the level of physical load, $F(3, 63) = 2.43$, $p = .092$. Despite the fact that the effect of physical load on set shifting is not significant, a trend had been observed. Participants' set shifting performance was most accurate during high physical load ($M = 79.90$), followed by low physical load ($M = 79.42$), no physical load ($M = 76.75$) and the baseline condition ($M = 75.91$). This result implies that physical load increases set shifting and is in contrast with the hypothesis that physical load decreases set shifting.

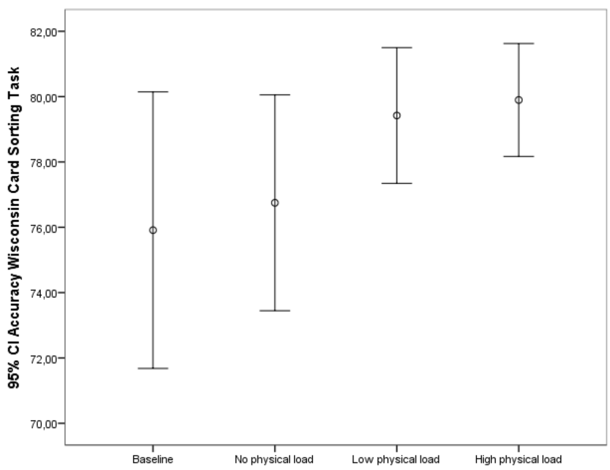

Figure 8. 95% confidence interval of accuracy of set shifting performance

The effect of physical load on problem solving

A repeated measures ANOVA is conducted to test the hypothesis that physical load decreases problem solving. Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 10.59, p = .060. The results show that problem solving is significantly affected by the level of physical load, F(3, 63) = 7.79, p < .001. Post-hoc tests and means revealed that problem solving was best at the baseline condition (M = 17.36) compared to the low physical load condition (M = 20.64, p = .001) and the high physical load condition (M = 20.05, p = .016). Despite the fact that differences between the other conditions were not significant, there was a minor trend observable. Problem solving decreased when physical load is present.

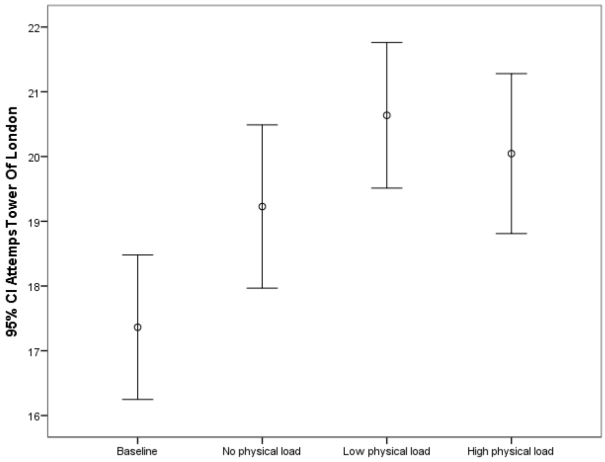

Figure 3. 95% confidence interval of attempts needed for problem solving.

The role of level of cognitive performance

A repeated measures ANOVA is conducted to discover whether the level of cognitive performance has influence on the effect of physical load on cognitive performance. Rank scores – from 1 to 22 – of the five measurements of cognitive performance are assigned to determine the level of cognitive performance. Two groups are created with a median-split on the basis of the average of the five rank scores of cognitive performance. Group 1 includes the lowest cognitive performance scores and group 2 includes the highest cognitive performance scores.

Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 8.44, p = .134. The results of the analysis – with BS-factor 'group' – show that overall cognitive performance is not significantly affected by the level of physical load, F(3, 57) = .01, p = .998. Furthermore, there is no significant interaction effect of 'physical load x group', F(3, 57) = .87, p = .527. Five additional analyses are conducted to discover whether the level of cognitive performance has influence on the effect of physical on the five cognitive tasks separately. Mauchly's test indicated that the assumption of sphericity had not been violated in the analyses. The results show that an effect of physical load on cognitive performance was not significantly affected by the level of cognitive performance while performing a task based on conscious attention, F(3, 60) = 2.19, p = .098, based on selective attention, *F*(3, 60) = .33, *p* = .803, based on working memory, *F*(3, 60) = 1.193, *p* = .320, and based on set shifting, *F*(3, 60) = 2.13, *p* = .105. However, an effect of physical load on problem solving is significantly affected by the level of cognitive performance, *F*(3, 60) = 9.642, *p* = .036.

The role of level of experienced physical load

A Pearson correlation was run to determine the relationship between the Borg RPE Scale and heart rate measures. As shown in table 2, there was a strong, positive correlation between Borg RPE Scale and heart rate measures during the four cognitive tasks, which were statistically significant. This implies that participants who perceived the physical load as highest, also had the highest heart rates and vice versa.

Table 2. Correlations between Borg RPE scale and Heart Rate measures

Measure	Heart Rate			
	Conscious attention	*Working memory*	*Set shifting*	*Problem solving*
Borg RPE Scale	.76**	.77**	.70**	.75**

Note. *p <.01, **p<.001

The alteration between heart rate in the no physical load condition and heart rate in the high physical load condition is determined. Rank scores – from 1 to 22 – are assigned to these scores to determine participants' experience of the heaviness of the experiment. Two groups are created with a median-split on the basis of the rank scores. Group 1 includes participants with the highest alteration in heart rates and group 2 includes participants with the lowest alteration in heart rates.

A repeated measures ANOVA is conducted to discover whether experience of heaviness has influence on the effect of physical load on cognitive performance. Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 8.81, *p* = .117. The results of the analysis – with BS-factor 'group' – show that overall cognitive performance is not significantly affected by the level of experienced physical load, *F*(3, 57) = 1.48, *p* = .229. Five additional analyses are conducted to discover whether the level of experienced physical load has influence on the effect of physical on the five cognitive tasks separately. Mauchly's test indicated that the assumption of sphericity had been violated in the analysis of set shifting, χ^2 (5) = 11.27, *p* = .047, therefore the Greenhouse-Geisser corrected tests are reported. The results show that an effect of physical load on cognitive performance was not significantly affected by the level of experienced physical load while performing a task based on conscious attention, *F*(3, 60) = .941, *p* = .426, based on selective attention,

$F(3, 60) = 2.07$, $p = .114$, based on working memory, $F(3, 60) = .564$, $p = .641$, based on set shifting, $F(3, 60) = 1.61$, $p = .206$, and based on problem solving, $F(3, 60) = 1.92$, $p = .136$.

References

Borg, E. & Kaijser L. (2006). A comparison between three rating scales for perceived exertion and two different work tests. *Scandinavian Journal of Medicine & Science in Sports, 16,* 57-69.

Choi, H-H., Merriënboer, J. G. van, & Paas, F. (2014). Effects of the physical environment on cognitive load and learning: Towards a new model of cognitive load. *Educational Psychology Review, 26,* 225-244.

DiDomenico, A., & Nussbaum, M. A. (2011). Effects of different physical workload parameters on mental workload and performance. *International Journal of Industrial ergonomics, 41,* 255 260.

DiDomenico, A., & Nussbaum, M. A. (2008). Interactive effects of physical and mental workload on subjective workload assessment. *Industrial ergonomicsm 38,* 977-983.

Draper, S., McMorris, T., & Parker, J. K. (2010). Effect of acute exercise of differing intensities on simple and choice reaction time and movement times. *Psychology of Sport and Exercise, 11,* 536-541.

Gazzaniga, M., Ivry, R. B., & Mangun, G. R. (2009). *Cognitive Neuroscience: The biology of the mind.* New York, NY: Norton.

Groome, D., Brace, N., Dewart, H., Edgar, G., Edgar, H., Esgate, A., … Stafford, T. (2006). *An introduction to cognitive psychology: processes and disorders.* Hove, United Kingdom: Psychology Press.

Hogervorst, E., Riedel, W., Jeukendrup, W., & Jolles, J. (1996) Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills, 83,* 479-488.

Horst, R. A. van der, & Martens, M. H. (2009). The Peripheral Detection Task (PDT): On-line Measurement of Driver Cognitive Workload and Selective Attention. In Rupp, G. L. (2010). *Performance metrics for assessing driver distraction: The quest for improved road safety* (pp.73-89). Warrendale, PA: SAE International.

Kohl, H. W., Fulton, J. E., & Caspersen, M. P. H. (2000). Assessment of physical activity among children and adolescents: a review and synthesis. *Preventive Medicine, 31,* 54-76.

Martens, M. H., & Winsum, W. van (2000). Measuring distraction: the Peripheral Detection Task. Proceedings NHTSA: Internet Forum on the safety impact of driver distraction when using in-vehicle technologies.

Murray, N. P., & Russoniello, C. (2012). Acute physical activity on cognitive function: A heart rate variability examination. *Applied Psychophysiology and biofeedback, 37,* 219-227.

Monchi, O., Petrides, M., Petre, V., Worsley, K., & Dagher, A. (2001). Wisconsin card sorting revisited: Distrinct neural circuits participating in different stages of the task identified by event-related functional magnetic resonance imaging. *Journal of Neuroscience, 21*, 7733 7741.

Neerincx, M. A., & Besouw, N. J. P. van (2000). Cognitive task load: a function of time occupied, level of information processing and task set switches (Report TM-00-A047). Retrieved from Digital Library TNO.

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*. 5:56.

Ryu, K., & Myung R. (2005). Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic. *International Journal of Industrial Ergonomics*, *35*, 991–1009.

Staal, M. A. (2004). Stress, cognition, and human performance: A literature review and conceptual framework (Report NO. NASA/TM – 2004 – 212824). Retrieved from Digital Library TNO.

Strauss, G. P., Allen, D. N., Jorgensen, M. L., & Cramer, S. L. (2005). Test-retest reliability of standard and emotional stroop tasks – An investigation of color-word and picture-word versions. *Assessment, 12,* 330-337.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112,* 297-324.

Valk, P. J. L. (2013). Eindrapportage V812 Militair Prestatievermogen en Gezondheidsmonitoring. (Report NO. TNO 2013 R10592). Retrieved from Digital Library TNO.

Valk, P. J. L., & Veenstra, B. J. (2010). Military Performance and Health Monitoring in Extreme Environments. *RTO-MP-IST-123*. Retrieved from Digital Library TNO.

Veltman, J. A., & Neerincx M. A. (2003). Cognitieve taaklast vliegers (Report NO. TM - 03 - A028). Retrieved from Digital Library TNO.