Applied Ergonomics 59 (2017) 274–282

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Individual differences in cardiorespiratory measures of mental workload: An investigation of negative affectivity and cognitive avoidant coping in pilot candidates

Mariel Grassmann [a, b], Elke Vlemincx [b], Andreas von Leupoldt [b], Omer Van den Bergh [b, *]

[a] Department of Aviation and Space Psychology, German Aerospace Center (DLR), Sportallee 54a, 22335 Hamburg, Germany
[b] Research Group on Health Psychology, University of Leuven, Tiensestraat 102, 3000 Leuven, Belgium

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form
6 September 2016
Accepted 14 September 2016

Keywords:
Individual differences
Cardiorespiratory reactivity
Mental workload

ABSTRACT

Cardiorespiratory measures provide useful information in addition to well-established self-report measures when monitoring operator capacity. The purpose of our study was to refine the assessment of operator load by considering individual differences in personality and their associations with cardiorespiratory activation. Physiological and self-report measures were analyzed in 115 pilot candidates at rest and while performing a multiple task covering perceptual speed, spatial orientation, and working memory. In the total sample and particularly in individuals with a general tendency to worry a lot, a cognitive avoidant coping style was associated with a smaller task-related increase in heart rate. Negative affectivity was found to moderate the association between cardiac and self-reported arousal. Given that physiological and self-report measures of mental workload are usually combined when evaluating operator load (e.g., in pilot selection and training), our findings suggest that integrating individual differences may reduce unexplained variance and increase the validity of workload assessments.

1. Introduction

Many laboratory and field studies investigating the assessment of operator load have used physiological parameters as dependent measures in addition to self-report measures of mental workload (e.g., Cain, 2007; Collet et al., 2009; Fallahi et al., 2016; Miyake et al., 2009). However, individuals differ in their physiological responses to an identical level of operator load just as they differ in respective self-reports. Some may perceive a task as threatening while others experience the same task as a challenge. Personality-related ways of coping with challenges and distress can affect physiological activation (Carver and Scheier, 2011; Engel and Talan, 1991; Higgins, 2000; Stemmler and Wacker, 2010) and elicit different psychophysiological patterns in association with emotional and motivational states (Izard et al., 1993; Mischel and Shoda, 1995). While interindividual variation in psychophysiology has been studied extensively in clinical, social, and health psychology, individual differences have little been addressed when studying the psychophysiology of mental workload in the field of human factors and ergonomics.

Szalma (2009), for example, argues for a consideration of motivational, emotional, and personality-related operator characteristics when investigating and developing human factors and ergonomics design methods, objecting against “the general trend […] to represent the human as a ‘black box’ of general cognitive mechanisms, while affective traits and states have been relatively neglected” (p. 382). Whether research is about human-machine interaction or, for instance, pilot selection and training, an incorporation of individual differences would reduce unexplained variance, which is usually treated as error or explained by possible variation in skill and ability.

Numerous studies have been devoted to the cardiovascular measurement of mental workload. Overall, mental workload has been found to increase heart rate with growing task difficulty (Backs and Seljos, 1994; Boucsein et al., 2011; Fournier et al., 1999; Mansikka et al., 2016; Turner, 1989; Veltman and Gaillard, 1998) by affecting vagal and sympathetic pathways to the heart (e.g., Grossman et al., 1990; Porges and Byrne, 1992). The variation of interbeat intervals, also known as heart rate variability, has been

* Corresponding author.
E-mail addresses: mariel.grassmann@ppw.kuleuven.be (M. Grassmann), elke.vlemincx@ppw.kuleuven.be (E. Vlemincx), andreas.vonleupoldt@ppw.kuleuven.be (A. von Leupoldt), omer.vandenbergh@ppw.kuleuven.be (O. Van den Bergh).

http://dx.doi.org/10.1016/j.apergo.2016.09.006
0003-6870/

reported to decrease in response to mental workload (Aasman et al., 1987; Backs and Seljos, 1994; Fallahi et al., 2016; Hansen et al., 2003; Mulder and Mulder, 1981; Mulder, 1992). However, a multitude of inconsistent findings exists that probably result from heterogeneous study designs and from neglecting the role of individual differences (Cain, 2007; Manzey, 1998).

Compared to cardiac parameters, respiration has rarely been investigated as a primary dependent measure in the assessment of operator load. Brookings et al. (1996), however, consider respiration rate to be one of the most sensitive measures of mental task demands. In general, individuals breathe faster when executing complex tasks (Fournier et al., 1999; Vlemincx et al., 2011; Wientjes et al., 1998; Wilson, 1993). Also variability in respiratory behavior (rate, minute ventilation) may be an interesting measure as it is thought to indicate the capability to flexibly adjust to environmental demands (Vlemincx et al., 2013). The total variability of respiration rate is considered to compound a correlated, structured portion that is usually determined on a breath-to-breath basis for a defined period (Tobin et al., 1995) and an uncorrelated, random portion which has been quantified by subtracting the correlated fraction from total variability measures such as statistical variance or the coefficient of variation (e.g., Vlemincx et al., 2011). Whereas cognitive and emotional demands appear to be accompanied by an increasing random variability, internal homeostatic regulation is supposed to cause an increase in correlated variability in order to stabilize the system (Vlemincx et al., 2010). Vlemincx et al. (2012) report that, compared to baseline, sustained attention is characterized by a decrease in total variability of respiration rate and that mental workload, as induced by a mental arithmetic task, is related to a decrease in correlated variability and an increase in total variability of respiration rate. The partial pressure of carbon dioxide (pCO_2) indicates whether ventilation is appropriate to metabolic demands. In the field of aviation, a few studies suggest that end-tidal and transcutaneous pCO_2 levels might be sensitive to workload changes related to characteristic job demands (Harding, 1987; Karavidas et al., 2010; Wientjes et al., 1996). However, individual differences have infrequently been addressed in these studies.

In order to investigate between-subject variation in cardiorespiratory measures of operator load, we will focus on trait characteristics that are considered to play a role in cardiorespiratory arousal measures and that additionally show substantial variation in the target sample of the present study. In a meta-analysis, neuroticism and trait anxiety have been reported in association with decreased cardiovascular reactivity to laboratory-induced stress but also with slower recovery (Chida and Hamer, 2008). Further recent reviews suggest neuroticism (Myrtek, 1998) as well as worry (Brosschot et al., 2006; Ottaviani et al., 2015) to be associated with slightly stronger cardiovascular arousal. Neurotic, anxious, and worried individuals have in common that they are more prone to experience negative emotions and more often concerned about negative cues than individuals with low negative affectivity. However, the divergent results suggest a separate investigation of neuroticism, trait anxiety, and worry.

Among the very few studies that have investigated the relationship between personality traits and respiratory measures under mental workload and stress, Masaoka and Homma (1997, 1999) reported positive correlations between trait anxiety and respiration rate in response to mental stress. Trait anxiety has further been shown to covary with lower respiratory variability during anxious imagery (Van Diest et al., 2006), implying that the respiratory system is less flexible in anxious individuals. Whether negative affectivity accounts for interindividual variation in respiratory responses to mental workload thus requires further investigation.

The small to medium effect sizes which are reported in the reviewing literature on cardiorespiratory reactivity may be due to the combined analysis of different kinds of stressful situations while not considering individual differences in coping with stress. A cognitive avoidant coping style, the general tendency to deal with stressful situations by turning one's attention away from stress-related cues (Krohne, 1996), has been found associated with hypertension (e.g., Rutledge and Linden, 2003) and with elevated cardiovascular reactivity to stress (Kohlmann et al., 1996; Schwerdtfeger and Rathner, 2015; Schwerdtfeger et al., 2005; Weinberger et al., 1979). A meta-analysis on coping strategies in stressful situations indicates, however, that avoidance might be a functional strategy in reducing stress reactions in the short run (Suls and Fletcher, 1985). There are, to our knowledge, no studies available that investigated whether cardiac arousal is likewise attenuated in avoidant coping individuals when dealing with a mentally demanding situation.

For a comprehensive assessment of operator load, physiological measures are often combined with well-established self-report measures of mental workload. Intriguingly, the relationship between autonomic and self-reported arousal has shown ample consistency over time (Schwerdtfeger et al., 2006) and may accordingly be suited to predict future performance of operators. In order to evaluate the combination of physiological and self-report measures of mental workload, we also aimed at investigating whether the relationship between both types of measures is impacted by personality traits. This research question could have particular implications for the selection and training of pilots, given that an accurate self-assessment of mental capacity and performance is one of the core requirements. Empirical findings on mental workload and stress indicate that personality traits, especially negative affectivity and cognitive avoidant coping, moderate the relationship between autonomic reactivity to mental workload and self-reports thereof (Newton and Contrada, 1992; Tomaka and Blascovich, 1994).

In sum, the objectives of our study were to investigate whether personality traits account for individual differences in cardiorespiratory measures under mental workload and to determine the influence of personality traits on the relationship between cardiorespiratory and self-report measures of mental workload. To this end, we assessed basic and variability measures of heart rate and respiration rate as well as pCO_2 in a sample of applicants for pilot training, both during rest periods and multiple task performance. We obtained neuroticism, trait anxiety, and worry in order to cover emotional as well as cognitive aspects of negative affectivity. In addition, we included dispositional avoidant coping as a trait variable. Self-reports of experienced task load and emotional states were taken after resting and task periods to capture individual appraisals. We hypothesized a stronger cardiorespiratory response to mental workload in individuals that are characterized by negative affectivity. Cognitive avoidant coping was expected to be accompanied by reduced levels of cardiorespiratory reactivity. Finally, negative affectivity and cognitive avoidant coping were expected to moderate the link between cardiorespiratory and self-report measures of mental workload.

2. Methods

2.1. Participants

The total sample consisted of 118 male pilot applicants who underwent psychological aptitude testing at the German Aerospace Center (Hamburg, Germany) and volunteered for this study subsequent to their regular assessment. Only healthy candidates who were non-smokers and had refrained from stimulants such as caffeine prior to the experiment were included. The data of three participants were excluded because of movement artifacts. The