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The effect of task demand and incentive on neurophysiological and cardiovascular markers of effort

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ABSTRACT

According to motivational intensity theory, effort is proportional to the level of task demand provided that success is possible and successful performance is deemed worthwhile. The current study represents a simultaneous manipulation of demand (working memory load) and success importance (financial incentive) to investigate neurophysiological (EEG) and cardiovascular measures of effort. A 2 × 2 repeated-measures study was conducted where 18 participants performed a n-back task under three conditions of demand: easy (1-back), hard (4-back) and very hard (7-back). In addition, participants performed these tasks in the presence of performance-contingent financial incentive or in a no-incentive (pilot trial) condition. Three bands of EEG activity were quantified: theta (4–7 Hz), lower-alpha (7.5–10 Hz) and upper-alpha (10.5–13 Hz). Fronto-medial activity in the theta band and activity in the upper-alpha band at frontal, central and parietal sites were sensitive to demand and indicated greatest effort when the task was challenging and success was possible. Mean systolic blood pressure and activity in the lower-alpha band at parietal sites were also sensitive to demand but also increased in the incentive condition across all levels of task demand. The results of the study largely support the predictions of motivational intensity using neurophysiological markers of effort.

1. Introduction

Motivational intensity theory describes those factors and mechanisms that mediate the relationship between task difficulty and energy mobilisation (Brehm and Self, 1989). The basic predictions of this theory have been tested and elaborated through thirty years of research in experimental psychophysiology; for reviews, see Gendolla, Wright & Richter (2012) or Richter et al. (2016). For example, Richter et al. (2008) had participants perform a memory task where presentation duration of target stimuli were manipulated to create a continuum of task difficulty from easy to impossible. They reported that systolic blood pressure (SBP) increased and pre-ejection period (PEP) decreased in response to task demand compared to rest, but only when success was likely or at least possible; there was no significant cardiovascular response when demand was impossible. In recent years, investigations into motivational intensity theory has extended to cover the influence of emotional processing on effort investment (Chatelain and Gendolla, 2015; Silvestrini and Gendolla, 2009) and how perceptions of ability and the presence of fatigue can influence motivation by moderating the assessment of task difficulty (Stewart et al., 2009).

According to Brehm's original theory of motivational intensity (Brehm and Self, 1989), there is a distinction between the level of effort invested in response to demand (motivational intensity) and the maximum effort the individual is willing to invest in order to satisfy a goal or motive associated with the task (potential motivation). The theory makes a crucial distinction between potential motivation defined as a function of success importance and motivational intensity determined by those actions performed in order to achieve task success (Wright, 2008). When the demand of the task is known and fixed, the theory predicts that effort investment is a function of both demand (if success is possible) and success importance (Richter et al., 2016); specifically the proportionate relationship between effort and demand remains unaffected by success importance, the latter exerts its influence by modulating the range of demand levels within which the proportionate relationship holds.

Previous research has explored the contribution of motivational intensity and potential motivation to effort investment by simultaneously manipulating demand and variables related to success importance, such as: instrumentality (Wright et al., 1992), self-focused attention (Silvia, 2015), ego involvement (Gendolla and Richter, 2010) and financial reward (Eubanks et al., 2002). The results of the latter indicated that effort investment (represented by heart rate reactivity) was enhanced by financial reward but only at highest levels of task demand. This pattern (Eubanks et al., 2002) demonstrated how variables that influence

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potential motivation extend the upper range of demand where the proportionate relationship between effort and demand is observed.

With the exception of Richter's work on handgrip studies (Richter, 2015), research on motivational intensity theory is characterised by exclusive reliance on cardiovascular measures to represent effort investment. Early work (Wright, 1996), based on the concept of active coping (Obrist, 1981), emphasised measurement of heart rate and systolic blood pressure as markers of myocardial sympathetic activity presumed to underpin increased effort. Given the extensive use of experimental tasks derived from cognitive psychology in this field, where increased effort represents a response to cognitive demand (e.g. short-term/working memory, perceptual search, sustained attention), it is surprising that neurophysiological activity has not been explored with reference to motivational intensity theory.

Spontaneous changes in the electroencephalogram (EEG) have been studied extensively with reference to attentional control and memory processes. For example, activity in the theta band (4–7 Hz) is broadly distributed across cerebral sites and is specifically associated with high-level cognitive activity, e.g. working memory, novelty detection (Cavanagh and Frank, 2014). Research in cognitive neuroscience on the theta band has focused specifically on activity in the frontomedial region, increased levels of theta in this area were found to increase in a linear fashion with working memory load (Gevins and Smith, 2003); (Onton et al., 2005) and during the execution of skilled motor performance (Sauseng et al., 2007). Increased theta at the frontomedial region has also been associated with successful working memory manipulation (Itthipuripat et al., 2013) and skilled sports performance in basketball (Chuang et al., 2013) and rifle shooting (Doppelmayr et al., 2008). It has been hypothesised that frontomedial theta plays a role in the maintenance of item and temporal order information during memory tasks (Roberts et al., 2013), see critical review (Hsieh and Ranganath, 2014). Others have suggested a generic association between frontomedial theta and those fundamental functions of monitoring and control functions that underpin the process of sustained attention (Clayton et al., 2015).

A number of studies have reported a suppression of alpha activity (8–12 Hz) at parietal sites that accompanies augmentation of frontomedial theta as verbal and spatial working memory demand increased (Gevins et al., 1998). An association between theta and alpha activity during memory processes was initially described by Klimesch (1999) who made a distinction between the lower part of the alpha band (lower-alpha: 8–10 Hz), which was topographically widespread and reflected alertness and general attentional processes, and upper-alpha (10–12 Hz) that was restricted from a topographical perspective and specifically responded to semantic processing. Subsequent research (Shack et al., 2005) described the existence of a fronto-parietal network wherein phase coupling between frontomedial theta and activity in the upper-alpha band were important for processes related to the central executive (theta) and storage processes (upper-alpha). However, the status of upper-alpha activity as a marker of semantic processing has been challenged, it was argued that upper-alpha represented an unspecific form of cortical activation observed during complex mental activity (Berger et al., 2014). It has also been postulated that upper-alpha activity represents a generic and ubiquitous process of active inhibition that is associated with demands on selective attention (Michels et al., 2008; Klimesch, 2012).

The goal of the current study is to investigate changes in frontomedial theta and upper/lower alpha activity when simultaneously manipulating working memory demand and success importance. Participants were required to perform the n-back working memory task at three levels of demand: easy (successful performance highly likely), hard (successful performance possible) and very hard (successful performance highly unlikely). The three versions of the n-back task were performed on two occasions - once in the presence of a financial incentive where good performance could earn significant additional payment and in a no-incentive condition that was presented to participants as a pilot trial where no data was recorded. It was predicted that:

(1) Frontomedial theta will significantly increase in a linear fashion with working memory demand provided that successful performance was likely or possible.
(2) Lower-alpha activity will significantly decrease in linear fashion with increased task demand provided that successful performance was possible.
(3) Upper-alpha activity will significantly decrease with increased task demand as a marker of semantic processing or active inhibition provided that successful performance was likely or possible.
(4) Systolic blood pressure would exhibit an interaction effect between demand and incentive. Systolic BP would increase in a linear fashion with demand in the incentive condition and exhibit a curvilinear relationship with demand in the no-incentive condition.

2. Method

2.1. Participants

20 participants (10 male) took part in the experiment. Two datasets were excluded from analysis due to an excessive preponderance of head movement artefacts in the EEG giving a sample size of $N = 18$ (9 male). Participants were aged between 18 and 33 years with a mean age of 24.25 years (SD 4.13). None of the participants were left handed or ambidextrous according to a modified version of the Hand Usage Questionnaire (Chapman and Chapman, 1987). All participants were free from hypertension, prescribed medication, cardiovascular and neurological conditions. All participants provided informed consent prior to data collection. The procedure for the experiment and data collection protocols was approved by the University Research Ethics Committee prior to commencement of the experiment.

2.2. Working memory task

Effort was elicited with a continuous matching verbal working memory task known as the n-back task, this particular version was based on the one described by Gevins et al. (1998). This task required participants to indicate if the currently presented stimulus matched an earlier stimulus presentation. Stimuli were single capital letters drawn at random from the following group of 12: B,F,G,H,K,M,P,R,S,T,X and Z. Letters were presented in black Arial Bold font size ~48 against a white background on colour monitor at a distance of ~60 cm. A fixation point (5 mm diameter green dot) was present at the centre of the screen for the block duration. Stimuli could appear at 12 possible locations. Each location lay on either of two imaginary (non-displayed) concentric circles, of radii 1 cm and 3.5 cm, centred on the fixation point with six locations that were hexagonally arranged on each circle. Blocks contained 48×2 s trials consisting of a 200 ms stimulus presentation followed by a 1.8 s interval. At the start of each block the fixation was present for 4.5 s prior to onset of the first stimulus, i.e. each block lasted for 100 s. Stimuli were delivered in a random order.

Blocks corresponded with one of three possible working memory loads. Participants were required to indicate whether the letter matched the previous one (1-back: easy), or the letter that had appeared four letters earlier (4-back: hard), or the letter that had appear seven letters earlier (7-back: very hard). This necessitated retention of a sequence of 1, 4 and 7 letters which had to be updated with every new stimulus. Responses were given with a keyboard press of 1 for match and 2 for non-match, using the right index and middle fingers. A response was required for every stimulus and participants were asked to be as fast and as accurate as possible. Match stimuli were present on 40% of all trials.