



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

Stephen H Fairclough <sup>a,\*</sup>, Kate Ewing <sup>b</sup>

<sup>a</sup> School of Natural Sciences and Psychology, Liverpool John Moores University, UK

<sup>b</sup> British Aerospace, UK



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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  $2 \times 2$  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.

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### 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

\* Corresponding author at: School of Natural Sciences & Psychology, Liverpool John Moores University, Tom Reilly Building, Byrom Street, Liverpool L3 3AF, UK.

E-mail address: [s.fairclough@ljmu.ac.uk](mailto:s.fairclough@ljmu.ac.uk) (S.H. Fairclough).

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 appeared 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.

### 2.3. Incentive manipulation

Participants completed easy, hard and very hard versions of the working memory task under two conditions designed to vary the consequences of successful performance. For the no-incentive condition, participants were told they were taking part in a pilot study, this trial would be conducted simply to test the apparatus and performance would not be recorded. For the incentive condition participants were told that: (1) task performance would be recorded and this was a formal trial, and in addition, (2) for each level of working memory demand (easy/hard/very hard), they would receive a £5 (approx. \$7.4 or 6.9€) voucher for good performance, a £10 voucher for very good performance and a £15 voucher for excellent performance. Therefore, the maximum earnings that could be made across all three tasks in the incentive condition were £45/\$67/62€. No guidance was provided to help participants gauge the quality of their performance and there was no feedback of performance accuracy during or after the task.

### 2.4. Experimental measures

The number of correct responses made by participants was scored as a percentage of total number of responses for all three versions of the working memory task. The reaction time for each response was also recorded and averaged for all versions of the working memory task.

Subjective workload after each working memory task was captured using NASA Task Load Index (TLX) (Hart & Staveland, 1988), which consists of six scales (subjective effort, mental demand, temporal demand, physical demand, performance perception and frustration). Self-reported motivation was also assessed after each task using an adapted form of the Motivation scale from Dundee State Stress Questionnaire (DSSQ) (Matthews et al., 1997). This scale contained six items, three that were positively scored (e.g. motivated by the task, enjoyed the task, be upset if performed badly on the task) and three items that were negatively (e.g. eager to do well on task, wanted to succeed on the task, doing the task was worthwhile). Both subjective questionnaires were completed after participants had completed each block of working memory demand.

Systolic blood pressure (SBP) was measured using a CARESCAPE Vital Signs Monitor (V100) that involved placement of an inflatable cuff on the upper left arm. Readings of systolic blood pressure were obtained using the oscillometric method. The apparatus also recorded measures of diastolic blood pressure, heart rate and mean arterial pressure, but these variables are not reported in the current paper. Readings were then taken for each experimental trial 60 s after commencement of the working memory task, giving 2 readings for each condition and subsequently averaged.

EEG was recorded from 64 Ag-AgCl pin-type active electrodes mounted in a BioSemi stretch-lycra head cap. Electrodes were positioned using the 10–20 system and recorded activity from the following sites: frontal pole (FPz, FP1, FP2), anterior-frontal (AFz, AF3, AF4, AF7, AF8), frontal (Fz, F1, F2, F3, F4, F5, F6, F7, F8), frontocentral (FCz, FC1, FC2, FC3, FC4, FC5, FC6), central (Cz, C1, C2, C3, C4, C5, C6), temporal (FT7, FT8, T7, T8, TP7, TP8), parietocentral (CPz, CP1, CP2, CP3, CP4, CP5, CP6), parietal (Pz, P1, P2, P3, P4, P5, P6, P7, P8, P9, P10), occipitoparietal (POz, PO3, PO4, PO7, PO8) and occipital (Oz, O1, O2, Iz). The use of active electrodes prevented signal deterioration through high impedances. AC differential amplifiers amplified signals at source with continuous digitization at 16384 Hz and online down sampling to 256 Hz. No filters were applied online to allow visual inspection of noise, offline filtering was performed using high and low pass filters of 0.05 Hz and 40 Hz respectively and a notch filter of 50 Hz. EEG was recorded continuously throughout a 3 min baseline prior to the task and continuously throughout the task.

Analysis was performed using BESA software (MEGIS software GmbH, Gräfelfing, Germany). A computer averaged montage was applied offline. Data was visually inspected for artefacts from external

electromagnetic sources. Automatic correction of blink artefacts and horizontal and vertical saccades was performed using detection through predefined topographies. Muscle activity over 100 µV was also excluded. An average of 1.7% of analysed data was rejected for each participant due to artefacts. Fast Fourier transforms were computed over 50% overlapping windows of 2 s (512 points). Average power spectra were then computed for each experimental condition by averaging mean FFT results of both blocks for each level. The total power in µV<sup>2</sup> was then obtained for theta frequency band (4–7 Hz), lower alpha frequency band (7.5–10 Hz), upper alpha frequency band (10.5–13 Hz) for each participant. Definition of bands for lower- and upper-alpha were based upon a previous (unpublished) study that employed an Individual Alpha Frequency (IAF) analysis as described by Klimesch (1999). Power spectra values were log transformed (using the natural log) to normalise distribution.

### 2.5. Procedure

Participants attended a training session on the day before the experimental session, the inclusion of pre-trial training was based on the protocol described by Gevins et al. (1997). Training consisted of 11 × 100.5 s blocks of each level of demand. Blocks were delivered in three groups of nine in ascending demand i.e. 3 × 1-back, 3 × 4-back, 3 × 7-back followed by one group of six where blocks were randomised then repeated after a 16 s interval, i.e. 4-back, repeat, 7-back, repeat, 1-back, repeat. Participants were able to take breaks between each group of task blocks and rests between each training block (or training block + repeat in the randomised group) so they could work through training at their own pace. No feedback on performance was provided during the training session. The training session lasted for approximately 2.5 h.

On day two (experimental session) participants completed a group of three random blocks (one of each level of demand) to warm-up then were fitted with EEG equipment. Participants completed a second group of three random blocks (one for each demand) to complete the warm-up. Participants then completed the experimental trials under incentive and no-incentive conditions. The order of presentation of incentive vs. no incentive conditions were counterbalanced across participants. Participants completed six blocks (2 × 3 demand levels) for each incentive condition while performance, subjective and EEG data was recorded. Presentation order of each level of working memory demand (easy, hard very hard) was randomised for each participant. Participants performed each of the six blocks as two consecutive 100 s periods of task activity followed by a 300 s 'break' during which they completed the TLX and subjective motivation scale. Participants were fully debriefed after the experiment.

## 3. Results

All statistical analyses were conducted using SPSS v.21. A priori hypotheses concerning effects for demand and incentive were tested using analyses of variance (ANOVA) and MANOVA. Significant analyses are reported with Greenhouse-Geisser corrections where the assumption of sphericity was violated, as indicated by Mauchly's test. Alpha levels were set at 0.05 for ANOVA model and pairwise comparisons (Bonferroni) on main effects for demand and site. Interaction effects were examined using post-hoc *t*-tests, the alpha level for which were corrected to minimize the possibility of type 1 errors using the Bonferroni adjustment. Effect sizes were calculated using Eta Squared ( $\eta^2$ ) for ANOVA and Cohen's *d* for paired comparisons.

### 3.1. Subjective measures

The six sub-scales of the TLX were averaged to provide a single index representing subjective mental workload. A repeated measures ANOVA revealed a significant main effects for task demand [ $F(2,16) = 15.25$ ,

$p < 0.01, \eta^2 = 0.66$ ] and incentive [ $F(1,17) = 48.77, p < 0.01, \eta^2 = 0.74$ ] on subjective workload. Paired comparisons (Bonferroni) indicated that subjective workload was significantly lower during easy demand compared to hard [ $p < 0.01, d = 0.36$ ] or very hard demand [ $p < 0.01, d = 0.72$ ]; there was also a significant increase of subjective workload from hard to very hard demand [ $p = 0.03, d = 0.31$ ]. It was also noted that subjective workload was significantly higher in the presence of an incentive compared to the no-incentive condition. There was no significant interaction between demand and incentive [ $F(2,16) = 0.57, p = 0.57$ ]. Descriptive statistics for subjective mental workload scores are provided in Table 1.

Scores on items from the DSSQ Motivation sub-scale had a high internal consistency [Cronbach's alpha = 0.93] and were collapsed into a single index of subjective motivation. A  $2 \times 3$  repeated measures ANOVA showed main effects for demand [ $F(2,16) = 20.87, p < 0.01, \eta^2 = 0.72$ ], incentive [ $F(1,17) = 44.01, p < 0.01, \eta^2 = 0.72$ ] and a significant interaction [ $F(2,16) = 19.98, p < 0.01, \eta^2 = 0.71$ ]. As anticipated, subjective motivation increased in the presence of incentive compared to no-incentive condition. Pairwise comparisons also indicated that subjective motivation was highest when working memory demand was easy compared to hard or very hard conditions, see descriptive statistics in Table 1.

Three post-hoc *t*-tests were performed in order to locate significance within the interaction effect (i.e. alpha level of  $p = 0.016$  using Bonferroni adjustment). It was found that subjective motivation was significantly higher during easy demand in the presence of an incentive compared to the no incentive condition [ $t(19) = 7.02, p < 0.01, d = 1.57$ ]; subjective motivation was also significantly higher in the incentive condition for easy vs. very hard levels of task demand [ $t(19) = 8.79, p < 0.01, d = 1.37$ ]. There was no significant change in subjective motivation between easy and very hard levels of demand in the no incentive condition [ $t(19) = 0.62, p = 0.54, d = 0.14$ ], therefore the influence of demand on subjective motivation observed as a main effect was specific to the incentive condition. Descriptive statistics for subjective motivation scores are presented in Table 1.

### 3.2. Task performance

Performance accuracy was scored as the percentage of correct responses as a proportion of the total number of responses made. A  $2 \times 3$  repeated measures ANOVA on accuracy scores revealed main effects for both demand [ $F(2,16) = 124.04, p < 0.01, \eta^2 = 0.94$ ] and incentive [ $F(1,17) = 6.29, p < 0.05, \eta^2 = 0.27$ ]. Post hoc tests indicated that performance accuracy increased in the presence of a financial incentive and a stepwise decline; performance was highest during easy demand compared to hard [ $p < 0.01, d = 2.67$ ] and very hard demand [ $p < 0.01, d = 2.75$ ] and performance accuracy declined during very hard compared to hard demand [ $p < 0.01, d = 1.40$ ]. Descriptive statistics are provided in Table 2.

A  $2 \times 3$  ANOVA was conducted on mean reaction time data, this analysis revealed a significant main effect for incentive [ $F(1,17) = 6.70, p = 0.019, \eta^2 = 0.28$ ] and task demand [ $F(2,16) = 5.53, p = 0.015, \eta^2 = 0.41$ ]; there was no significant interaction effect [ $F(2,16) = 1.27, p = 0.31$ ]. Paired comparisons revealed that reaction time was significantly reduced in the incentive condition compared to no incentive condition. It was also found that reaction time was significantly reduced during the

easy demand compared to hard [ $p = 0.04, d = 0.29$ ] and very hard demand [ $p = 0.01, d = 0.18$ ]. Descriptive statistics for RT data are provided in Table 2.

### 3.3. Systolic blood pressure

Systolic blood pressure was recorded twice for each of six blocks of activity, both readings were averaged and subjected to a  $2 \times 3$  repeated measures ANOVA. This analysis revealed significant main effects for incentive [ $F(1,17) = 15.73, p < 0.01, \eta^2 = 0.48$ ] and demand [ $F(2,16) = 3.53, p = 0.05, \eta^2 = 0.31$ ]. Pairwise comparisons revealed that mean SBP was significantly higher in the presence of an incentive ( $M = 115.62, s.d. = 14.79$ ) compared to the no incentive condition ( $M = 111.86, s.d. = 12.78$ ) [ $p < 0.01, d = 0.18$ ]. With respect to task demand, mean SBP was significantly higher during the hard task ( $M = 115.01, s.d. = 14.14$ ) compared to the very hard task ( $M = 112.33, s.d. = 13.94$ ) [ $p = 0.04, d = 0.13$ ] but neither were significantly different to mean SBP during easy demand ( $M = 113.87, s.d. = 13.28$ ).

### 3.4. EEG data

A subset of EEG sites was selected for statistical analysis moving from the anterior to the occipital region on left and right hemispheric areas. This subset of sites for analyses included: AF7, AF3, AFz, AF4, AF8, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, Oz and O2. It was decided to focus exclusively on frontomedial sites for the analysis of theta activity. For lower- and upper-alpha effects, which could be topographically diverse, it was decided to analyse data in each "row" of electrode sites (i.e. anterior-frontal, frontal, central, parietal, occipital) separately via 2 (incentive)  $\times$  3 (demand) MANOVA models. Multivariate analyses are reported using the Wilks Lambda statistic unless the assumption of sphericity was violated (as indicated by Mauchly's test), in which case, the df were adjusted via Greenhouse-Geisser correction and univariate statistics are reported as in the previous analyses.

#### 3.4.1. EEG activity: theta bandwidth (4–7 Hz)

Theta data from the anterior-frontal sites (AF7, AF3, AFz, AF4, AF8) were analysed via a  $2 \times 3 \times 5$  (site) MANOVA. This analysis revealed a significant main effect for demand and site (see Table 4). Paired comparisons indicated that theta at AF sites was significantly higher during hard [ $M = 0.15, s.d. = 0.55$ ] compared to either easy [ $M = -0.03, s.d. = 0.57$ ] [ $p < 0.05, d = 0.22$ ] or very hard [ $M = -0.04, s.d. = 0.63$ ] demand [ $p < 0.05, d = 0.21$ ]. The significant main effect due to electrode site revealed that theta power was lower at AF3 ( $M = -0.36, s.d. = 0.59$ ) and AF4 ( $M = -0.36, s.d. = 0.64$ ) compared to AF7 ( $M = 0.26, s.d. = 0.49$ ), AFz ( $M = 0.29, s.d. = 0.75$ ) and AF8 ( $M = 0.26, s.d. = 0.49$ ). There were no significant interactions (Table 3).

The same MANOVA model was applied to the frontal sites (F7, F3, Fz, F4, F8). This analysis revealed significant main effects for demand and site plus a significant interaction between site and incentive (see Table 4). Pairwise comparisons revealed that theta was significantly higher during hard demand ( $M = 0.51, s.d. = 0.46$ ) compared to easy ( $M = 0.42, s.d. = 0.45$ ) [ $p = 0.04, d = 0.13$ ] and very hard demand ( $M = 0.40, s.d. = 0.47$ ) [ $p = 0.03, d = 0.16$ ]. The effects of working memory demand and incentive on activity in theta bandwidth is illustrated in Fig. 1. The main effect for site indicated that theta power was highest at Fz ( $M = 0.89, s.d. = 0.55$ ) compared to all other sites [ $p < 0.01$ ]: F7 ( $M = 0.49, s.d. = 0.44$ ), F3 ( $M = 0.17, s.d. = 0.53$ ), F4 ( $M = 0.35, s.d. = 0.63$ ) and F8 ( $M = 0.32, s.d. = 0.39$ ); theta at F7 was also significantly higher than all other sites with the exception of Fz [ $p < 0.01$ ]. The interaction between electrode site and incentive revealed that theta power at F4 was significantly higher in the presence of an incentive ( $M = 0.40, s.d. = 0.64$ ) compared to the no incentive condition ( $M = 0.30, s.d. = 0.62$ ) [ $t(17) = 2.40, p = 0.03, d = 0.11$ ].

**Table 1**

Descriptive statistics for subjective workload and motivation (N = 18).

		Easy	Hard	Very hard	Average
TLX	Incentive	4.99 [1.65]	6.04 [1.64]	6.65 [1.66]	5.90 [1.51]
	No incentive	3.15 [1.89]	3.76 [1.69]	4.37 [1.14]	3.76 [1.39]
	Average	4.07 [1.60]	4.90 [1.42]	5.52 [1.17]	
Motivation	Incentive	45.39 [6.77]	32.78 [5.99]	33.17 [4.27]	37.11 [4.29]
	No incentive	31.50 [4.12]	30.06 [4.78]	30.61 [4.83]	30.72 [3.37]
	Average	38.44 [4.49]	31.42 [4.29]	31.89 [3.21]	

**Table 2**

Descriptive statistics for performance accuracy and mean reaction time (N = 18).

		Easy	Hard	Very hard	Average
Performance accuracy (%)	Incentive	97.27 [1.65]	79.66 [8.64]	61.36 [6.29]	79.43 [5.53]
	No incentive	89.53 [13.55]	73.71 [11.13]	58.23 [10.07]	73.82 [11.57]
	Average	93.40 [7.60]	76.69 [9.89]	59.80 [8.18]	
Mean RT (ms)	Incentive	729.95 [207.47]	826.63 [254.40]	796.14 [242.54]	784.24 [217.17]
	No incentive	803.45 [229.51]	885.24 [276.66]	919.16 [214.14]	869.28 [221.58]
	Average	766.70 [197.54]	855.94 [247.19]	857.65 [213.44]	

### 3.4.2. EEG activity: lower alpha bandwidth (7.5–10 Hz)

Alpha activity in the lower bandwidth was subjected to analyses via MANOVA at five ‘bands’ of electrode sites, which were located at: anterior-frontal (AF7, AF3, AFz, AF4, AF8), frontal (F7, F3, Fz, F4, F8), central (T7, C3, Cz, C4, T8), parietal (P7, P3, Pz, P4, P8) and occipital (O1, Oz, O2). A 2 × 3 MANOVA was performed at each of the five bands. No significant effects were found with the exception of the analysis of parietal sites, summary of MANOVA is reported in Table 5.

The main effect for incentive revealed that lower-alpha power in the parietal sites was significantly reduced in the presence of an incentive ( $M = 1.66$ , s.d. = 0.95) compared to the no-incentive control ( $M = 1.78$ , s.d. = 1.03) [ $p < 0.01$ ,  $d = 0.08$ ]. It was also found that lower-alpha power was significantly reduced during hard demand ( $M = 1.58$ , s.d. = 0.96) compared to either easy ( $M = 1.78$ , s.d. = 1.00) [ $p = 0.02$ ,  $d = 0.14$ ] or very hard demand ( $M = 1.79$ , s.d. = 1.04) [ $p = 0.01$ ,  $d = 0.14$ ]. The main effect for site indicated that lower-alpha power at P3 ( $M = 1.44$ , s.d. = 1.06) was significantly lower than Pz ( $M = 1.73$ , s.d. = 1.08), P4 ( $M = 1.81$ , s.d. = 1.10) and P8 ( $M = 1.93$ , s.d. = 1.05) [all,  $p < 0.01$ ] but did not differ from power at P7 ( $M = 1.66$ , s.d. = 0.89). The main effects for incentive and demand are illustrated in Fig. 2.

Four post-hoc *t*-tests were conducted to explore the interaction effect between incentive and site with alpha level adjusted to  $p = 0.012$ . These analyses revealed that lower-alpha was significantly reduced during incentives at all sites with the exception of the two peripheral sites of P7 and P8, see Table 6 for summary of tests and descriptive statistics.

### 3.4.3. EEG activity: upper alpha bandwidth (10–12.5 Hz)

Alpha activity in the upper bandwidth was subjected to an identical series of MANOVA analyses as described for the lower bandwidth. No significant effects were found at anterior-frontal and occipital sites. The results of the MANOVA at frontal, central and parietal sites are summarised in Table 7.

Descriptive statistics and pairwise comparisons for the significant main effect of demand are summarised in Table 8. These analyses revealed a consistent suppression of power in the upper-alpha band during the hard (4-back) task compared to the easy (1-back) task; the equivalent effect was noted for the very hard (7-back) task at frontal and parietal sites, but no significant differences were found between hard and very hard levels of demand.

The main effect for site revealed that upper-alpha power at F7 ( $M = 0.96$ , s.d. = 0.76) was significantly higher than all other sites: F3 ( $M =$

0.59, s.d. = 0.80), Fz ( $M = 0.79$ , s.d. = 0.80), F4 ( $M = 0.63$ , s.d. = 0.80), F8 ( $M = 0.77$ , s.d. = 0.65) [ $p < 0.01$ ]; power at F3 was also lower than Fz [ $p < 0.01$ ]. A similar effect was found at central sites as upper-alpha power at T7 ( $M = 1.16$ , s.d. = 0.75) was significantly higher than C3 ( $M = 0.61$ , s.d. = 0.75), Cz ( $M = 0.71$ , s.d. = 0.71), C4 ( $M = 0.89$ , s.d. = 0.71) and T8 ( $M = 0.91$ , s.d. = 0.69) [ $p < 0.01$ ]; in addition, power at C3 was significantly lower than C4 and T8 [ $p < 0.01$ ]. This pattern was reversed at parietal sites where alpha power was significantly higher at P8 ( $M = 1.54$ , s.d. = 0.85) compared to Pz ( $M = 1.23$ , s.d. = 0.97), P3 ( $M = 1.15$ , s.d. = 0.95) and P7 ( $M = 1.35$ , s.d. = 0.75) [ $p < 0.01$ ]; power at P4 ( $M = 1.48$ , s.d. = 0.97) was also significantly higher than Pz and P3 [ $p < 0.01$ ].

## 4. Discussion

The goal of the study was to investigate changes in EEG activity and mean SBP in response to working memory demand while manipulating the consequences of successful performance. A manipulation check using subjective mental workload (Table 1) demonstrated a significant differentiation between easy, hard and very hard levels of demand experienced by participants. Furthermore, the analysis of response accuracy confirmed that demand manipulation represented an appropriate range of demand, from easy (approx. 93% correct) to very hard (approx. 60% correct), accuracy fell in a linear and equidistant fashion by approximately 16.8% from easy to hard and from hard to very hard (Table 2). The addition of a financial incentive increased both subjective motivation and mental workload (Table 1), the TLX scale used to measure the latter included sub-scale on level of effort investment, which explained the sensitivity of this scale to the incentive manipulation. As expected, subjective motivation declined as working memory demand increased (Table 2), however, this effect was specific to the incentive condition and subjective motivation remained unaffected by demand in the no-incentive condition (Table 2). It should be noted that participants were instructed that they would be taking part in a pilot study and no data would be collected in the no-incentive condition, hence subjective motivation indicated that our participants effectively disengaged motivation from the demand manipulation when the task was presented as an inconsequential pilot trial.

Previous research revealed a linear increase of heart rate as demand increased from easy to extremely challenging when a large financial reward was available (Eubanks et al., 2002), others reported a curvilinear trend in systolic blood pressure under standard experimental conditions when participants were paid a stipend for their time (Richter et al., 2008). The current study found a significant increase of mean SBP

**Table 3**

Summary of MANOVA on theta power at AF sites (N = 18).

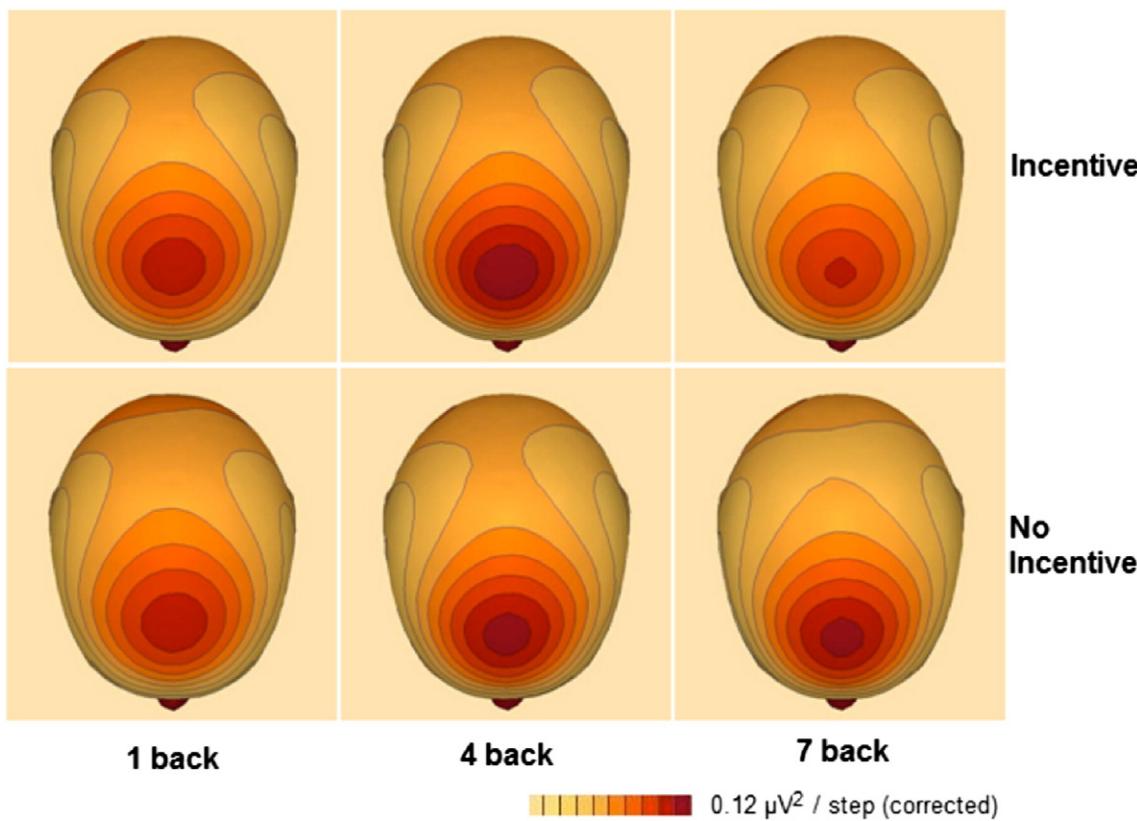
	F	df	Sig	$\eta^2$
Incentive (i)	0.66	1,17	0.43	
Demand (d)	<b>10.60</b>	<b>2,16</b>	<b>&lt;0.01</b>	<b>0.57</b>
Site (s)	<b>17.27</b>	<b>4,14</b>	<b>&lt;0.01</b>	<b>0.83</b>
i*d	1.51	2,16	0.25	
i*s	1.15	4,14	0.37	
d*s	1.14	8,10	0.41	
i*d*s	1.05	8,10	0.45	

Bold values denote effects that are statistically significant ( $p < .05$ ).**Table 4**

Summary of MANOVA on theta power at F sites (N = 18).

	F	df	Sig	$\eta^2$
Incentive (i)	0.71	1,17	0.41	
Demand (d)	<b>3.82</b>	<b>2,16</b>	<b>0.04</b>	<b>0.32</b>
Site (s)	<b>22.40</b>	<b>4,14</b>	<b>&lt;0.01</b>	<b>0.87</b>
i*d	0.98	2,16	0.39	
i*s	<b>3.22</b>	<b>4,14</b>	<b>0.05</b>	<b>0.47</b>
d*s	0.51	8,10	0.82	
i*d*s	1.17	8,10	0.39	

Bold values denote effects that are statistically significant ( $p < .05$ ).



**Fig. 1.** Grand average ( $N = 18$ ) topographic distribution of spectral power in the Theta bandwidth (4–7 Hz) for easy (1-back), hard (4-back) and very hard (7-back) levels of working memory demand ( $N = 18$ ).

in the presence of an incentive and that SBP was significantly lower during very hard demand compared to hard demand. While the effect of the incentive manipulation on mean SBP was pervasive, it did not influence the pattern of relationship between effort and demand; the contrast between incentive and no-incentive conditions merely increased mean SBP. There are a number of factors that explain the absence of any equivalent interaction effect for mean SBP. In the first instance, [Eubanks et al. \(2002\)](#) reported a linear effect when demand and incentive were combined for heart rate only, mean SBP was measured but did not reveal any significant interaction. Secondly, the manipulation of incentive in the current study contrasted the presence of a financial incentive that was contingent on ‘good’ performance with a no-incentive condition where the task was unimportant and performance quality was inconsequential; this manipulation was developed to contrast the consequences of performance, but differs markedly from a scenario where the additional performance-related payment are simply added to a standard stipend. In addition, SBP has been associated with higher measurement error than other indices of beta-adrenergic activity, such as PEP ([Richter et al., 2008](#)) and it should be noted that our mean scores of SBP were based on only two samples for every 200 s of

performance, hence the low number of SBP samples may have blunted the sensitivity of this measure in the current study.

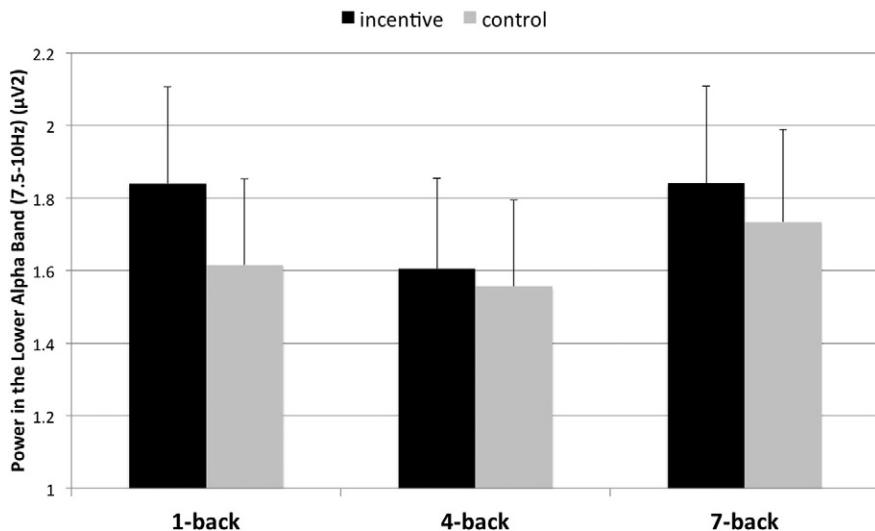
Average power in frontomedial theta exhibited a pattern of response that was largely consistent with the predictions of motivational intensity theory ([Fig. 1](#)); frontomedial theta was significantly enhanced when demand increased and diminished when the task was easy or success likelihood was low. It has been argued that increased levels of frontomedial theta are associated with maintenance of item and temporal order information during a memory task ([Hsieh and Ranganath, 2014](#)); this hypothesis would explain the relationship between demand and theta activation. Previous research has used source localization analysis to identify increased frontomedial theta with activity in the anterior cingulate cortex ([Gevins et al., 1997](#)); the same area of the brain is associated with blood pressure control ([Critchley, 2005](#); [Critchley et al., 2000](#); [Asada et al., 1999](#)), hence cardiovascular and neurophysiological markers of effort in response to demand may share a common neural covariate. There was no significant effect of financial incentive, which suggests that frontomedial theta activity had relatively greater sensitivity to the influence of cognitive demand as opposed to extrinsic sources of motivation.

[Klimesch \(1999\)](#) hypothesised that activity in the lower-alpha band was widespread topographically and related to general attentional processes, he specifically reported a link between suppression in lower-alpha activity and increased alertness/expectancy in preparation for the presentation of a target. Our analyses revealed significant suppression of lower-alpha activity in response to the incentive manipulation and increased demand that was localized to parietal sites ([Fig. 2](#)). It is logical to assume that alertness is enhanced in response to incentive and modulated in response to success likelihood. The sensitivity of activity in the lower-alpha band to both independent variables was similar (but not identical) to the pattern observed for mean SBP. There is also suggestive evidence for a negative correlation between the magnitude of the alpha rhythm at parietal sites (Pz, P4) and systolic blood

**Table 5**  
Summary of MANOVA on lower alpha power at parietal sites ( $N = 18$ ).

	F	df	Sig	$\eta^2$
Incentive (i)	<b>7.51</b>	<b>1,17</b>	<b>0.01</b>	<b>0.31</b>
Demand (d)	<b>5.28</b>	<b>2,16</b>	<b>0.02</b>	<b>0.40</b>
Site (s)	<b>6.95</b>	<b>4,14</b>	<0.01	<b>0.67</b>
i*d	3.05	2,16	0.08	
i*s	<b>4.61</b>	<b>4,14</b>	<b>0.01</b>	<b>0.57</b>
d*s	0.52	8,10	0.81	
i*d*s	2.01	8,10	0.15	

Bold values denote effects that are statistically significant ( $p < .05$ ).



**Fig. 2.** Mean power ( $\mu\text{V}^2$ ) in the lower alpha bandwidth (7–10.5 Hz) for easy (1-back), hard (4-back) and very hard (7-back) levels of working memory demand during incentive and no-incentive conditions ( $N = 18$ ). Error bars represent standard error.

pressure (Foster and Harrison, 2004) but it is difficult to speculate further on the root cause of this association. Activity in the upper-alpha band was originally associated with semantic processing (Klimesch, 1999) and has subsequently been associated with a fronto-parietal network during working memory performance with connections to frontomedial theta activity (Shack et al., 2005). Our analyses revealed a widespread effect of demand on upper-alpha suppression at frontal, central and parietal sites, but like the analysis of frontomedial theta, no significant of financial incentive was observed (Table 1). The absence of localized effect at parietal sites may point towards an association between upper-alpha and a generic, ubiquitous role during working memory processing, such as active inhibition of competing sources of attention (Michels et al., 2008; Klimesch, 2012).

The analyses of EEG provided evidence that frontomedial theta and upper-alpha responded to working memory demand in a curvilinear fashion, which is broadly consistent with the predictions of motivational intensity theory. However, the methodology of the current study differed in a number of significant ways from existing work in the field and these original findings on the relationship between spontaneous EEG and motivational intensity should be interpreted with caution until they have been replicated. The most fundamental deviation from existing research (Richter et al., 2016) was the decision to use a within-participants design. The selection of this methodology renders data susceptible to a number of systematic order effects, such as fatigue and learning effects. We can confidently dismiss the influence of the latter, participants received over two hours of training with the task prior to the test session in order to prevent skill acquisition during data capture. The influence of boredom or fatigue is a more plausible confound given that participants performed  $2 \times 100$  s duration tasks for each level of demand and in each incentive condition, i.e. 1200 s of n-back performance per session. Despite the use of counterbalancing and randomisation, it is possible that order effects due to fatigue may have occurred in the data. However, it should be noted that performance on

the n-back task was presented as  $2 \times 100$  s tasks and followed by a 300 s period for participants to complete subjective questionnaires and to rest between successive periods of working memory performance, hence participants did receive an opportunity to recover from each period of task activity. A second potential source of order effect relates to the counterbalancing of the two incentive conditions, the presentation of the no-incentive condition followed by the incentive condition is perhaps more credible from the perspective of our participants than vice versa and perhaps granted those participants additional practice before they performed for a financial incentive.

The decision to expose participants to a substantial pre-test training period on all versions of the n-back task was motivated by a desire to both replicate the methodology described by Gevins et al. (1998). It is possible that pre-training may have rendered our participants atypical in the sense that they had an opportunity to become skilled and highly familiar with the experimental task. There is evidence from earlier work (Wright and Dill, 1993; Fairclough and Roberts, 2011) that perceptions of high task ability can increase systolic reactivity in response to increased demand. In the case of the current study, participants did not

**Table 7**

Summary of MANOVAs on upper alpha power at frontal, central and parietal sites ( $N = 18$ ).

		F	df	Sig	$\eta^2$
Frontal	Incentive (i)	0.82	1,17	0.78	
	<b>Demand (d)</b>	<b>4.55</b>	<b>2,16</b>	<b>0.03</b>	<b>0.36</b>
	<b>Site (s)</b>	<b>14.15</b>	<b>4,14</b>	<b>&lt;0.01</b>	<b>0.81</b>
	i*d	1.25	2,16	0.31	
	i*s	0.75	4,14	0.58	
	d*s	0.31	8,10	0.94	
	i*d*s	1.32	8,10	0.31	
	Incentive (i)	0.67	1,17	0.42	
Central	<b>Demand (d)</b>	<b>4.12</b>	<b>2,16</b>	<b>0.04</b>	<b>0.34</b>
	<b>Site (s)</b>	<b>12.23</b>	<b>4,14</b>	<b>&lt;0.01</b>	<b>0.78</b>
	i*d	0.23	2,16	0.79	
	i*s	0.31	4,14	0.87	
	d*s	0.52	8,10	0.82	
Parietal	i*d*s	1.22	8,10	0.38	
	Incentive (i)	0.52	1,17	0.48	
	<b>Demand (d)</b>	<b>4.36</b>	<b>2,16</b>	<b>0.03</b>	<b>0.40</b>
	<b>Site (s)</b>	<b>5.61</b>	<b>4,14</b>	<b>&lt;0.01</b>	<b>0.62</b>
	i*d	0.65	2,16	0.54	
	i*s	1.22	4,14	0.32	
	d*s	0.96	8,10	0.45	
	i*d*s	0.20	8,10	0.94	

Bold values denote effects that are statistically significant ( $p < .05$ ).

**Table 6**

Summary of post-hoc t-tests conducted to investigate incentive  $\times$  site interaction ( $N = 18$ ).

Site	Incentive M (s.d.)	No-incentive M (s.d.)	df	t	p	d
P7	1.61 (0.85)	1.71 (0.94)	17	-2.04	0.058	0.08
P3	1.37 (1.03)	1.51 (1.11)	17	-2.96	0.009	0.09
Pz	1.66 (1.05)	1.80 (1.13)	17	-3.11	0.006	0.09
P4	1.75 (1.09)	1.87 (1.14)	17	-2.86	0.011	0.07
P8	1.90 (1.04)	1.97 (1.08)	17	-1.54	0.142	0.04

**Table 8**

Mean power ( $\mu\text{V}^2$ ) in the upper alpha bandwidth (10–12.5 Hz) for easy (1-back), hard (4-back) and very hard (7-back) levels of working memory demand at frontal, central and parietal sites ( $N = 18$ ). Results of Bonferroni pairwise comparisons included with significance levels.

	1-back	4-back	7-back	Pairwise
Frontal	0.86 [0.76]	0.67 [0.64]	0.72 [0.76]	4b < 1b [ $p = 0.02$ ] 7b < 1b [ $p = 0.04$ ]
	0.93 [0.72]	0.78 [0.64]	0.86 [0.78]	4b < 1b [ $p = 0.01$ ]
Central	1.44 [0.93]	1.25 [0.85]	1.36 [0.89]	4b < 1b [ $p < 0.01$ ] 7b < 1b [ $p = 0.05$ ]

receive feedback so had no means by which to assess their actual ability but they were made very familiar with the task, hence they may have been more willing to expend effort in response to an incentive (as evidenced by increased subjective motivation, mean SBP and suppression of low-alpha in parietal area) because intensive preparation imbued participants with greater degree of confidence. The inclusion of an extensive training regime may also have exerted a more subtle effect whereby our participants were particularly susceptible to boredom due to the highly routinised nature of the task, especially during the no-incentive condition; this susceptibility was absent from the incentive condition where the prospect of performance-contingent reward enhanced motivation and imbued the task with a salience that was absent in the other condition. There is evidence from research on error-related negativity (ERN) to suggest that intrinsic motivation and boredom may interact with task salience or novelty in this way (Tjew-A-Sin et al., 2016; Tops and Boksem, 2010). The generic instructions that “good” “very good” and “excellent” performance would be rewarded may have also potentiated the influence of financial incentive. In hindsight, this instruction was open to interpretation as definitions of good/very good/excellent performance could be interpreted as calibrated to the performance of a particular individual or adjusted to reflect whether demand was easy, hard or very hard. This ambiguity was compounded by the absence of performance feedback, either during training or experimental task, both of which created a scenario where the conditions of earning a reward were vague and participants were unable to respond to financial incentive in the strategic fashion due to uncertainty. In addition, the manipulation of potential motivation/success importance represented a particularly stark contrast and begs a question about the interpretation of the incentive manipulation, namely – are the observed effects due to enhancement of potential motivation in the presence of an incentive? Or can they be explained by a collapse of motivation for highly-trained participants who regarded the no-incentive condition as little more than a practice trial? The precise interpretation of the incentive effect remains open to question until a further study is performed that includes a second ‘control’ condition where performance is recorded for analysis.

The results demonstrated that predictions from motivational intensity theory were largely but not fully supported using neurophysiological measures of effort, frontomedial theta and upper-alpha activity responded to task demand while lower-alpha was found to be sensitive to both demand and success importance. The observed convergence between neurophysiological and cardiovascular measures of effort may point to a common mechanism or covariate and this aspect of the study can be explored by further work on the interaction between neural and autonomic systems.

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## References

- Asada, H., Fukuda, Y., Tsunoda, S., Yamaguchi, M., Tonoike, M., 1999. Frontal midline theta rhythms reflect alternative activation of prefrontal cortex and anterior cingulate cortex in humans. *Neurosci. Lett.* 274, 29–32.
- Berger, B., Omer, S., Minarik, T., Sterr, A., Sauseng, P., 2014. Interacting memory systems—does EEG alpha activity respond to semantic long-term memory access in a working memory task? *Biol. (Basel)* 4, 1–16.
- Brehm, J.W., Self, E.A., 1989. The intensity of motivation. *Annu. Rev. Psychol.* 40, 109–131.
- Cavanagh, J.F., Frank, M.J., 2014. Frontal theta as a mechanism for cognitive control. *Trends Cogn. Sci.* 18, 414–421.
- Chapman, L.J., Chapman, J.P., 1987. The measurement of handedness. *Brain Cogn.* 6, 175–183.
- Chatelain, M., Gendolla, G.H.E., 2015. Implicit fear and effort-related cardiac response. *Biol. Psychol.* 111, 73–82.
- Chuang, L.Y., Huang, C.J., Hung, T.M., 2013. The differences in frontal midline theta power between successful and unsuccessful basketball free throws of elite basketball players. *Int. J. Psychophysiol.* 90, 321–328.
- Clayton, M.S., Yeung, N., Cohen Kadosh, R., 2015. The roles of cortical oscillations in sustained attention. *Trends Cogn. Sci.* 19, 188–195.
- Critchley, H.D., 2005. Neural mechanisms of autonomic, affective, and cognitive integration. *J. Comp. Neurol.* 493, 154–166.
- Critchley, H.D., Corfield, D.R., Chandler, M.P., Mathias, C.J., Dolan, R.J., 2000. Cerebral correlates of autonomic cardiovascular arousal: a functional neuroimaging investigation in humans. *J. Physiol.* 523, 259–270.
- Doppelmayr, M., Finkenzeller, T., Sauseng, P., 2008. Frontal midline theta in the pre-shot phase of rifle shooting: differences between experts and novices. *Neuropsychologia* 46, 1463–1467.
- Eubanks, L., Wright, R.A., Williams, B.J., 2002. Reward influence on the heart: cardiovascular response as a function of incentive value at five levels of task demand. *Motiv. Emot.* 26, 139–152.
- Fairclough, S.H., Roberts, J., 2011. Effects of performance feedback on cardiovascular reactivity and frontal EEG asymmetry. *Int. J. Psychophysiol.* 81, 291–298.
- Foster, P.S., Harrison, D.W., 2004. The covariation of cortical electrical activity and cardiovascular responding. *Int. J. Psychophysiol.* 52, 239–255.
- Gendolla, G.H.E., Richter, M., 2010. Effort mobilization when the self is involved: some lessons from the cardiovascular system. *Rev. Gen. Psychol.* 14, 212–226.
- Gendolla, G.H.E., Wright, R.A., Richter, M., 2012. Effort intensity: some insights from the cardiovascular system. In: Ryan, R.M. (Ed.), *The Oxford Handbook on Motivation*. Oxford University Press, New York, NY, pp. 420–438.
- Gevins, A., Smith, M.E., 2003. Neurophysiological measures of cognitive workload during human-computer interaction. *Theor. Issues Ergon. Sci.* 4, 113–121.
- Gevins, A., Smith, M.E., McEvoy, L., Yu, D., 1997. High resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing and practice. *Cereb. Cortex* 7, 374–385.
- Gevins, A., Smith, M.E., Leong, H., McEvoy, L., Whitfield, S., Du, R., Rush, G., 1998. Monitoring working memory load during computer-based tasks with EEG pattern recognition models. *Hum. Factors* 40, 79–91.
- Hart, S.G., Staveland, L.E., 1988. Development of the NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock, P.A., Meshkati, N. (Eds.), *Human Mental Workload*. North-Holland, Amsterdam, pp. 139–183.
- Hsieh, L.T., Ranganath, C., 2014. Frontal midline theta oscillations during working memory maintenance and episodic encoding and retrieval. *NeuroImage* 85 (Pt 2), 721–729.
- Ithipuripat, S., Wessel, J.R., Aron, A.R., 2013. Frontal theta is a signature of successful working memory manipulation. *Exp. Brain Res.* 224, 255–262.
- Klimesch, W., 1999. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Res. Rev.* 29, 169–195.
- Klimesch, W., 2012. Alpha-band oscillations, attention, and controlled access to stored information. *Trends Cogn. Sci.* 16, 606–617.
- Matthews, G., Joyner, L., Gilliland, K., Campbell, S., Falconer, S., Huggins, J., 1997. Validation of a comprehensive stress state questionnaire: towards a state ‘Big Three’? In: Mervielde, I., Deary, I.J., De Fruyt, F., Ostendorf, F. (Eds.), *Personality Psychology in Europe*. Tilburg University Press, Tilburg.
- Michels, L., Moazami-Goudarzi, M., Jeanmonod, D., Sarnthein, J., 2008. EEG alpha distinguishes between cuneal and precuneal activation in working memory. *NeuroImage* 40, 1296–1310.
- Obrist, P.A., 1981. *Cardiovascular Psychophysiology: A Perspective*. Plenum, New York.
- Onton, J., Delorme, A., Makeig, S., 2005. Frontal midline EEG dynamics during working memory. *NeuroImage* 27, 341–356.
- Richter, M., 2015. Goal pursuit and energy conservation: energy investment increases with task demand but does not equal it. *Motiv. Emot.* 39, 25–33.
- Richter, M., Friedrich, A., Gendolla, G.H.E., 2008. Task difficulty effects on cardiac activity. *Psychophysiology* 45, 869–875.
- Richter, M., Gendolla, G.H.E., Wright, R.A., 2016. Three Decades of Research on Motivational Intensity Theory. 3 pp. 149–186.
- Roberts, B.M., Hsieh, L.T., Ranganath, C., 2013. Oscillatory activity during maintenance of spatial and temporal information in working memory. *Neuropsychologia* 51, 349–357.
- Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C., Hummel, F.C., 2007. Dissociation of sustained attention from central executive functions: local activity and interregional connectivity in the theta range. *Eur. J. Neurosci.* 25, 587–593.
- Shack, B., Klimesch, W., Sauseng, P., 2005. Phase synchronization between theta and upper alpha oscillations in a working memory task. *Int. J. Psychophysiol.* 57, 105–114.
- Silvestrini, N., Gendolla, G.H.E., 2009. The joint effect of mood, task valence, and task difficulty on effort-related cardiovascular response and facial EMG. *Int. J. Psychophysiol.* 73, 226–234.

- Silvia, J.P., 2015. Self-striving: how self-focused attention affects effort-related cardiovascular activity. In: Gendolla, H.E.G., Tops, M., Koole, L.S. (Eds.), *Handbook of Biobehavioral Approaches to Self-regulation*. Springer New York, New York, NY, pp. 301–314.
- Stewart, C.C., Wright, R.A., Hui, S.A., Simmons, A., 2009. Outcome expectancy as a moderator of mental fatigue influence on cardiovascular response. *Psychophysiology* 46, 1141–1149.
- Tjew-A-Sin, M., Tops, M., Heslenfeld, D.J., Koole, S.L., 2016. Caring about errors: effects of simulated interpersonal touch and trait intrinsic motivation on the error-related negativity. *Neurosci. Lett.* 617, 134–138.
- Tops, M., Boksem, M.A.S., 2010. Absorbed in the task: personality measures predict engagement during task performance as tracked by error negativity and asymmetrical frontal activity. *Cogn. Affect. Behav. Neurosci.* 10, 441–453.
- Wright, R.A., 1996. Brehm's theory of motivation as a model of effort and cardiovascular response. In: Gollwitzer, P.M., Bargh, A. (Eds.), *The Psychology of Action: Linking Cognition and Motivation to Behaviour*. Guilford Press, New York, pp. 424–453.
- Wright, R.A., 2008. Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. *Soc. Personal. Psychol. Compass* 2, 682–701.
- Wright, R.A., Dill, J.D., 1993. Blood pressure responses and incentive appraisals as a function of perceived ability and objective task demand. *Psychophysiology* 30, 152–160.
- Wright, R.A., Williams, B.J., Dill, J.C., 1992. Interactive effects of difficulty and instrumentality of avoidant behavior on cardiovascular reactivity. *Psychophysiology* 29, 677–686.