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Experienced Stress Produces Inhibitory Deficits in Elderlies' Flanker Task Performance: First Evidence for Lifetime Stress Effects Beyond Memory

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Highlights

- Study assessed impact of cumulative life stress on elderlies' Flanker task performance
- High stress elderly show general slowing of reaction times for in-/congruent arrays
- Slowed reaction times correlate with higher levels of alpha ERD by high stress elderly
- Findings suggest a break-down of inhibition in sensory and attentional domains

Abstract

Studies regarding aged individuals' performance on the Flanker task differ with respect to reporting impaired or intact executive control. Past work has explained this discrepancy by hypothesising that elderly individuals use increased top-down control mechanisms advantageous to Flanker performance. This study investigated this mechanism, focussing on cumulative experienced stress as a factor that may impact on its execution, thereby leading to impaired performance. Thirty elderly and thirty young participants completed a version of the Flanker task paired with electroencephalographic recordings of the alpha frequency, whose increased synchronisation indexes inhibitory processes. Among high stress elderly individuals, findings revealed a general slowing of reaction times for congruent and incongruent stimuli, which correlated with alpha desynchronisation for both stimulus categories. Results found high performing (low stress) elderly revealed neither a behavioural nor electrophysiological difference compared to young participants. Therefore, rather than impacting on top-down compensatory mechanisms, findings indicate that stress may affect elderly participants' inhibitory control in attentional and sensorimotor domains.

Keywords: ageing; EEG; inhibition; experienced stress; flanker task

Introduction

Ageing is known to produce a progressive decline in multiple cognitive domains, resulting in impaired processing speed (Madden, 2001), a reduction of working memory capacity (Grady, 2000), impaired cognitive flexibility (Mayr, 2001) and an inability of top-down control processes to guard against the effects of distracting information (Kramer et al., 1999). Similarly, a number of studies report age-related changes in the ability to resist distractor interference (Mund et al., 2012; Pettigrew & Martin, 2014). Reports of age related inhibitory impairments, coupled with findings indicating that the prefrontal cortex is vulnerable to age-related cognitive decline, gave rise to theories such as the 'Frontal Hypothesis of Cognitive Ageing' (Dempster, 1992) and the 'Age-related Inhibitory Deficit Theory' (Lustig, Hasher & Zacks, 2007). Both theories posit that elderly individuals suffer from a general deficit in tasks of executive control as these rely on frontal areas of the cortex, which are prone to decline with advancing age. A further theory relating to ageing executive control states that inhibitory performance decrements are not abolished but merely delayed by normal ageing (Salthouse, 1996; Andres, Parmentier & Escera, 2006). Thus, shortcomings will be apparent if a timely response is elicited but will disappear if elderly individuals are given more time to engage attentional resources before responding. This idea was recently advocated by Gazzaley and colleagues (2008) who reported a direct link between neural processing speed and elderly individuals' ability to inhibit information at early processing stages. To further investigate this account, Wascher and colleagues (2012) recently paired an inhibitory suppression task with event related potential (ERP) recordings of the N1pc and N2pc components, thus allowing them to explore distinct sub-processes of early stimulus processing as well as subsequent selection and control processes. The authors found evidence for both attentional slowing and increased early susceptibility to distracting information among elderly individuals, thus highlighting the wide-ranging changes advanced age produces in the domain of inhibitory control.

However, evidence from different inhibitory task paradigms demonstrates that inhibitory deficits in old age are not as general as originally assumed (Hsieh, Liang & Tsai, 2012). Whereas paradigms such as the Stroop (Kok, 1999) and the Simon task (Proctor et al., 2005) consistently indicate elderly participants' enhanced susceptibility to distractors, research on the well-known Flanker Task (Eriksen & Eriksen, 1974) has produced inconsistent results. As such, some studies indicate ageing deficits corresponding to those discovered in the Stroop and Simon task, namely that relative to young, elderly individuals show greater reaction time costs in interference compared to non-interference trials (Zeef & Kok, 1993; Zeef et al., 1996). However, a large body of research reports no age differences in Flanker interference (Nieuwenhuis et al., 2002; Wild-Wall et al., 2008; Hsieh et al., 2012).

The standard version of the Flanker paradigm was first introduced by Eriksen and Eriksen (1974) and consists of a five stimulus array: a central target stimulus (➔) requiring either a right or left hand response embedded within four flanking stimuli to either side. Task demands require an accurate and timely response to the central target while disregarding the flanking stimuli, which can be congruent (➔➔➔➔➔) or incongruent (🡐🡐➔🡐🡐) to the central target. Common findings of this paradigm are increased reaction times (RTs) and error rates when comparing the incongruent to the congruent trials, which based on its nature, are thought to occur through motor interference (Coles et al., 1985; Eriksen & Eriksen, 1974). This interpretation has led to the hypothesis that ageing differentially affects different forms of inhibition. In line with this idea, performance on perceptual inhibition tasks such as the Simon and

Stroop paradigm which include spatial overlap between response relevant and response irrelevant stimuli presentations is reduced as a function of age, whereas Flanker performance which is thought to rely primarily on motor suppression, and does not incorporate overlapping stimulus dimensions, remains largely unaffected (Kawai et al., 2012).

However, Hsieh and colleagues (2012) argue that the Flanker task contains aspects of both motor and perceptual interference. Investigating participants' performance patterns on a modified Flanker version distinguishing between both forms of interference, Van't Ent (2002) likewise concluded that the Flanker task incorporates both forms of interference.

Thus, discrepant age findings are unlikely to be the result of differing inhibitory demands among paradigms and have led to the hypothesis that elderly participants make use of a processing strategy, which carries specific advantages for Flanker task performance (Hsieh & Fang, 2012). To this effect, Wild-Wall and colleagues (2008) suggested that elderly individuals place a strategic emphasis on performance accuracy which results in top-down enhanced processing of the central target and delayed information transmission from visual to motor areas of the cortex and results in increased reaction times to compensate for performance accuracy (Hoffmann & Falkenstein, 2011). Hsieh and colleagues (2012) tested age differences with Van't Ent's modified Flanker version and found no age differences in task performance. Thus, the authors concluded that older adults maintained efficiency akin to that of young participants by employing enhanced top-down inhibitory control strategies to compensate for deficiencies in task accuracy performance.

In their 2013 review of the neural and behavioural components of inhibition, Bari and Robbins classify top-down inhibitory control as a higher order cognitive performance involving the complete or partial termination or overriding of a mental process (see also MacLeod, 2007). This process is largely carried out by frontal brain regions such as the dorso-lateral prefrontal cortex (dlPFC) (Delgado et al., 2008), the ventro-lateral prefrontal cortex and insula (vlPFC) (Boehler et al., 2010; Swick et al., 2008) as well as the anterior cingulate cortex (ACC) (Wascher et al., 2012; Rubia et al., 2001) which have been found to largely overlap in terms of cognitive and motor control (D'Esposito et al., 1999; Michael et al., 2006; Temel et al., 2005). In addition to age-related changes, frontal brain regions have also been highlighted as particularly vulnerable to the adverse effects of stress, which are thought to occur through an increased number of micro lesions produced by heightened hypertonic strain (Rabbitt, 2005). Stress, especially in its chronic or cumulative form has also been shown to affect higher order cognitive processes such as working memory in old age. For example, recent longitudinal studies investigating the impact of experienced stress on cognitive ageing report that elderly individuals experiencing a greater amount of cumulative stressful incidents in the course of their lives display accelerated cognitive decline and perform worse on cognitive tasks (Pesonen et al., 2013). For example, Peavy and colleagues (2009) reported that higher amounts of cumulative stressful experiences over the course of three years resulted in decreased working memory performance among a sample of elderly individuals suffering from mild cognitive impairment. Similar findings are reported by a number of cross-sectional studies which state that higher amounts of cumulative stressful events coincide with reduced working memory performance among healthy elderly participants (Dickinson et al., 2011; Tschanz et al., 2012). In addition, rencently published work (Marshall, Cooper, Segrave & Geeraert, 2015) established an inverse relationship between the amount of cumulative experienced stress and cognitive working memory performance among elderly individuals, which was not present among young control participants. Results advocating the adverse effects of stress on cognition among elderly but not young individuals, highlight the possibility of a cumulative impact of experienced stress, which emerges late in life and causes cognitive impairments among the elderly. Memory has been the primary focus of studies investigating the effects of cumulative experienced stress on ageing, however as impaired executive control has been found to compromise memory performance (Hasher & Zacks, 1988) a reasonable extension to the field lies in investigating whether cumulative experienced stress impacts on related cognitive domains. As stress is also known to affect brain regions integral to the top-down compensatory mechanism elderly individuals are hypothesised to engage while completing the Flanker task, a further reasonable approach lies in investigating how this factor may affect compensatory Flanker performance.

The aforementioned work by Wascher and colleagues (2012) provides an edifying example of how investigations of electrophysiological recordings (in the form of oscillatory event-related activity or ERPs) can provide insight into underlying attentional compensation mechanisms. As such, many studies interested in investigating underlying cognitive processing strategies have paired the Flanker task with EEG recordings, many of which focus on the alpha bandwidth (8-12 Hz) whose increased event-related-synchronisation (ERS) is thought to indicate underlying inhibitory processes. In a recent review article, Fox and Snyder (2011) discussed a range of their own studies investigating functionality of alpha band oscillations in light of an attention suppression mechanism. Reviewing studies on intersensory selective and feature based attention over multiple sensory domains, the authors concluded that a central role of alpha oscillations relates to the attentional suppression of distracting stimulus features which have to be suppressed for successful task execution. Similarly, in their gating by inhibition theory, Jensen and Mazaheri (2010) implicate oscillatory alpha activity as one of the main mechanisms responsible for intact transmission of information between relevant neuronal assemblies by inhibiting task irrelevant brain regions. The inhibitory role of alpha has also been highlighted with respect to top-down sensorimotor control, in which alpha ERD is thought to indicate an activated brain region engaged in motor preparation, execution or imagery, whereas alpha ERS is thought to reflect a deactivated or inhibited cortical network. Alpha suppression of a task irrelevant region was illustrated by work undertaken by Neuper, Woertz and Pfurtscheller (2006) who demonstrated that mental imagery of foot movement led to an increase of the mu rhythm (alpha ERS expressed over the motor cortex) for the hand area. Similarly, Deiber and colleagues (2012) implicate alpha activity in higher order motor control functions and conducted a study in which they convincingly demonstrated that motor preparation was accompanied by posterior alpha ERD (reflective of attentional engagement with respect to motor preparation) as well as mid parietal alpha ERS (indicative of inhibiting task irrelevant visual activity), thereby nicely demonstrating the interplay between the inhibitory and motoric roles attributed to the alpha band.

As such, alpha synchronisation observed during Flanker task performance has likewise been linked to task evoked inhibitory attentional and sensorimotor control processes (Hogan et al., 2013). For example, Compton and colleagues (2014) reported increased levels of alpha synchronisation over frontal and parietal as well as motor regions following errors committed on a Flanker task, especially in motivational trials promising a monetary return. The authors therefore concluded that enhanced levels of alpha ERS reflected executive control processes, monitoring and constraining the motor response and perceptual interference from flanking stimuli.

Similarly, Tang and colleagues (2013) found increased alpha ERS in widespread regions of the cortex in response to completing an inhibitory Stroop task. The authors likewise concluded that alpha band activity reflects a process of conflict control. Findings to this effect highlight that one possible compensatory mechanism engaged in by elderly individuals to keep up Flanker task performance might lie in devoting more cognitive resources towards inhibiting conflicting stimulus information, thus demonstrating higher levels of alpha ERS during incongruent Flanker task conditions in which misleading stimulus information needs to be supressed.

The aim of the present study was to investigate whether the adverse impact of cumulative experienced stress extended to elderlies’ inhibitory performance. Simultaneously, the study aimed to shed light on the controversy regarding age differences in the Flanker task, exploring whether cumulative experienced stress impacts on the proposed top-down compensatory processes engaged in by elderly participants. In order to gain further insight into the associated neural mechanisms, the study paired behavioural performance with EEG recordings of the alpha frequency band. We hypothesise that elderly high stress participants will display reduced behavioural performance. This can either manifest in reduced accuracy or in higher reaction times in incongruent compared to congruent Flanker conditions when compared to young and elderly low stress counterparts. Furthermore, we hypothesise that elderly high stress participants will display reduced levels of alpha synchronisation indicating an impairment of inhibitory control strategies.

Materials and Method

Participant selection

The study consisted of 30 young (17 females; Mean age = 21.3, SD = 3.4; Range 18-30 years) and 30 elderly (14 females; Mean age = 68.73, SD 6.4; Range 60-82) participants. Young participants were recruited from the University of Essex student population via e-mail advertising. Elderly volunteers were recruited via an advertisement in the local branch of the University of the 3rd Age newsletter. All participants were right-handed and healthy. Participants were screened for major medical conditions (e.g. diabetes, heart disease), major neurological damage (e.g. stroke), current diagnosis of a mental or psychiatric disorder (e.g. dementia, depression, anxiety disorder), use of psychoactive medication and a history of substance abuse. To further ensure against the presence of undiagnosed cognitive pathologies all elderly participants completed the Mini Mental State Examination (Folstein, Folstein & McHugh, 1975) in which all scored full marks. Participants provided written informed consent. The study was approved by the University of Essex Ethics Committee.

Preceding analysis, both age groups were split into high and low experienced stress groups based on the median split of scores from the Social Readjustment Rating scale for elderly (Median Split value 697) and the Student Life Events Scale for young (Median Split Value 606). Using independent-samples t-tests and the chi-square test for contingency tables for the nominal gender variable, no significant stress group differences emerged when comparing Mini Mental State performance, State/Trait anxiety scores, age, gender, educational attainment, cigarette/alcohol consumption or amounts of exercise ($p_s > 0.05$; see Table 1).

Stress and Demographical Measures

Past work (Dickinson et al., 2011; Peavy et al., 2009) as well as recent investigations into the effects of stress on cognitive ageing (Marshall et al., 2015) have focussed on cumulative life stress and have reported promising findings by ascertaining the number of stressful life experiences individuals encounter over a particular time course. Therefore, this study employed a similar method. Given that our elderly participants have on average three times the age of younger participants, they are likely to have experienced more and different stressful events. Thus, in order to assess prolonged stress exposure appropriate to each age group and make the argument that the long-term effects of cumulative stress exposure are responsible for behavioural shortcomings (not purely high amounts of immediate stress) different instruments were used for elderly and young participants.

The amount of experienced stress was therefore assessed by the Social Readjustment Rating Scale (Holmes & Rahe, 1967) for elderly and the Student Life Events Scale (Clements & Turpin, 1996) for young participants. Both scales use a similar format to assess stressful experiences, consisting of a brief, self-administered scale (43 and 36 items respectively). Both scales contain incidents ranging from extremely stressful (i.e. 'Death of Spouse/Parent') to mildly stressful (i.e. 'Finding a part-time job'). Scores can range from 0-1466 for the Social Readjustment Rating Scale and 0-1849 for the Student Life Events Scale. Higher scores reflect high amounts of experienced stress for both scales. In order to ensure values measured from different scales contributed equally to the analysis, the scores for each participant were standardised within age groups.

The possible impact of stress tolerance and non-pathological levels of anxiety were assessed by the State-Trait-Anxiety Inventory (STAI) developed by Spielberger (1968, 1977).

Further control measures included participants' gender, age, educational level, cigarette and alcohol intake, amount of physical exercise and whether participants suffered from a disability whose discomfort may impair performance on the task (units of measurement displayed in Table 1).

Procedure and Stimuli

Before completing the Flanker task, each participant took part in an EEG eye-movement calibration session (Croft & Barry, 1998), which was followed by an eyes closed/resting EEG interval lasting two minutes.

Participants moved on to complete a modified version of the Eriksen Flanker task (Eriksen & Eriksen, 1974) programmed using Neuroscan Stim2 (Compumedics, Melbourne) software. Stimuli were developed after a template introduced by Fan and colleagues (2002; 2004) and consisted of five arrows embedded within the images of fish, displayed on a computer screen for congruent and incongruent conditions. This version was chosen to make the task user friendly and engaging. In order to ensure low error rates, target and flanking stimuli were presented on screen simultaneously.

Stimuli were presented in blue against a white background on a 19 inch computer monitor (refresh rate 100 Hz). Participants were seated directly in front of the computer monitor (approximately 0.65m) and were asked to respond as quickly and as accurately as possible to the direction of the central target arrow by pressing the corresponding response button (buttons on a response pad for left and right hand respectively). Trials began with a blank screen presented for 500 ms, after which the stimulus array appeared for a further 500 ms. Compared to standard flanker paradigms, slightly longer stimulus presentation times were chosen to enable elderly participants to complete the task with low error rates. Stimulus congruency and direction were balanced equally across trials and varied pseudo-randomly between participants. Following a short block of practice trials, participants completed 2 blocks of 160 trials for a total of 320 trials. Participants were given the opportunity of a break between blocks.

Electrophysiological recording and data preparation

Electroencephalography (EEG) was recorded from 64 electrodes placed within a soft-cap according to the 10-20 method of electrode positioning. Recordings were referenced to a point midway between Cz and CPz. Impedances were lowered to below 10 kΩ in all electrodes before acquisition. EEG signals were recorded and subsequently analysed using a Neuroscan Synamps2 system in conjunction with SCAN 4.5 software (Compumedics, Melbourne, Australia). Data was collected at a sampling rate of 1000 Hz with a band-pass filter of 0.05-200 Hz.

Data was visually inspected and noisy data blocks, general artifacts and bad electrodes rejected. Principal components analysis was carried out on the eye movement calibration data to obtain components reflecting saccades and blinks. These acquired components were subsequently rejected from the task data traces (Vigário, 1997; Vigário et al., 2000). Before data pruning, data was re-referenced to a common average reference. In order to investigate the topography of possible age and stress related group differences, the 64 electrodes were averaged into nine brain regions: left (FP1, AF3, F7, F5, F3, F1, FT7, FC5, FC3, FC1), mid (FPz, Fz, FCz) and right (FP2, AF4, F8, F6, F4, F2, FT8, FC6, FC4, FC2) frontal; left (T7, C5, C3, C1, TP7, CP5, CP3, CP1), mid (Cz, CPz) and right (T8, C6, C4, C2, TP8, CP6, CP4, CP2) central; left (P7, P5, P3, P1, PO7, PO5, PO3, CB1, O1), mid (Pz, POz, Oz) and right (P8, P6, P4, P2, PO8, PO6, PO4, CB2, O2) posterior.

To calculate event-related synchronisation and desynchronisation (ERS/D), data segments for periods of Flanker monitoring were cut into 2000 ms epochs (ranging from -1000 to 1000 ms after stimulus onset). The first and last 500ms of the trials were trimmed to avoid filter warm-up artifacts, leaving a 500 ms test (plus 500 ms baseline reference before onset of the stimulus) interval for analysis. Only correct trials were used for electrophysiological analysis.

Using the Event-related-band-power transformation (SCAN 4.5 editing software) data underwent complex demodulation and concurrent filtering (zero phase-shift, 24 dB roll-off, envelope computed) into the alpha (8-12 Hz) bandwidth. Event-related activity was calculated as a percentage change between the active period and the reference period and summed as the mean value across the experimental time window (500ms) according to the following formula: ((reference – test)/reference)x100). According to this method developed by Pfurtscheller and Lopes da Silva (1999), positive values represent desynchronisation of the alpha frequency band whereas synchronisation is indexed by negative values.

Results

Behavioural Analysis

Error rates as well as reaction times were analysed by means of a 2 (age: elderly vs. young) x 2 (stress: high vs. low) x 2 (congruency: incongruent vs. congruent) mixed measures ANOVA in which congruency acted as the within-subjects factor.

Analysis of error rates revealed a main effect of congruency ($F_{1\ 56} = 4.18$, $p = .046$) which indicated that incongruent Flanker arrays elicited more errors (*M* = 6.02, *SD* = 1.78) than congruent ones (*M* = 4.19, *SD* = 1.12). No further main effects or interactions reached significance (all p’s > .05).

Looking at reaction times next, a main effect of congruency emerged ($F_{1,56}$ = 7.16, p = .01) indicating that participants took significantly longer to correctly respond to the target in incongruent (*M* = 437.2, *SD = 95.67)* compared to congruent (*M = 396.7, SD* = 93.39) trials. Results further revealed a main effect of age ($F_{1,56}$ = 9.21, p = .01), indicating that elderly individuals took longer to respond (*M* = 457.7, *SD* = 70.18) than young (*M* = 387.3, *SD* = 85.7*)*. The main effect of age was qualified by a significant age x experienced stress interaction ($F_{1, 56}$= 12.72, p= .001). No further effects reached significance (all p's > .05). To decompose the interaction, differences between stress and age groups were compared by means of simple effects contrasts. In order to ensure against Type I error as a result of multiple comparisons, follow-up tests were Bonferroni corrected (adjusted p-value .008). These comparisons revealed a significant age difference between high stress group elderly and high stress young participants ($F_{1,56}$ = 36.02, p<.001) and between high stress elderly and low stress young individuals ($F_{1,56}$ = 38.71, p<.001) indicating that elderly high stress participants (*M* = 492.2, *SD* = 73.1) took significantly longer to respond to both congruent and incongruent target stimuli when compared to both young high (*M* = 334.5, *SD* = 50.6) and low stress counterparts (*M* = 398.0, *SD* = 64.15) (see Figure 1). No further comparison points reached significance (all p's > .008).

Electrophysiological Analysis

Electrophysiological data was analysed by means of a 2 (age) x 2 (stress) x 2 (congruency) x 3 (laterality: left, mid, right scalp regions) x 3 (sagitality: frontal, central, posterior scalp regions) mixed measures ANOVA with repeated measures on the latter three factors.

Analysis found a main effect for congruency ($F_{1,56}$= 4.37, p=.024) indicating higher levels of alpha synchronisation to the incongruent relative to the congruent trials. Results further revealed an interaction of age x stress x laterality x sagitality ($F_{4,184}$= 3.46, p=.037). This interaction was decomposed by running two separate age x laterality x sagitality ANOVAs for high and low stress groups. For the low stress group the model did not reach significance ($F_{4,88}$= 1.3, p=.28). The model for the high stress group showed a significant three-way interaction ($F_{4,88}$= 3.26, p=.015). To decompose this, simple effects comparisons were carried out comparing elderly and young high stress group participants across each of the nine brain regions (Bonferroni adjusted p-value .005). Results found a significant difference in alpha activity over the left central ($F_{1,24}$= 8.77, p=.003) and right posterior ($F_{1,24}$= 7.65, p=.004) scalp area[1] (see Figure 2) both indicating that whereas young high stress participants (see black bold line in Figure 2) manifested synchronous alpha activity during responding, elderly high stress participants (Figure 2 grey bold line) showed levels of event-related-desynchronisation to both congruent and incongruent flanker arrays. No significant differences were observed between elderly and young low stress individuals for either the left central ($F_{1,24}$= 1.02, p=.149) or right posterior ($F_{1,24}$ = 1.3, p =.081) brain region, between high and low stress young for the left central ($F_{1,24}$ < 1) and right posterior region ($F_{1,24}$ = 1.01, p = .138) or between high and low stress elderly for the left central ($F_{1,24}$ = 2.07, p = .075) or right posterior ($F_{1,24}$ = 1.89, p = .089) region. In addition no significant differences emerged across any other scalp regions (all p's > .005) (see Figure 3 for a distribution of topographical effects).

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[1] As the signal to noise ratio will vary between different sized electrode clusters, we re-ran our analysis using a non-parametric approach to rule out this possible confound. To this effect, a Kruskal-Wallis test undertaken between elderly and young high stress participants found a significant difference over left central (χ^2(1, N = 29) = 6.12, p = .013) and right posterior regions (χ^2(1, N = 29) = 5.73, p = .026), thereby confirming the original parametric findings.

To investigate whether alpha findings are more applicable to the attentional or sensorimotor inhibitory domain, we re-ran the above ANOVA for both the lower and upper beta frequency range. This bandwidth has been explicitly linked to motor processes (Pfurtscheller et al., 2003). Should our findings be more applicable to the motor domain we would therefore expect to find corresponding age and stress effects in this frequency range. For the lower beta frequency, analysis revealed a sagitality x age interaction ($F_{2, 102} = 9.45$, $p < .001$) which found that elderly participants manifested high levels of lower beta ERD over the central motor region. Results of the upper beta range similarly revealed a sagitality x age interaction ($F_{2, 102} = 5.04$, $p = 0.029$) for which elderly likewise displayed higher levels of upper beta ERD over frontal scalp sites. No further main effects or interactions reached significance (all ps > 0.05).

EEG and Behavioural Correlations.

Correlating reaction time performance with alpha activity over the entire participant sample found a significant correlation between the level of alpha synchronisation and reaction times for the left central (r= 0.32, p= 0.039) and right posterior cortex (r= 0.28, p= 0.042), indicating that higher levels of alpha synchronisation corresponded to shorter RTs. This correlation was found to be stronger within the elderly participant sample as performing the correlation for both young and elderly participants revealed non-significant results for young over both the left central (r= 0.27, p= 0.054) and the right posterior cortex (r = 0.23, p = 0.072) while demonstrating significant results among elderly participants for both the left central (r= 0.37, p= 0.029) and right posterior (r= 0.36, p= 0.033) cortical region (see Figure 4.). Results therefore highlight an association between the reduced ERS displayed by elderly high stress participants and their reduced performance on the Flanker task. It must be noted however that differences between correlation coefficients for elderly and young participant groups did not reach significance for either the left central ($z = 0.12$, $p = 0.91$) or the right posterior ($z = 0.15$, $p = 0.88$) region.

Correlating reaction times with lower beta activity over central scalp sites and upper beta activity over frontal scalp regions found no significant correlations (all $p_s > .05$).

Discussion

This study explored the impact of experienced stress on elderly participants' cognitive performance in domains related to memory. By choosing the Flanker task to measure executive control, the study hoped to shed further light on the discrepant age-related performance differences reported in past papers using this paradigm. Behavioural findings indicated a general reaction time deficit among high stress elderly relative to young participants, which extended to both congruent and incongruent stimulus arrays. These behavioural shortcomings were found to correlate with heightened levels of event-related-desynchronisation in the alpha frequency range manifested by high stress elderly participants over left central and right posterior regions of the cortex.

Behavioural Findings

Results discovered no age differences modulated by interference between young and elderly participants. This finding is in line with previous work comparing elderly and young on the Flanker paradigm and reporting no increased interference effects for elderly individuals (Wild-Wall et al., 2008; Hsieh et al., 2012). However, both of the aforementioned studies reported a general age-related slowing of response speed, which is a common occurrence across multiple executive reaction time paradigms (Bashore et al., 2014) and which likewise manifested in our data set. Interestingly, this general age-related slowing was magnified when comparing elderly and young participants in the high experienced stress group. Findings to this effect indicate that Flanker task performance may vary between elderly participants and provide a possible explanation for the discrepant findings in the literature (Zeef & Kok, 1993; Hsieh et al., 2012). This highlights the importance of considering factors which may exacerbate ageing decline and provides evidence that the impact of experienced stress on ageing is not exclusive to working memory retrieval and maintenance, as evidenced by a number of past studies (Peavy et al., 2009; Dickinson et al., 2011; Marshall et al., 2015), but extends to sensory-motor and inhibitory control performance on executive paradigms.

However, with respect to inhibitory control, elderly high stress participants' behavioural shortcomings diverge from those reported in previous papers, as no age differences regarding the increase from congruent to incongruent conditions emerged, but a general deficit extending to both kinds of stimulus arrays. Past studies found significant age differences and reported that these manifested by elderly individuals displaying longer reaction times in the incongruent compared to the congruent condition, a difference which was less pronounced among young participants (Zeef & Kok, 1993; Zeef et al., 1996).

Two possible scenarios can account for this study's divergent behavioural findings. One interpretation given the observed behavioural data pattern is that rather than promoting inhibitory deficits among elderly participants, cumulative stress relates to increased decline of sensorimotor control, exacerbating the general age-related slowing normally found when comparing elderly to young individuals (Bashore et al., 2014). In line with this idea, a number of studies report that a breakdown of inhibitory performance is reflected in reduced accuracy rates rather than increased reaction times (Penades et al., 2007; Hutton & Ettinger, 2006), a difference which did not manifest for our data set. A second possibility is that cumulative stress does relate to impaired executive control, exacerbating general age-related slowing by adding an inhibitory deficit of irrelevant information processing. In this scenario the performance pattern reported in this study may be the result of our Flanker task design. Similar to designs by Carrasco and colleagues (2013) and Hsieh, Liang & Tsai (2012) flankers and target stimuli in the current study appeared on screen simultaneously. As flanking stimuli did not precede the target stimulus, they did not guide attention in an either advantageous or misleading way. Therefore, they acted purely as distractors from the central target and since their appearance could not be used to obtain information ahead of target presentation, the best strategy may lie in screening out the flanking stimuli completely to focus accurately on responding to the target. Behavioural deficits of elderly high stress participants may therefore be explained as an overall inability to shield against the flanking stimuli drawing attention from the central target and may thus produce the observed increase in reaction times.

Electrophysiological Findings

Results revealed that elderly high stress individuals showed increased levels of alpha event-related-desynchronisation (ERD). Inspection of group average waveforms revealed that elderly high stress participants were the only group to manifest desynchronisation, as both young and low stress elderly participant groups displayed enhanced levels of synchronous alpha activity during encounter of the flanker array. Increased levels of alpha synchronisation have been linked to both sensorimotor and attentional inhibitory control. With respect to sensorimotor involvement, alpha ERS is thought to indicate an inhibited or deactivated motor region while ERD is thought to reflect an active brain region engaged in motor execution (Neuper, Woertz & Pfurtscheller, 2006; Deiber et al., 2012). In terms of attentional control, alpha ERS is linked to the successful inhibition of brain regions not necessary for stimulus processing or maintenance (Cooper et al., 2003; Klimesch, 2012), thereby facilitating the reduction of potentially distracting information (Sauseng et al., 2009). In line with these accounts, a number of Flanker studies report heightened levels of alpha synchronisation (Hogan et al., 2013; Compton et al., 2014). Similarly to the behavioural findings, electrophysiological results can therefore be explained in two possible ways. Corresponding to the idea that cumulative stress relates to a sensorimotor control deficit, the high levels of alpha ERD displayed by high stress elderly participants may highlight an over-activation of the motor system (which is successfully inhibited by ERS displayed by young and elderly low stress counterparts). This may lead to the observed increase in reaction times due to response inhibition from conflicting non-motor (right posterior) and motor (left central) regions which should have been suppressed for optimal task performance. Ageing has been shown to produce deficits regarding motor cortex excitability (Yordanova et al., 2004). However, past investigations of age-related Flanker performance focussing on the lateralised readiness potential as an EEG indicator of motor preparation reported no age effects on the motor level (Hsieh et al., 2012). Similarly, should our alpha findings be restricted to motor control and execution we would have expected to find a corresponding pattern in the beta frequency range (12-30 Hz). Finding no age or stress effects in the beta range which has been explicitly linked to planning and execution of movement (Pfurtscheller et al., 2003) detracts from this interpretation.

Conversely, if cumulative stress produces impairments regarding attentional inhibition, the increased levels of alpha ERS displayed by low stress elderly and young participants can be argued to reflect the successful inhibition of flanking distractors, an assumption which is further strengthened by the main effect of congruency, indicating higher alpha synchronisation towards the more distracting, incongruent stimuli. Coupled with the increased reaction times manifested by high stress elderly participants, their ERD may therefore indicate a breakdown of inhibitory control processes, thus leaving them more vulnerable to the distracting influence of the flanking stimuli. This interpretation corresponds to past work (Wascher et al., 2012; Gazzaley et al., 2008) which reported that elderly individuals do not suffer from impaired sensory/perceptual processing but suffer from an impaired as well as delayed top-down control mechanism responsible for reallocating attention in the face of distracting information.

Conclusions and Limitations

This study provides a possible explanation for previous discrepant findings concerning age-related Flanker task differences, highlighting that performance may not homogenously decrease among elderly individuals but may relate to individual rates of cognitive decline as a result of multiple impacting factors. Thus, findings complement the picture of increased inter-individual variability among elderly individuals' cognitive performance (Christensen et al., 1999) and provide further evidence for the detrimental effect of cumulative stress on cognitive ageing, highlighting that impairments as a result of increased stress exposure are not exclusive to memory but extend to other cognitive domains. However, a number of questions still remain.

In terms of study design, we chose not to vary the inter-stimulus interval between the blank screen and onset of the flanker display. We adopted this approach after designs by Hsieh and colleagues (2012) as well as Wild-Wall and colleagues (2008) to make our findings compatible with their earlier reports. However, this may have resulted in anticipatory preparation processes, which could have affected our electrophysiological results. For example, enhanced beta activity has been reported to occur both as a result of motor planning as well as perceptual anticipation (Birbaumer et al., 1981) and thus, our beta findings may be exacerbated due to our task design. Furthermore, we used two different measures to assess cumulative experienced stress among elderly and young participants which impacts on direct comparisons between both scales. For this reason, we refrained from comparing any main effects of experienced stress scores and focussed instead on the interactive relationship between age and experienced stress. We would further argue that even if the same scale had been used for both age groups it would nevertheless not be pertinent to compare this main effect as relative to young, elderly participants would necessarily obtain a higher stress score and might construe the scale differently based on their viewpoint (looking back after having lived most of their lives vs. young individuals having most of their time still ahead). For this reason we chose to use two different scales which were more appropriate for our different age groups. To ensure differences resulting from different scales were kept to a minimum we further standardised cumulative stress scores within age groups.

With respect to our data pattern, our behavioural as well as our electrophysiological data can be explained with two different accounts regarding inhibition[2]. Therefore, it is, at this moment, not possible to firmly conclude whether the adverse effect of cumulative stress extends to inhibitory shortcomings in the sensorimotor or attentional domain. While our behavioural data points to a sensorimotor deficit, our findings are also compatible with an attentional interpretation. The absence of age and stress effects in the beta frequency range make the results more compatible with the latter. Further research should therefore extend this line of enquiry to determine which inhibitory domain is negatively affected by prolonged cumulative stress exposure. Past research has hypothesised that non-existent age-related performance differences may be the result of top-down compensatory control strategies engaged in by elderly individuals (Wild-Wall et al., 2008; Hsieh et al., 2012). These specify that elderly individuals may place greater emphasis on accuracy, maintaining error rates akin to those of young individuals at the cost of higher reaction times (Hoffmann & Falkenstein, 2011). In line with this speed-accuracy trade-off we discovered a general slowing of reaction times among elderly individuals without any age differences concerning error rates. As increased reaction times were magnified among our high stress elderly participants one could hypothesise that these individuals are engaging in inhibitory compensatory mechanisms to a higher extent, possibly as a result of stress induced depletion of cortical processing resources. However, should this be the case, we could expect elderly high stress participants to display higher amounts of alpha ERS (signifying increased top-down inhibitory control) and not the pronounced levels of alpha

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[2] With respect to the inhibitory interpretation of our findings, we must note that neither our behavioural nor electrophysiological data produced a stress or age related interference effect (i.e. increased alpha activity and reaction times to incongruent relative to congruent trials). This may be a result of our design, which presented targets and flankers simultaneously. As a result, both types of flanker arrays may have acted as a distracting influence by drawing attention away from the central target and differences between corresponding and conflicting stimuli may not have emerged. However, as interference is more likely from incongruent stimuli, an inhibitory interpretation should be approached with caution.

desynchronisation we observed. However, compensatory processes may occur on a different level to that of top-down inhibitory control, possibly manifesting in domains of sensory perception or motor preparation and execution. Indeed, our findings of increased beta ERD among elderly participants implicate performances related to motor execution as relevant processes (Pfurtscheller et al., 2013). Therefore, even though our alpha findings detract from a compensatory account concerning inhibitory mechanisms, instead indicating a breakdown of inhibitory functioning among low performing high stress elderly participants, we cannot rule out that the age- and stress-related response slowing may point to a compensatory mechanism occurring in motor or perceptual domains.

Interestingly, our topographical findings did not emerge for frontal scalp sites relating to cortical regions (dlPFC; ACC) which are integral to executive top-down control as well as vulnerable to the effects of cumulative stress and ageing. Instead our group differences emerged for the left central and right posterior scalp regions. While the left central area relates to movement control over the motor cortex, the right posterior area is engaged in visual attentional domains, thus in light of both the sensorimotor as well as the attentional inhibition explanation, the increased alpha ERD displayed by high stress elderly individuals may signify an inability to shut-down brain regions either irrelevant or actively opposed to the screening of irrelevant information or execution of correct motor actions. What must be noted with respect to our topographical maps is that, compared to high stress young, elderly high stress participants display a widespread cortical increase of alpha ERD which only reaches significance for the aforementioned two scalp regions. As such, elderly high stress individuals seem to have a global difficulty in constraining brain regions unconducive to task performance.

A final point of discussion concerns the relationship between cumulative stress and elderly high stress individuals' task performance. As our work assesses a longitudinal phenomenon, we are unable to manipulate this variable and therefore cannot make concrete claims about the direction of our proposed relationship (i.e. do higher levels of stress accelerate cognitive decline or do individuals with reduced cognitive resources experience higher levels of stress due to impaired coping abilities). However, in-vitro cell work demonstrates that cumulative experienced stress causes direct damage to brain regions integral to cognitive performance (Sapolsky & Meaney, 1986; Rabbitt, 2005). Furthermore, longitudinal work undertaken by Pesonen and colleagues (2013) demonstrates that individuals reporting high levels of experienced stress show cognitive impairments in later life while no performance differences were apparent between these individuals at the age of 20 years. Both lines of work advocate the interpretation that stress accelerates cognitive shortcomings in old age.

In conclusion, this study sheds light on multiple issues regarding cognitive ageing. Behavioural as well as electrophysiological results indicate that experienced stress is not only harmful to elderly participants' memory performance but extends to executive control processes in the form of inhibition. To the best of our knowledge this paper is the first to widen the current literature regarding cumulative experienced stress and cognitive ageing in this manner. Furthermore, results provide a possible explanation for the discrepant age findings regarding Flanker task performance. Results therefore contribute to a deeper understanding of ageing cognitive processes and the factors or circumstances that may impact on them.

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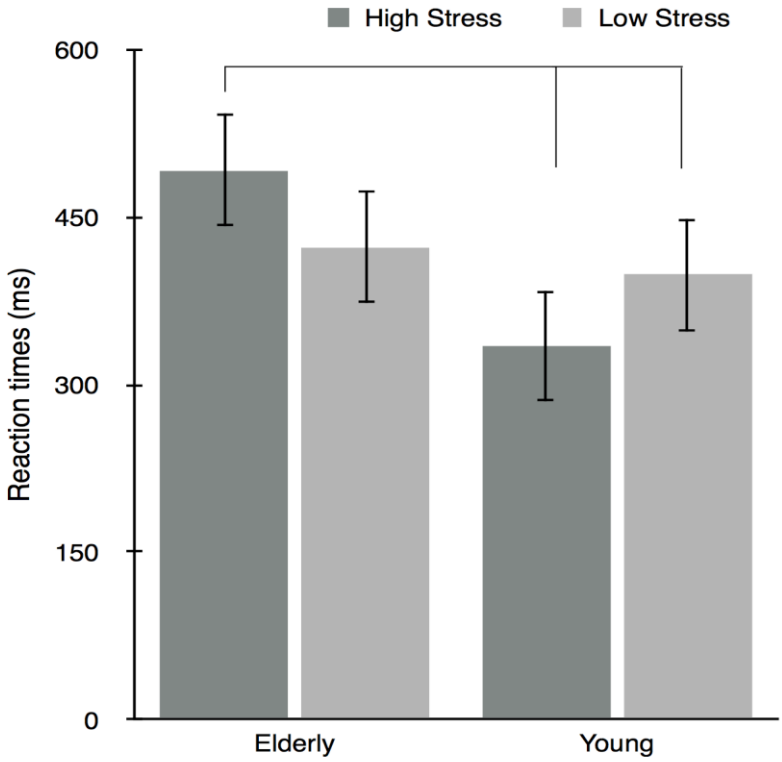

Figure 1. Reaction time scores of both age and stress groups. Results indicate significantly longer reaction times of high stress elderly group members relative to young low and high stress participants. Error bars reflect SEM.

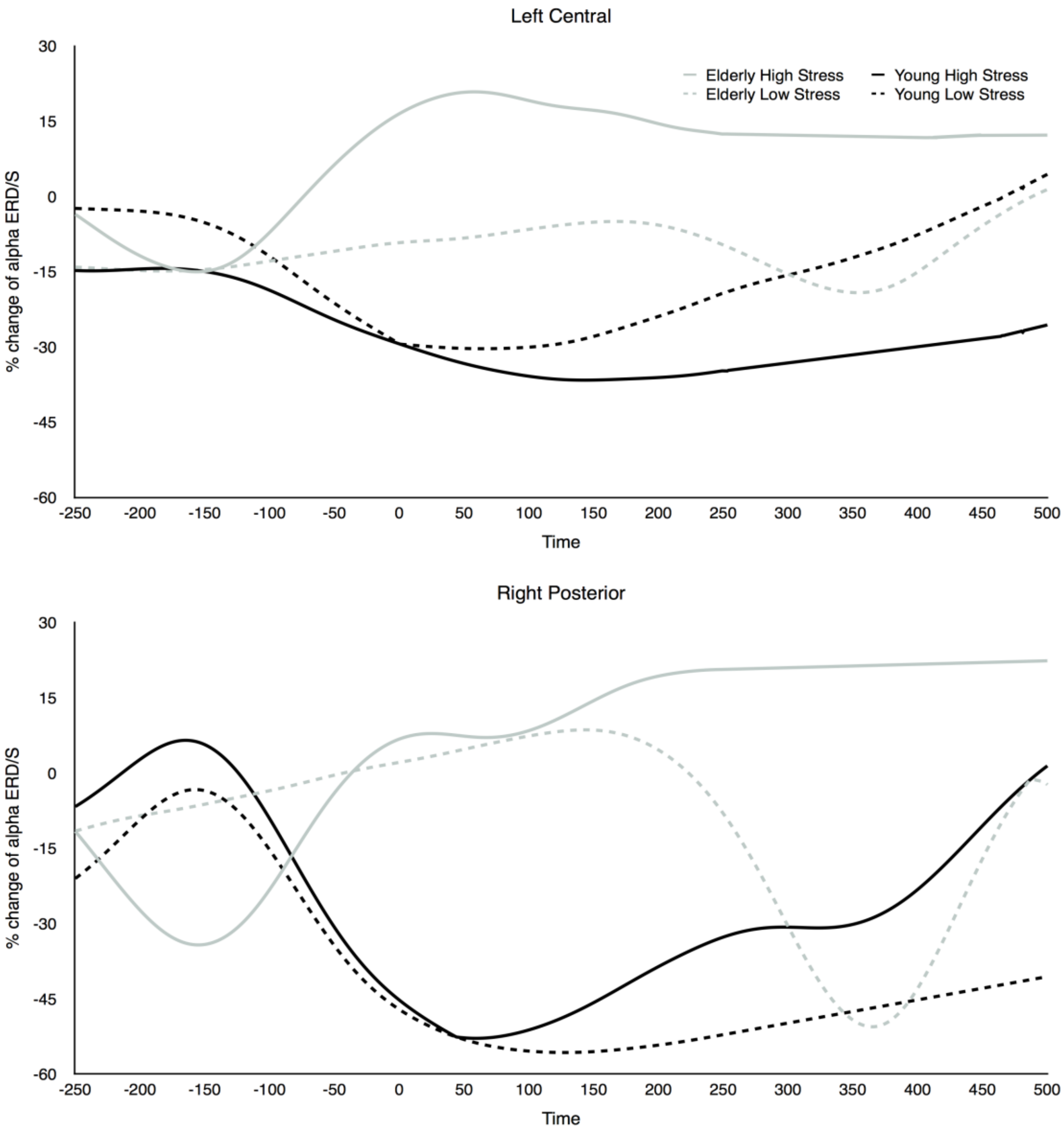

Figure 2. Grand average waveforms of the alpha frequency range computed for both stress and age groups over the left central and right posterior cortex. Axis show the % change of alpha ERD/S (x-axis) over the time course of stimulus encounter (y-axis): -250 – 0 pre stimulus baseline, 0 - 500 stimulus presentation. Elderly high stress participants show heightened levels of alpha ERD, which produces a significant difference relative to young high stress counterparts.

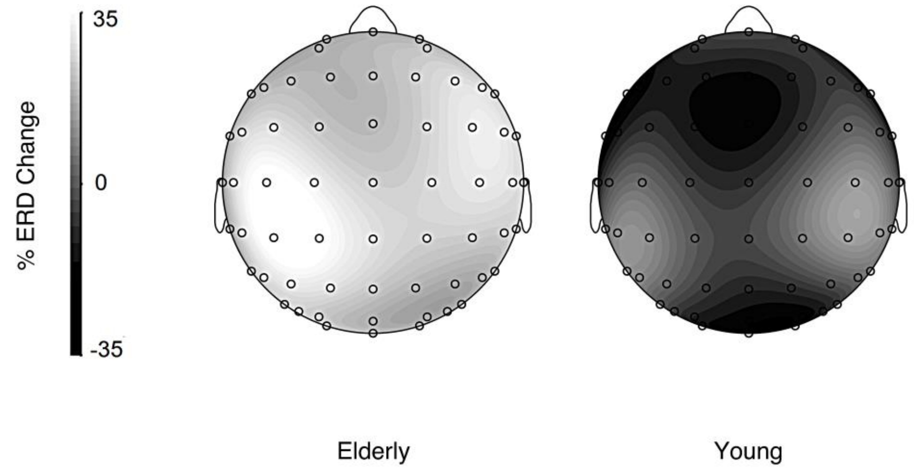

Figure 3. Topographical map of % ERD change for high stress elderly and high stress young participants. Elderly high stress participants show globally enhanced levels of alpha ERD (significant compared to young high stress individuals for left central and right posterior scalp regions). On the scale, negative values indicate alpha ERS while positive (lighter) values signify ERD.

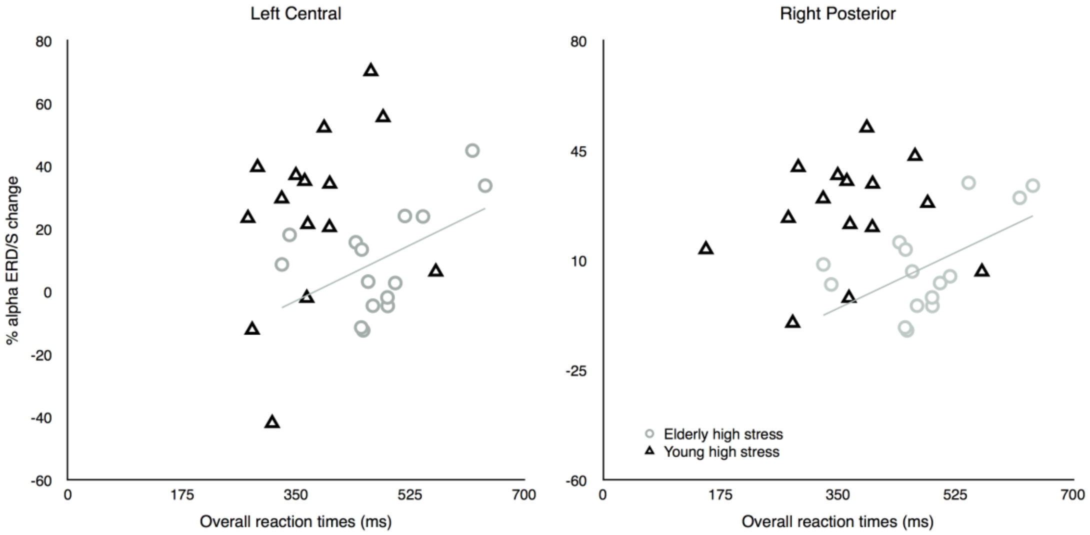

Figure 4. Correlations between % change of alpha event-related activity (y-axis) and overall reaction times (x-axis) for both congruent and incongruent flanker arrays. For both the left central and right posterior scalp areas, higher amounts of alpha ERD correlates with longer reaction times for high stress elderly participants.

Table 1. Demographical information of elderly and young participants split by experienced stress group

	Elderly		Young	
	Low Stress	High Stress	Low Stress	High Stress
Group Size	15	15	15	15
Age	67.8 (6.3)	68.6 (5.4)	21.9 (4.1)	20.7 (2.5)
Gender	8 ♂	8 ♂	6 ♂	7 ♂
Education	3.4 (1.3)	3.5 (1.1)	4.1 (1.2)	4.27 (0.6)
Cigarette Consumption	0	0	0	0.2 (0.6)
Alcohol Consumption	1.53 (1.5)	2.2 (1.7)	1.3 (1.7)	0.9 (1.0)
Presence of Physical Disability	2	3	0	1
Exercise	2.73 (1.1)	2.67 (1.1)	2.1 (1.0)	2.7 (1.0)
Mini Mental State Score	30	30	n.a.	n.a.
Trait Anxiety Score	35.53	35.8	39.87	37.87
State Anxiety Score	29.47	26.73	32.53	30.8
Experienced Stress Score	461.3 (142.7)	864.5 (94.5)	389.67 (112.5)	736.5 (109.0)

Note. Education ranging from 1 (lower than High School) – 6 (University PhD degree); Cigarette Consumption: cigarettes per day; Alcohol Consumption: units per week; Exercise: hours per week.