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Title: Gender Differences in Prefrontal Brain Activation Across Sitting Postures: A Functional Near-Infrared Spectroscopy Study

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Abstract

Purpose: Gender differences in cognitive processing and brain function have been widely studied, but their interaction with postural changes remains underexplored. This study assessed how sitting posture (upright vs. forward head posture) affects prefrontal brain activation in males and females, as measured by functional near-infrared spectroscopy (fNIRS).

Methods: Twenty-seven healthy participants (14 males, age = 21.5 ± 1.5, 13 females, age = 24.6 ± 1.9) performed the Stop-Signal task in the upright and forward head sitting posture. At the same time, the oxygenation levels of the prefrontal cortex were measured. Gender-based differences in oxygenation patterns were analysed.

Results: We observed a significant difference in deoxy-Hb levels between males and females across different sitting postures. However, sitting posture did not significantly affect prefrontal activity, processing speed, accuracy, or inhibitory control abilities overall.

Conclusion: Within the confines of this study, significant differences were found in deoxy-Hb levels between males and females across different sitting postures. However, sitting posture did not significantly affect participants' inhibitory control abilities or prefrontal activity. The interaction between gender and sitting posture suggests possible differences in the effects on cognitive processes between males and females. It is plausible that the limited duration of sitting posture exposure may have mitigated substantial changes in cognitive performance or brain oxygenation. Future studies should consider longer intervention durations and a more thorough exploration of potential confounding variables.

Keywords: Sitting Posture, Inhibition, Functional Near-Infrared Spectroscopy (fNIRS), Processing Speed, Processing Accuracy

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Highlights

- A significant gender difference in prefrontal cortex deoxygenated haemoglobin (Deoxy-Hb) levels was observed across different sitting postures.
- Females exhibited higher Deoxy-Hb levels than males, specifically in the forward head posture, suggesting gender-specific neural responses to posture.
- Sitting posture did not significantly affect cognitive performance, including response inhibition, processing speed, or error rates.
- Oxygenated haemoglobin (Oxy-Hb) levels were generally higher in the upright posture, though not statistically significant.

Plain Language Summary

This study examined how different sitting postures- upright and forward head- affect brain activity and cognitive performance in males and females. Using a brain imaging technique called functional near-infrared spectroscopy (fNIRS), researchers found notable differences in how men and women's brains respond to these postures. While posture alone did not change cognitive abilities such as reaction time or accuracy, women showed higher levels of brain activity in the forward head posture than men. These results highlight the importance of considering gender when studying posture and brain function, and suggest that posture may influence brain oxygenation even if it does not immediately impact task performance.

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Introduction

Whether for work or recreation, a significant portion of people spend a lot of time sitting. Increased sitting time may be harmful to people's health, particularly psychological and mental health issues, including anxiety and depression (1,2). Risk factors for incorrect posture include a sedentary lifestyle, low levels of physical activity, and improper sitting posture (3). This problem has been worsened by the current technology era, which has increased people's poor posture, especially among students expected to conform to greater academic requirements (4,5). Long-term computer and smartphone use combined with a sedentary lifestyle might weaken the surrounding soft tissues by causing stiffness in the shoulders and neck muscles (6,7). This can often result in Forward Head Posture (FHP), which is defined by chronic muscle contractions that impair the craniocervical junction and increased lordosis at the skull-neck intersection (7,8). Interestingly, people who spend much time in front of computers are more likely to acquire FHP (8). Furthermore, studies indicate that these lifestyle and postural factors may impact psychological cognitive functions (9). Therefore, it makes sense to investigate the possible connections between posture and cognitive function in more depth. This is because postural abnormalities that result in muscle imbalances and tension can also induce cognitive impairment in professionals, students, and anybody else who spends a lot of time sitting still (5). Research indicates a relationship between cognitive functions and bodily cues, and that body position significantly impacts cognitive function (10). According to the literature, sitting upright improves cognitive processing, while slumped postures are associated with reduced cognitive function (10,11). This emphasizes how crucial it is to look into how body position affects cognitive function to further our knowledge of the complex interaction between posture and cognition. Though, in certain instances, it was stated that there was no change in specific cognitive characteristics in different sitting positions, the accuracy of these findings has not yet been shown beyond a reasonable doubt (10). Also, most studies that used intentionally adjusted posture are included in these findings (10,12). As a result, it is not unreasonable to adjust the height of the desks and chairs to prevent participants from being aware of the study's manipulation and to motivate them to adopt a particular posture.

Inhibition control indicates the ability to control inappropriate behavior or override the processing of distracting or irrelevant information (13). It is strongly connected to young people's mental health (14) and good habits (15); thus, it is possible to find some associations with postural habits in human beings. Effective inhibition control is related to forming and keeping good habits and fostering behaviors that support long-term health and productivity (14,16).

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Given its importance, there is a growing interest in understanding how different factors, including postural habits, can influence inhibition control (17,18). Owing to its significance, there is a rising curiosity about how various elements, such as posture, can affect inhibitory control. According to research, our physical posture can affect our mental health and cognitive function. This means that how we sit, stand, or walk might affect our ability to control distractions and stay focused (19). Exploring the connections between postural habits and cognitive functions like inhibition control could provide useful insights into suggestions for enhancing mental health and maximizing cognitive performance in everyday life (20).

Functional Near-Infrared Spectroscopy (fNIRS) assessments using optical absorption reveal hemodynamic changes in the prefrontal cortex that are important for understanding cognitive functions, including postural control (21). fNIRS records changes in regional cerebral blood flow, showing higher oxygenation in activated brain regions in the same way that magnetic resonance imaging identifies brain activity. These activations can provide insight into the brain mechanisms controlling postural stability and cognitive performance since they are closely associated with cognitive tasks (22). To be more precise, the prefrontal cortex is critical for executive functions, including motor planning, attention, and decision-making—all of which are necessary for maintaining balance and proper posture (13). Research has demonstrated that deficits in postural control and cognitive function are linked to disturbances in prefrontal activation (23). To clarify how the brain integrates sensory information to coordinate motor responses and maintain stability in various environmental settings, it is necessary to understand the link between posture and prefrontal activation/cognitive functions (14). A growing body of research indicates that postural behaviors may impact cognitive function (10), and some studies have found a link between postural modifications and prefrontal activation (23). To definitively prove this association, more research is necessary. Using fNIRS, we can evaluate the relationship between changes in various sitting postures during cognitive processing and the temporal dynamics of prefrontal activation. In addition to advancing our knowledge of the neurological underpinnings of postural control, this research will shed light on the potential effects of various sitting postures on cognitive performance, which will have ramifications for ergonomics and posture-correction techniques (10,24).

Furthermore, previous studies suggest that gender differences majorly affect prefrontal brain activation and cognitive tasks (25). Studies reveal that differences in brain structure and function across genders may affect how males and females react to certain postural demands and cognitive tasks (26,27). For example, prior research has demonstrated that cerebral blood flow patterns

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and cognitive strategies may differ in females and males (25,27). Gender analysis allows us to investigate whether male and female prefrontal activation patterns and postural control methods differ when they complete cognitive tasks in various sitting postures. This may enable us to provide cognitive enhancement and posture correction procedures for different genders more successfully.

Despite numerous studies on the effects of sitting postures on cognitive functions (24), limited research has examined the effects of these postures on brain activity, especially in the prefrontal cortex (10). In addition, most of the existing studies have not paid sufficient attention to gender differences in this field. This is while gender differences in brain activation patterns and postural control strategies can affect cognitive function differently. Therefore, examining the effects of sitting postures on prefrontal cortex activity by considering gender differences can lead to a better understanding of the relationship between body posture, brain function, and cognition. Therefore, this study aimed to examine the effects of sitting posture on prefrontal brain activation while emphasizing gender differences in these responses. Based on previous research, we hypothesized that (A) gender would significantly influence prefrontal activation and inhibition control patterns across different postures, and (B) prefrontal activation and inhibition control would be affected during different sitting postures.

Method

Participants

Twenty-seven students from Allameh Tabatabai's University in Tehran, Iran (14 males, age = 21.5 ± 1.5, 13 females, age = 24.6 ± 1.9) participated in this study. We determined that, with an effect size (Cohen's d) of 0.5, a power of 0.8, and an alpha level of 0.05, the necessary sample size was 27. This sample size was determined using G*Power based on an effect size (Cohen's d) derived from a previous related study examining posture effects on cognitive functions (28). In other words, prior research reported moderate effect sizes, justifying the selection of 0.5 to ensure adequate statistical power. All subjects had normal or corrected to be normal vision. The following were listed as exclusion criteria: (1) previous or current medical or psychological disorders, (2) having FHP, (3) being left-handed, defined by the short form of the Edinburgh Handedness Inventory (29). Left-handed people were excluded since students would use their right hands to answer the stop-signal task. All study participants provided written informed consent after receiving study information. Ethics approval for this research was obtained from the Ethics Committee of the Sport Sciences Research Institute (Ethical code:

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IR.SSRC.REC.1402.322). The authors confirm that all methods were performed in accordance with the relevant guidelines and regulations.

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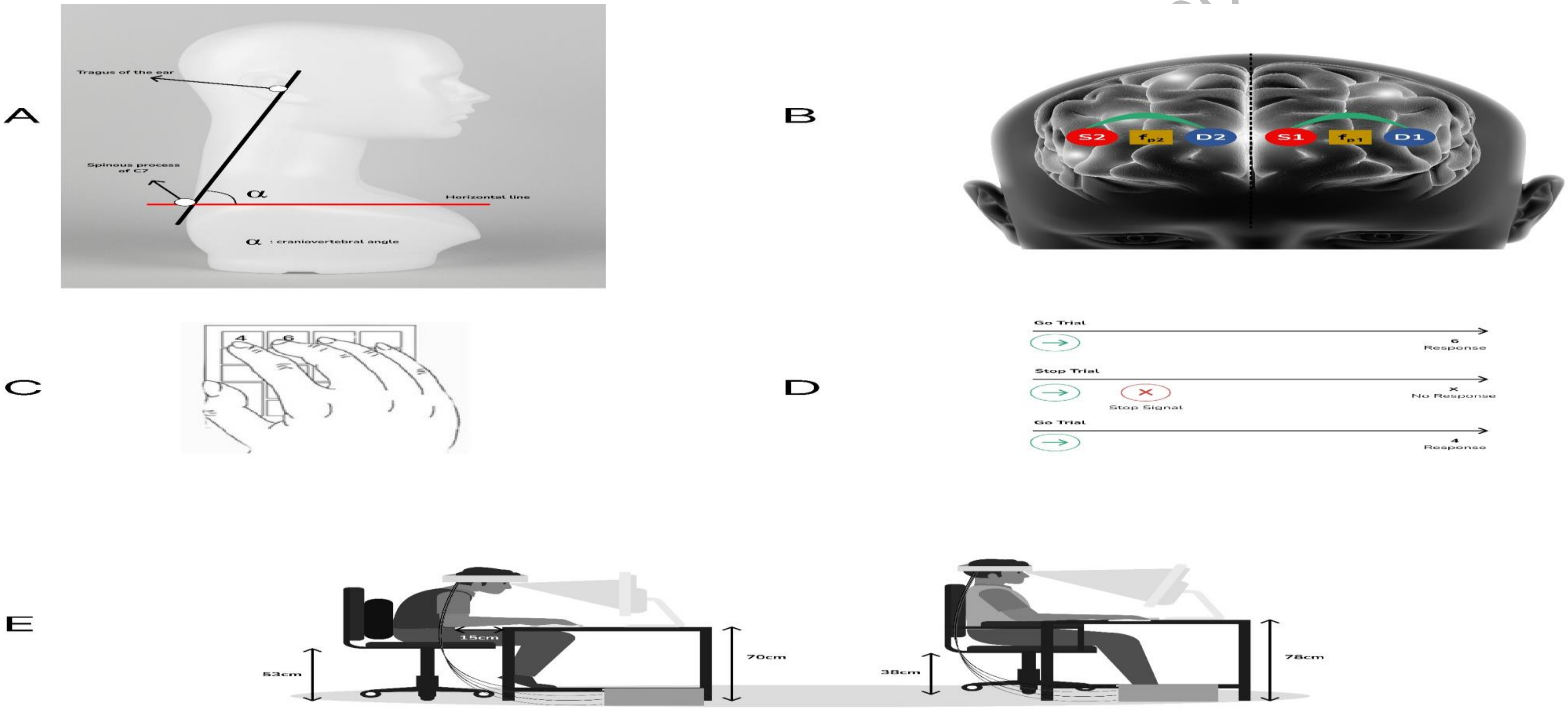
Figure 1. A Measurement of the Craniovertebral Angle**.** B The schema of the location of the source (red) and optical detectors (blue) given the position of FP2 and FP1 in recording fNIRS signals, given the international 10-20 system (yellow). **C, D** Stop-Signal task **E** Illustration of posture modification



Body posture manipulation

The purpose of the posture adjustment was to prevent the participants from paying attention to their own posture (10). As a result, before the test, we altered the participants' chairs and height-adjustable computer monitors, manipulating their posture: The desk and computer monitor were situated at a reasonably high height for the group that was seated upright, and the chairs were placed at a relatively low height (height of desk + computer: 78 cm; height of chair: 38 cm). Additionally, it was decided that there should be no space between the subjects' trunks and the table. The manipulation was performed in reverse on the group of participants instructed to sit with FHP (height of desk + computer monitor: 70 cm; height of chair: 53 cm; distance of trunk from the table: 15cm) (Figure 1). The findings demonstrated that when the distance between the trunk and desk was 15 cm, the shift in FHP was much higher during computer use(30). However, using support in the thoracic region also causes the thoracic spine and trunk to shift forward and towards thoracic kyphosis. The head can lean forward and downward in this circumstance(31). Therefore, to help the subjects with FHP, we used support in the thoracic spine region. We modified these changes in accordance with the height of Iranian students. Male and female students in Iran aged 18 to 25 are, on average, 1.74 meters and 1.59 meters tall, respectively, according to data from 911 Iranian universities (32).

Measures

Questionnaire

Furthermore, the International Physical Activity Questionnaire-Short Form (IPAQ-SF) was utilized to evaluate the physical activity levels of the included participants. This assessment evaluated the physical activity a week prior. This questionnaire's validity (0.85) and reliability (0.70) in Persian were both confirmed(33). The number of minutes devoted to each activity class was multiplied by the unique metabolic equivalent (MET) score for that activity in order to translate the IPAQ data to MET-minweek-1 for each type of activity. Each activity type's energy cost is taken into account when calculating the MET score. One MET is roughly equivalent to 3.5 ml O2/kg/min in adults and measures energy expenditure while at rest. In response to the IPAQ's scoring system, physical activity levels were ultimately divided into three levels: light, moderate, and vigorous(34,35).

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Moreover, we used the Depression, Anxiety, and Stress Scale-21 (DASS-21) to assess the mental health of participants. This questionnaire has high reliability (Cronbach's alpha > 0.90) and demonstrated validity across diverse populations (36). According to reports, the DASS questionnaire's Cronbach's alpha scores for depression, anxiety, and stress in Iranian people were 0.77, 0.79, and 0.78, respectively (37). Each category of mental health, comprising depression, anxiety, and stress, is covered by 7 items in this questionnaire. The ratings for the responses range from zero ("did not apply to me at all") to three ("applied to me very much or most of the time") on a Likert scale. Each scale's total score was determined by adding up the scores for the pertinent components and multiplying them by two, with a possible range of 0 to 42. Five categories of depression, anxiety, and stress were assigned to the participants: normal, mild, moderate, severe, and extremely severe. To determine the seriousness of each sub-scale, cut-off scores suggested by Lovibond and Lovibond were employed (36). Consequently, scores ≥ 21, 15, and 26 (respectively) for depression, anxiety, and stress were deemed serious. Each scale's higher score indicated a more severe mental condition (36,38).

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Test Paradigm: Response Inhibition Test

In our research, we evaluated inhibitory control using the Stop Signal paradigm (Schuhfried GmbH, Austria) (form S1; (39)). A set of arrows pointing either left or right is displayed on a screen in this task (40). In order to respond, participants must press the "5" key to indicate a left arrow or the "6" key to indicate a right arrow as rapidly as possible (Figure 1). Every arrow is shown for one second, after which the screen is blank for one second. There are 200 trials total in the test, split into two parts of 100 trials each.

Stop signal delay (SSD) and stop signal reaction time (SSRT) are two of the four main factors that the stop signal paradigm measures. The Stop Signal Presentation Time (SSRT) measures how long it takes to suppress a response after it has been presented. The interval of time between the display of the go stimulus and the stop signal is referred to as the SSD (41). Furthermore, records were kept of commission errors, which are wrong answers to go trials, and omission errors, which are incorrect responses to go trials.

fNIRS measurement

In this work, we employed the Oxymap124 fNIRS system of the University of Tehran (66, 67). Oxymap124, which is a continuous wave (CW) fNIRS equipment, uses two wavelengths of 730 and 850 nm with a sampling rate of 10 Hz. Using double-sided medical adhesive, two Optodes were applied to the forehead with the midpoint of each probe centered on the Fp1/Fp2 locations (International 10-20 system) (Figure 1). An elastic cap was then applied over the optodes on the head to shield them from the ambient light. The prefrontal Cortex (PFC) was chosen as the location for signal recording because it is connected to higher cognitive and attention activities (42). The source-detector distance of each Optod was set to 25 mm. Both fNIRS channels were categorized as belonging to Brodmann area 10 (BA 10), which contributes to attention, inhibitory control (43), and prefrontal oxygenation (44). Numerous NIRS investigations document changes in BA 10's hemodynamics. The majority have been done on healthy people. In the data provided, the distribution of medial and lateral alterations appears to be equal. While medial BA 10 was said to exhibit oxygenated deactivations after pain (5/5 studies), lateral BA 10 is more frequently linked to oxygenation activations (4/5 studies) (44).

In accordance with probabilistic anatomical craniocerebral correlation (45), probes were projected to belong to the left and right medial prefrontal cortex (MPFC). To prevent motion artifacts, the participants were asked to minimize head movements during the signal recording (42,46).

Procedure

The craniovertebral angle (CVA), which is determined by the position of the head when viewed laterally at the seventh cervical (C7) vertebra, was measured to determine whether or not the patients had an FHP. This angle is obtained by drawing a line through the C7 vertebra's spinous process on the horizontal plane and connecting it to the tragus of the ear with a line (Figure 1). The angle is lower as the head position is perceived to be more forward(47). The subjects looked at a fixed point that corresponded to their eye height while maintaining their upright position, relaxing both of their arms adjacent to their trunk. The locations of the tragus of the ear and the spinous process of the C7 vertebra were noted in order to assess the position when taking a picture accurately. A digital camera mounted on a tripod was then placed 80 centimeters from the participants while they stood next to the wall in a specified area. Each participant's C7 vertebra served as the reference point for the height adjustment of the camera. Participants were instructed to stand naturally and securely with their arms above their heads three times while

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concentrating on an imagined spot on the wall. A tester took three pictures from the lateral side after a 5-second break. The CVA was ultimately determined by transferring the selected picture to a computer and utilizing ImageJ software (Rasband, USA) (48). A CVA less than 48–50 is considered FHP, and a smaller CVA is suggested for a greater FHP. The CVA cut-off in this study was 48; patients with a CVA of 48 or less were classified as FHP, and those with a CVA of 48 or more were classified as healthy(31). As a result, the CVA criterion for FHP in this study was set at ≥48°.

Previous research on the performance of cognitive tasks has demonstrated that effects may not be present when respondents are informed about the context of the investigation (10). Therefore, our participants were debriefed about the purpose of the study at the end of the experiment. The testing was performed at the same time of day for everyone. Each participant completed the task twice, once in the upright posture and once in the FHP. To control for order effects, participants were randomly assigned to two groups. Half of the participants started the task in the upright posture and then switched to the FHP, while the other half started in the FHP and then switched to the upright posture. A ten-minute rest period was provided between the two postures to prevent participants' mental states from adapting to the cognitive task.

First, participants had to complete the IPAQ-SF and DASS questionnaire in their considered posture for the task. This means that before beginning the cognitive task and fNIRS measurement, the participants had been in the altered posture for around 5 minutes. Following the instructions, the participants completed the stop-signal task while measurements of fNIRS were made in a quiet and dimly lit room.

fNIRS data pre-processing

The captured fNIRS signals in the present study were pre-processed using the HomER3 package (49), which was implemented in MATLAB R2020a (MathWorks, Natick, MA, USA). Using a pass range of 0.01-0.9 Hz, we implemented a 4th-order Butterworth band-pass filter to eliminate physiological artifacts while maintaining functional data (50,51). Motion artifacts were corrected using wavelet-based techniques available in HomER3 (52,53).

To eliminate slow signal drifts, baseline drifts were modified using a high-pass filter (52). For additional analysis, the raw light intensity data were transformed to optical density (49). Using

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the modified Beer-Lambert law, the fNIRS gadget automatically converted optical density to changes in concentration in OXY-Hb and Deoxy-Hb.

Statistical analysis

Data were analyzed with IBM SPSS Statistics 24.0 software for Windows (SPSS, Inc., Chicago, Ill, USA). The homogeneity of variances and normality of the distribution of the parameters were tested using Levene's and Shapiro-Wilk's tests, respectively. Two-way Repeated Measures ANOVA was performed in order to assess the stop signal task and hemodynamic changes. Our experimental design determined posture as the within-subject factor, representing the time variable with two levels: Upright and Forward Head Posture (FHP). Additionally, gender was the between-subject factor, with participants grouped into male and female categories. Partial eta squared was used as an effect size. Statistical significance was set at the level of $p < 0.05$.

Results

Participants Demographics

The demographic data in Table 1 shows key differences between genders in physical characteristics and health assessments. Significant differences in physical activity levels were seen between genders. Compared to females (38.4%), a considerable percentage of males (57.1%) reported high physical activity levels. On the other hand, 71.4% of males and 61.5% of females reported normal depression and anxiety levels, while similar proportions reported typical stress levels.

This contextual data assures that the participants' backgrounds will be appropriately considered when interpreting the results. Furthermore, the previously mentioned demographic findings underscore significant differences and similarities between male and female participants, providing a basis for comprehending plausible impacts on research outcomes.

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Table 1. Participant demographics.

Variable		Male (N = 14)	Female (N = 13)
Age (years)		21.5 ± 1.5†	24.6 ± 1.9
height(cm)		177.7 ± 6.2	163.0 ± 4.4
Weight (kg)		72.1 ± 9.3	58.1 ± 6.8
BMI (kg.m2)		22.8 ± 2.7	21.4 ± 3.0
CVA (degree)		55.0 ± 5.0	55.3 ± 4.4
Physical activity			
Low (n (%))		0(0)	1(7.6)
Moderate (n (%))		6(42.8)	7(53.8)
High (n (%))		8(57.1)	5(38.4)
Subjective health assessment			
Depression	Normal (n (%))	10(71.4)	8(61.5)
	Mild (n (%))	2(14.2)	3(20.0)
	Moderate (n (%))	1(7.1)	2(15.3)
	Severe (n (%))	1(7.1)	0(0)
	Extremely severe (n (%))	0(0)	0(0)
Anxiety	Normal (n (%))	10(71.4)	8(61.5)
	Mild (n (%))	2(14.2)	3(20.0)
	Moderate (n (%))	1(7.1)	2(15.3)
	Severe (n (%))	1(7.1)	0(0)
	Extremely severe (n (%))	0(0)	0(0)
Stress	Normal (n (%))	10(71.4)	8(61.5)
	Mild (n (%))	2(14.2)	3(20.0)
	Moderate (n (%))	1(7.1)	2 (15.3)
	Severe (n (%))	1(7.1)	0(0)
	Extremely severe (n (%))	0(0)	0(0)

Notes: † mean ± SD. **P-value ,0.05 considered to be statistically significant.
Abbreviations: BMI = Body Mass Index; CVA = Craniovertebral Angle.

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Cognitive performance

Stop Signal Reaction Time

Both male and female participants were tested for the Stop Signal Reaction Time (SSRT) in their forward head posture and upright positions. According to the study, there were no significant gender-posture interactions ($p = 0.800$) or differences in SSRT across the two postures ($p = 0.101$, partial $\eta^2 = 0.003$). This suggests that the inhibition process's speed was not substantially affected by either gender or posture (Table 2).

Stop Signal Delay

In addition, the mean Stop Signal Delay (SSD) for both genders and postures was assessed. The findings revealed no gender or statistically significant differences in SSD between the forward and upright head postures ($p = 0.150$, partial $\eta^2 = 0.053$). This implies that SSD did not change based on the individual's gender or posture (Table 2).

Error Analysis

We examined commission and omission errors to evaluate the participants' accuracy. In the forward head posture ($M = 9.74$, $SD = 5.57$) vs. the upright posture ($M = 10.7$, $SD = 5.04$), there were fewer commission errors; however, this difference was not statistically significant ($p = 0.206$, $\eta^2 = 0.040$). The number of commission errors in each of the different postures was not substantially influenced by gender ($p = 0.318$).

Gender did not have a significant effect on omission errors ($p = 0.402$), and there were no significant differences between postures ($p = 0.193$, $\eta^2 = 0.028$). These results imply that gender and posture had no discernible effects on the mistake rates (Table 2).

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Table2. Mean of cognitive task values for each sitting participants' posture during the Stop-signal task.

Variable	Upright posture		Forward head posture		Posture effect	Interaction effect	Partial Etta squared
	Male	Female	Male	Female			
Stop signal reaction time	0.2 ± 0.05	0.2 ± 0.07	0.2 ± 0.06	0.2 ± 0.05	0.101	0.800	0.003
Mean stop signal delay	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.150	0.247	0.053
Number of commission errors	10.7 ± 4.7	10.6 ± 5.5	10.5 ± 6.0	8.9 ± 5.0	0.206	0.318	0.040
Number of Omission errors	0.7 ± 1.1	4.2 ± 10.4	0.0 ± 0.0	1.0 ± 2.1	0.193	0.402	0.028

Notes: †statistically significant differences between the PLBP and Non-PLBP groups. **P-value 0.05 is considered to be statistically significant.
Abbreviations: ES; effect size

These results demonstrate that posture and gender did not significantly impact cognitive task performance regarding SSRT, SSD, and error rates.

Hemodynamic changes

To analyze hemodynamic changes, we measured the levels of oxygenated hemoglobin (OXY-Hb) and deoxygenated hemoglobin (Deoxy-Hb) in both upright and forward head postures for male and female subjects. According to the research, different sitting postures and genders had different OXY-Hb and Deoxy-Hb values.

Oxygenated Hemoglobin (OXY-Hb)

Gender and posture differences were observed in the mean OXY-Hb values. The mean OXY-Hb level in the upright posture was 4.1 ± 1.8 for male participants and 3.2 ± 0.8 for female participants (Figure 2). The OXY-Hb levels in the forward head posture were 2.7 ± 1.3 in males and 3.8 ± 0.8 in females. It appears that posture did not significantly affect OXY-Hb levels across genders, as revealed by the ANOVA results, which showed no significant interaction effect for OXY-Hb values ($p = 0.321$, partial $\eta^2 = 0.002$).

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Deoxygenated Hemoglobin (Deoxy-Hb)

Deoxy-Hb levels were found to follow different patterns depending on gender and sitting posture. In the upright posture, the mean Deoxy-Hb level of male participants was 4.0 ± 1.2, whereas that of female participants was somewhat lower at 3.0 ± 1.0. In contrast to males, who had a Deoxy-Hb level of 2.9 ± 0.9, females had a higher level of 4.3 ± 1.1 in the forward head posture. When taking into account the gender role, the main effect of posture on Deoxy-Hb values was significant ($p < 0.01$, partial $\eta^2 = 0.502$), showing that women performed the task with higher Deoxy-Hb values when in the forward head posture, which was not observed in men. Additionally, in different sitting postures, there was a significant difference in Deoxy-Hb levels between males and females (Table 3).

As illustrated in Figure 2, OXY-Hb values were generally higher in the upright posture (M = 3.7, SD = 1.52) as opposed to the forward head posture (M = 3.32, SD = 1.2). In contrast, the forward head posture (M = 3.61, SD = 1.23) had more intense Deoxy-Hb values than the upright position (M = 3.55, SD = 1.24). These results demonstrate how gender and posture have a major influence on Deoxy-Hb levels during the task.

Table 3. Mean of the concentration changes of oxy-Hb and deoxy-Hb during the stop-signal task.

Variable	Upright Posture		Forward Head Posture		Posture effect	Interaction Effect	Partial Etta squared
	Male	Female	Male	Female			
OXY-Hb	4.1 ± 1.8	3.2 ± 0.8	3.8 ± 0.8	2.7 ± 1.3	0.321	0.818	0.002
Deoxy-Hb	4.0 ± 1.2	3.0 ± 1.0	2.9 ± 0.9	4.3 ± 1.1	0.668	<0.01	0.502

Notes: †statistically significant differences between the PLBP and Non-PLBP groups. **P-value ,0.05 considered to be statistically significant.
Abbreviations: ES; effect size, OXY-Hb; oxygenated, Deoxy-Hb; deoxygenated.

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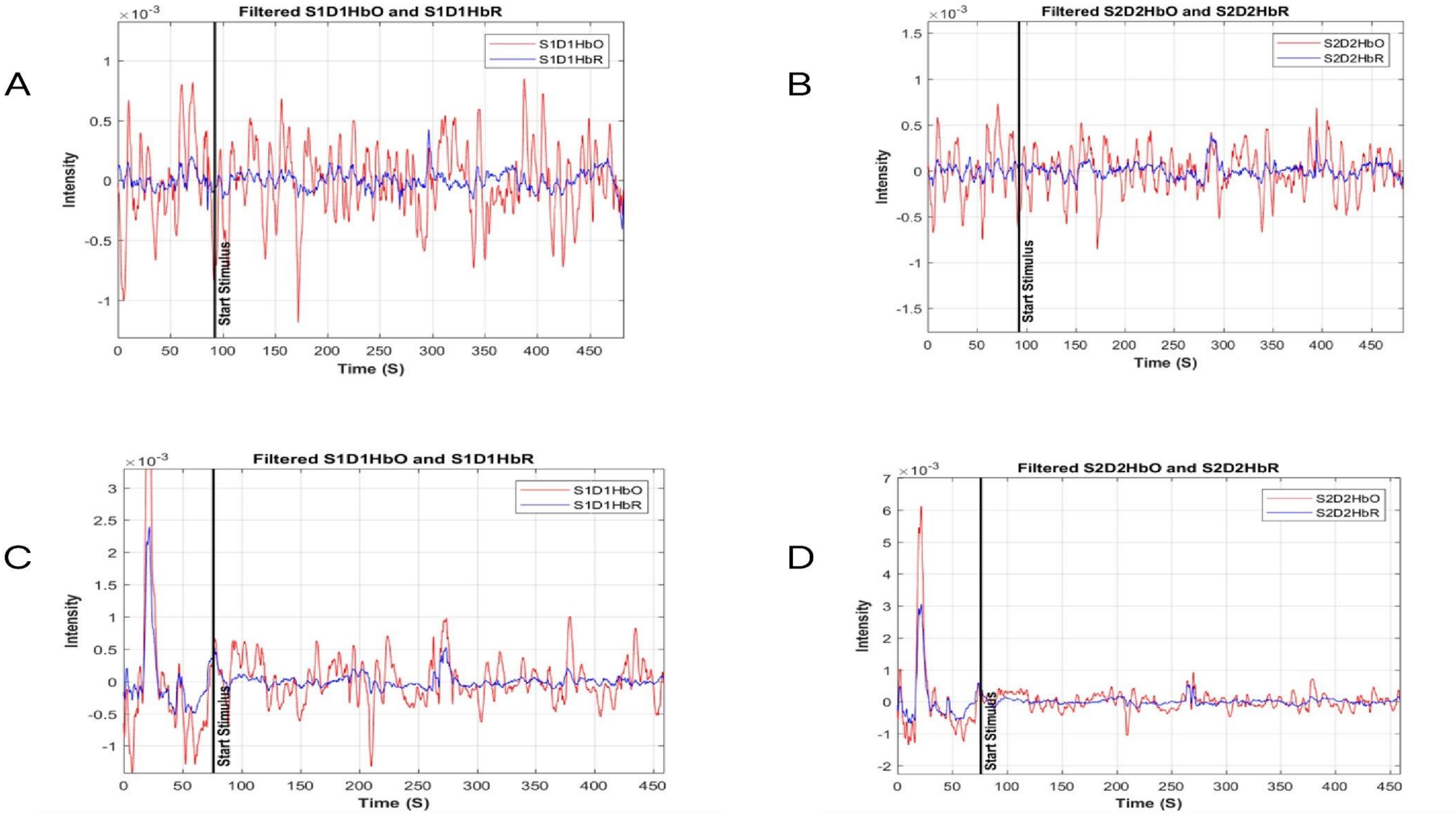
Figure 2. A, B Oxy-Hb and Deoxy-Hb Concentrations of the Brain Hemodynamic Response in Upright Posture, Recorded Based on the Inhibition Task. **C, D** Oxy-Hb and Deoxy-Hb Concentrations of the Brain Hemodynamic Response in Forward Head Posture, Recorded Based on the Inhibition Task.



Discussion

Our findings indicate that while short-term alterations in sitting posture do not significantly impact inhibition control or overall cognitive performance, gender differences in prefrontal oxygenation responses are evident. Specifically, females exhibited significantly higher deoxy-Hb levels in the forward head posture than males, suggesting distinct neural and vascular adaptations to postural changes. The main conclusions are as follows: (1) A statistically significant difference in [Deoxy-Hb] values between males and females ($p < 0.01$). (2) Higher [OXY-Hb] levels in the upright posture, but this was not statistically significant ($p = 0.321$); and (3) No significant difference in task performance between the two sitting postures in terms of processing speed and accuracy.

Our findings indicate that posture alone may not directly impact cognitive performance, as evidenced by the lack of significant differences in processing speed and accuracy between the upright and forward head postures during the Stop-Signal task. Regarding processing speed, previous work revealed that subjects in an upright position processed more objects in the d2-R task compared to a stoop sitting posture(10). Nevertheless, in our experiment, no significant differences were observed in the processing speed in either the male or female participants while performing the Stop-Signal task. Since they applied a different cognitive task, our results are not directly comparable. We propose various theories for why others' results differ from ours. One factor could be that earlier research predicted the advantageous benefits of upright posture on subject processing speed based on the number of processed items during the d2-R test(10). As a result of the differences in processing objects and speed processing in the current inhibition task, it is possible that findings in terms of processing objects cannot be easily translated to speed processing as measured in the Stop-signal task. Meanwhile, we calculated the speed of processing by considering SSRT and SSD. The SSRT is the amount of time needed to stop the reaction that the signal triggered. The SSD period for which participants successfully withhold the response 50% of the time is subtracted from the average response time to go trials to get this inference(54). Also, the stop signal delay (SSD) is the amount of time that passes after the arrow is displayed before the beep is heard. Using a step-by-step process, the task modifies the SSD based on performance. The SSD is reduced, making it simpler on the subsequent trial when a person fails to suppress their response after failing to react to a stop signal. The SSD is increased, which raises the challenge in the following trial when the individual effectively blocks their button click in response to the stop signal(54). By deducting SSD from the completion time, SSRT can be determined(41).

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Furthermore, contrary to our predictions, there are no significant variations in the number of errors and processing accuracy between the two sitting postures in the present inhibition test. Surprisingly, in a cross-sectional study of 82 participants conducted in Germany, there was no significant difference in processing accuracy between stooped sitting posture and upright posture. Actuality: In that study, participants did not perform less accurately when they were in an upright sitting position (M = 10.25, SD = 9.60) than when stooped (M = 10.14, SD = 7.42) (p =.477). In the current study, we could not find any significant effect of posture on participants' error analysis. Thus, it sounds like we should consider other possibilities for the interaction between posture and cognitive function. For instance, it is possible that posture influences attitudes and metacognitive thinking, which in turn influences cognitive performance(10). Participants who sat in an upright posture reported feeling substantially more proud after positive performance-related comments than subjects who slouched(55). On the same side, another study indicated that participants in upright postures had more confidence in their thoughts than those in stooped positions(56).

It has been proposed that physiological changes occur as a result of an alteration in posture(10). For instance, it has been demonstrated that an upright posture enhances electroencephalographic (EEG) arousal and focused attention, implying that postural adjustments can be beneficial in preventing fatigue in sleep-deprived persons(57). Furthermore, the upright participants had a greater pulse pressure response throughout the stressor and recovery than the slumped ones(19). During the stress task, individuals in the upright position experienced greater pulse pressure, which was sustained during the recovery time. These findings represent higher physiological arousal in the upright group than the slumped group(10,19). Our findings, however, are not directly comparable to those of these investigations because they used a different task and a different postural task. The current study showed no significant differences in prefrontal oxygenation between the two different sitting postures when doing a stop-signal activity.

However, participants in upright posture exhibited higher [oxy-Hb] values than those in FHP, which is in line with similar findings. This implies that sitting posture can greatly influence prefrontal cortex oxygenation levels. According to studies, maintaining an upright posture can improve cerebral blood flow and oxygenation by improving cervical spine alignment, which lowers vascular resistance and encourages more effective blood circulation. Additionally, keeping one's body upright may aid in respiration, which could result in more oxygen and, ultimately, higher [oxy-Hb] levels. It is important to note that the impact of sitting posture on prefrontal brain oxygenation was only seen during the current study. This result is consistent

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with findings indicating that sustained exposure may be required to notice more severe effects and that brief posture alterations may not be adequate to produce significant changes in brain oxygenation. The minimal effects observed in our study may also be explained by individual differences in physiological adaptability and baseline cognitive function, which may reduce the impact of posture on brain oxygenation.

However, the significant difference in [Deoxy-Hb] values between males and females in the FHP was an especially notable observation. Females showed greater amounts. The difference in hemodynamic response between both genders highlights the need for more investigation into how sitting posture affects brain oxygenation and cognitive function differently in each gender. Females' greater [Deoxy-Hb] levels during the FHP may indicate different vascular or metabolic reactions to postural changes, which may be mediated by differences in hormones or anatomy (58). This physiological reaction unique to gender may affect cognitive function, indicating the need for specialized cognitive therapies and ergonomic suggestions (59). For example, females might benefit more from interventions that address forward head posture to optimize cognitive function and brain oxygenation. Taking these differences in gender into consideration, future studies should examine the long-term impact of posture on cognitive function as well as the underlying physiological mechanisms. A greater comprehension of the connections between posture, cognitive function, and brain oxygenation may be achieved by extending the duration of posture exposure and utilizing a range of cognitive tasks.

Limitations and directions

The lack of significant differences in task performance and prefrontal oxygenation between the two sitting postures supports the theory that the short sitting duration on this test may not be enough to cause significant changes in brain oxygenation or cognitive function. The effects of sitting posture on prefrontal brain activity and inhibition control may also need longer exposure times or particular interventions to become noticeable. In addition, various factors, including individual differences in comfort and alternative postures, might have affected the outcomes.

These findings contribute to our understanding of the complex relationship between sitting postures, cognitive characteristics, and brain interest. They advise that while sitting posture may additionally have theoretical implications for cognitive performance and brain oxygenation, its practical significance in a short-term context can be constrained.

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Future studies on this area need to take a few things into account. Initially, extended exposure to specific sitting postures and cognitive interventions (e.g., ergonomic adjustments) may help clarify whether more significant effects develop gradually. Investigating how a person's decisions and habits related to their sitting posture affect their cognitive abilities and mental traits may also yield insightful results.

Ultimately, during a brief Stop-signal mission, this study found no significant differences in prefrontal oxygenation or cognitive function between participants in Forward Head Posture and Upright Posture. These results imply that while sitting posture remains an intriguing area of study, its effects on inhibition control and prefrontal brain activity may be minor, calling for more research under particular conditions and over longer periods.

Conclusion

Within the confines of this study, significant differences were observed in deoxy-Hb levels between males and females across different sitting postures. However, overall, sitting posture did not significantly influence participants' inhibitory control abilities or prefrontal activity. The interaction between gender and sitting posture suggests potential differences in the effects on cognitive processes between males and females. It is plausible that the limited duration of sitting posture exposure may have mitigated substantial changes in cognitive performance or brain oxygenation. Future research should consider longer intervention durations and a more thorough exploration of potential confounding variables.

These findings contribute to the ongoing dialogue about the multifaceted elements that affect cognitive strategies and brain interest. While our observation no longer yields definitive effects, it underscores the complexity of the relationship between sitting postures and inhibition manipulation, imparting valuable insights for future investigations.

Declarations:

Ethics approval and consent to participate

Prior to starting the investigation, study approval was obtained from the Ethics Committee of the Sport Sciences Research Institute (Ethical code: IR.SSRC.REC.1402.322)., and all participants gave written informed consent.

Consent for publication

Not applicable

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Competing interests

The authors declare no competing interests.

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Authors contributions

MS, HP, KS, RS, and FS contributed to the study design and data collection. MS, RS, KS, MS, HP, MG, and SA drafted the manuscript and made critical revisions. All authors read and approved the final manuscript.

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Availability of data and material

All data analyzed during this study are included in Supplementary File 1.

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