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RESEARCH ARTICLE

Effect of cognitive stress on isometric contraction task

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ABSTRACT

Background: Many daily life activities require motor performance while simultaneously performing a cognitive task that increases levels of arousal. **Aims and Objectives:** This study aimed to know the effect of a cognitive stressor (CS) on time to task failure (TTF). **Materials and Methods:** Each subject underwent three sessions. The first session included an isometric fatiguing contraction (isometric contraction [IMC]) using handgrip dynamometer. In the second session, CS was given for 2 min. In third session (IMC + CS), CS was given simultaneously with IMC. Heart rate (HR), blood pressure (BP), rate pressure product (RPP), and visual analog scale scores for anxiety (AVAS) and stress (SVAS) were recorded at rest, during three sessions and after 5 min of rest after completing the protocol. These parameters were analyzed by Student's *t*-test and Pearson correlation test. **Results:** TTF was significantly more in males and was positively correlated with initial strength. HR, BP, RPP, AVAS, and SVAS scores increased significantly with no gender differences during all three sessions from their respective resting levels. Systolic BP, RPP, and HR were significantly more during IMC + CS versus IMC session. **Conclusion:** Exposure to CS can increase fatigability for both genders when performing low-force fatiguing contractions.

KEY WORDS: Cognitive Stress; Time to Task Failure; Isometric Contraction; Rate Pressure Product, Visual Analog Scale

INTRODUCTION

Handgrip strength is a form of isometric or static exercise, characterized by a change in the muscle tension with no change in the muscle length. Muscle fatigue is defined as a decrease in maximum force generating capacity of the muscle,[1] and the ability to resist fatigue is sometimes expressed as muscle endurance or time to failure to maintain target tension.[2] The forearm muscles are used frequently in daily functional activities such that handgrip strength is used as an indicator of overall muscle strength and has been reported to highly predict disability with aging.[3] Therefore, forearm muscle endurance is an important aspect of physical performance and needs to be considered when assessing musculoskeletal function. The mechanisms responsible for endurance time (ET) or time to task failure (TTF) are specific to the task performed which is known as the task dependency of muscle fatigue and is well documented.[1,4,5] According to this principle, there is no single cause of muscle fatigue and the dominant mechanism is specific to those processes that are stressed during the fatiguing exercise. This is because varying the task requirements will stress different sites within the neuromuscular system, and therefore, will influence the magnitude of muscle fatigue or TTF.[6,7]

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Stress task generally evokes both negative emotions such as anxiety and cardiovascular responses, which are important determinants of health and mediated by the neuroendocrine and sympathetic nervous system.[8] Many daily life activities, however, require motor performance while simultaneously performing a cognitive task that increases levels of arousal.[6] The effect of a cognitive stressor (CS) that increases levels

of arousal on motor fatigue and performed simultaneously is less explored. Recent studies[6,9] have showed increased fatigability of a submaximal, sustained contraction for the elbow flexor muscles when performing a difficult mental math task (high CS). The increased fatigability was greater in women than men and was also accompanied by an increase in indices of sympathetic activation. Sex differences in muscle fatigue have been reported frequently, with females generally exhibiting a greater relative fatigue resistance than males.[2] This phenomenon has been observed in a variety of muscles with the use of various fatigue protocols, yet the mechanisms for the apparent sex difference are not completely understood. Few studies also showed conflicting results in gender differences in ET in young adults of India. One study[10] reported that ET was greater in women compared to men, and other studies[11-13] reported males having greater strength and ET compared to females. Very few studies have been conducted in India to know the gender differences in task failure of sustained submaximal isometric contraction (IMC); and to best of our knowledge, this is the first study conducted in India to know the effect of cognitive stress on TTF and also to know the cardiovascular responses evoked by the cognitive stress on task failure. Hence, this study is undertaken to test the hypothesis that cognitive stress during IMC will reduce the work performance and cardiovascular responses; and negative emotions evoked by stress also further worsen the work performance and cardiovascular responses. The main objectives of this study were as follows:

1. To compare the TTF for sustained submaximal IMC both in the presence and absence of CS in young males and females
2. To determine the association between the TTF and initial strength (maximum voluntary isometric contraction [MVC] force) in both the genders
3. To compare cardiovascular responses during sustained submaximal IMC in the presence and absence of a CS
4. To compare the levels of anxiety and stress, using visual analog scale, in the presence and absence of a CS.

MATERIALS AND METHODS

This is an interventional study done in 25 medical undergraduate students aged between 18 and 24 years. Ethical clearance for the protocol was obtained from the Institution Ethics Committee. Informed consent was taken from each subject. All subjects were healthy with no known neurological, cardiovascular, or any systemic illnesses and reported no history or current mental disorders including anxiety and depression. Subjects performing the exercise in the form of yoga or aerobics every day, subjects who smoke, consume alcohol and are on treatment with drugs of any kind are excluded from the study. Physical characteristics such as age, height, weight, and body mass index (BMI) were obtained. BMI was calculated as weight (kg)/height $(m)^2$.

Each subject was seated comfortably upright in an adjustable chair with the non-dominant arm abducted slightly, and the elbow resting on a padded support with the elbow joint flexed to 90°. After 15 min of rest in this sitting posture, blood pressure (BP), heart rate (HR), rate pressure product (RPP), anxiety, and stress score using visual analog scale (AVAS and SVAS) were recorded. In addition, trait score of State-Trait Anxiety Inventory (STAI),[14] to determine the baseline values of anxiety, was also noted.

The subject was instructed to perform MVC with the elbow flexor muscles of the non-dominant arm using hand grip dynamometer. Three trials were given, and the maximum value was noted for each subject. The non-dominant arm was chosen to minimize variability between subjects that may occur due to differences in activities performed with the dominant arm.

Then, the subject underwent three sessions with 15 min of rest between each session:

IMC Task

The subject was asked to perform a fatiguing contraction at 20% of maximum voluntary contraction (MVC) force using handgrip dynamometer (Inco, Ambala, India) and was verbally encouraged to sustain this force for as long as possible. The task was terminated when the target force declined by 10% or when the subject voluntarily expressed that he was unable to sustain the force further. TTF was recorded in seconds. During this session, after 15 s of beginning or just before the termination of task, the cardiovascular responses and VAS scores of anxiety and stress were recorded. Subjects were not informed of their TTF until completion of their last session.

CS Session (Mental Math Task)

Difficult mental math is an established psychosocial technique to induce stress[8] and was used as the CS during this session. Each subject was asked to perform serial subtraction from a four digit number by 13 and 7 alternatively, with 1 count required every 3 s.[15] Once the subject made an error in the math or was not able to provide the correct answer within 3 s, they were asked to start the mental math again from the first number in the series. After three errors, the subject was asked to begin with a new four digit number. Such cognitive stress was administered for 2 min. During this session, after 1 min of cognitive stress, the cardiovascular responses and VAS scores of anxiety and stress were recorded.

IMC Task with CS Session (IMC+CS)

In this session, the subject performed fatiguing IMC as in the first session and mental math as in the second session simultaneously to know the effect of CS on IMC task failure (TTF). During this session, after 15 s of beginning or just

before the termination of IMC task, the cardiovascular responses and VAS scores of anxiety and stress were recorded.

All these sessions were administered to the study subjects after explaining the procedure and also presenting before them a demonstration of the same.

Parameters Measured

HR was calculated from a Lead II recording of an electrocardiogram (ECG Machine, Phillips). HR = 1500 divided by R-R interval. BP was recorded by a digital sphygmomanometer (Omron HEM-7111) in the right upper arm in sitting position. RPP was calculated as HR times the systolic BP (SBP) times 10^{-3}. Cognitive levels of anxiety and stress were assessed throughout the protocol using VAS. Each VAS (one for AVAS and another for SVAS) involved a 10cm line anchored at the far left of "not at all anxious" or "not at all stressed" and the far right by "very anxious" or "very stressed." The right anchor corresponded to the most stressful or most anxious moment in the life of the subject. Each subject was instructed that anxiety was defined as the negative feelings regarding the immediate future, whereas stress represented the physical changes such as increase in HR and perspiration perceived by the subject that was above and beyond the expectation for their level of exertion.[6] HR, BP, VAS for anxiety and stress were recorded five times during the protocol: First at rest before the beginning of protocol; second, third, and fourth during first, second, and third sessions, respectively, and then fifth after 5 min of rest after completion of the protocol.

Statistical Analysis

Results were presented as mean±standard deviation. Student's *t*-test was used to compare and find the significance of study parameters using SPSS 20 version. $P < 0.05$ was considered statistically significant. Pearson correlation was used to know the association between TTF and initial strength (MVC force).

RESULTS

This study involved 25 young adult subjects (12 males and 13 females). There was no statistically significant difference in the age, weight, BMI, and t-STAI score except for height and maximal voluntary contraction force of both the genders, which shows that the two groups are comparable for the statistics applied. Each subject had moderate levels of anxiety for the t-STAI score (Table 1).

Males had significantly prolonged time to failure than females in both first (IMC) and third (IMC and CS) sessions. TTF was reduced significantly during the third session compared with the first session in both the genders (Table 2). In females, percentage reduction of TTF was more compared to that of males but was not statistically significant (19.7% vs. 17%, $P = 0.27$). Males had almost twice the strength of females in MVC (Table 1), and there was significant positive correlation between initial strength (MVC) and TTF during IMC ($r = 0.716$, $P = 0.00$) and IMC + CS session ($r = 0.595$, $P = 0.00$).

The VAS scores for anxiety and stress were almost same for males and females at rest. There was no significant gender difference in mean AVAS and SVAS scores except during IMC session where males had significantly high AVAS scores ($P = 0.03$) compared to that of females (Table 3).

HR and diastolic BP (DBP) were more in females, whereas SBP, mean arterial pressure (MAP), and RPP were more in males, but this gender difference was not statistically significant except for SBP and MAP after 5 min of rest after completing the protocol (Table 4).

All the cardiovascular parameters (HR, SBP, DBP, MAP, and RPP) and VAS scores of anxiety and stress were increased significantly during IMC, CS, and IMC + CS session from their respective resting levels. There was no statistical difference between resting levels and after 5 min of rest on completing the protocol in all the above parameters implying that all these parameters reached near resting levels after 5 min of completing protocol (Table 5).

When compared session wise in both the genders, there was no significant difference in the mean values of AVAS and SVAS scores. Similar comparison of all cardiovascular

Table 1: General characteristics of the study subjects

Characteristics	Mean±SD		*t* value	*P* value
	Males	Females		
Age (years)	18.41±0.51	19±1.29	1.505	0.16
Height (m)	1.74±0.051	1.61±0.08	4.710	0.001
Weight (kg)	64.25±14.08	54.08±12.92	1.878	0.07
BMI (kg/m^2)	19.89±7.08	20.75±4.15	0.366	0.71
MVC (kg)	30.42±7.05	16.69±4.64	5.698	0.001
t-STAI score	48.00±4.99	49.08±6.03	0.488	0.63

SD: Standard deviation, BMI: Body mass index, MVC: Maximum voluntary isometric contraction, t-STAI: Trait score of state-trait anxiety inventory

Table 2: Time to task failure in study subjects during various interventions

Parameters	IMC	IMC+CS	*t* value	*P* value
Males	118.33±41.59	97.42±35.58	3.952	0.002
Females	69.77±27.54	56.00±22.18	3.800	0.003
t value	3.413	3.459		
P value	0.003	0.003		

IMC: Isometric contraction, IMC+CS: Isometric contraction with cognitive stressor

Table 3: Gender differences in AVAS and SVAS scores during various interventions

Parameters	At rest	IMC	CS	IMC+CS	After 5 min
AVAS score (maximum score=10)					
Males	2.83±1.39	5.54±1.30	4.79±1.77	5.47±2.20	2.63±1.87
Females	2.88±2.01	4.25±1.40	4.85±1.44	5.05±1.83	3.34±1.97
t value	0.063	2.383	0.084	0.508	0.920
P value	0.95	0.03	0.93	0.61	0.37
SVAS score (maximum score=10)					
Males	2.48±1.73	4.94±2.10	4.85±2.34	5.91±1.82	2.25±1.69
Females	2.17±1.71	3.68±1.41	3.77±2.07	4.67±2.39	2.70±1.94
t value	0.445	1.753	1.219	1.464	0.619
P value	0.66	0.09	0.23	0.16	0.54

AVAS: Visual analog scale scores for anxiety, SVAS: Visual analog scale scores for stress, IMC: Isometric contraction, CS: Cognitive stressor, IMC+CS: Isometric contraction with cognitive stressor

Table 4: Gender differences in cardiovascular parameters during various interventions

Parameters	At rest	IMC	CS	IMC+CS	After 5 min
HR in beats/min					
Males	84.33±17.99	92.42±13.08	93.33±15.01	96.25±14.61	81.08±7.67
Females	89.85±24.98	100.23±20.13	96.69±25.14	104.23±20.56	88.38±16.33
t value	0.637	1.159	0.40	1.125	1.448
P value	0.54	0.27	0.69	0.28	0.17
SBP in mm Hg					
Males	117.50±13.16	135.42±11.27	133.92±12.46	143.17±14.66	125.83±14.66
Females	108.46±11.30	130.77±15.31	123.00±17.01	133.23±12.98	107.92±11.08
t value	1.836	0.869	1.84	1.784	3.425
P value	0.08	0.40	0.08	0.09	0.001
DBP in mm Hg					
Males	63.33±10.59	80.25±9.56	72.58±5.92	79.92±9.87	66.50±7.57
Females	64.08±9.79	80.15±15.34	71.92±9.71	78.77±12.02	62.23±11.83
t value	0.182	0.019	0.207	0.262	1.083
P value	0.86	0.99	0.84	0.80	0.30
MAP in mm Hg					
Males	81.39±9.68	98.63±9.40	92.36±7.86	101.00±9.94	86.28±8.96
Females	78.84±9.39	97.02±14.24	88.18±11.83	96.92±10.74	77.46±10.44
t value	6.66	0.336	1.048	0.985	2.271
P value	0.51	0.74	0.31	0.34	0.03
RPP					
Males	9.87±2.13	12.42±2.02	12.47±2.21	13.81±2.70	16.19±2.05
Females	9.52±2.66	13.18±3.34	12.05±4.25	13.94±3.40	9.62±2.43
t value	0.362	0.698	0.313	0.102	1.127
P value	0.72	0.50	0.76	0.92	0.25

IMC: Isometric contraction, CS: Cognitive stressor, IMC+CS: Isometric contraction with cognitive stressor, HR: Heart rate, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial pressure, RRP: Rate pressure product

parameters session wise in both the genders (Table 5) resulted as follows:

1. IMC versus CS: There was significantly more DBP (in males) and MAP (in both males and females) during IMC session.
2. IMC versus IMC + CS: SBP and RPP in males and HR in females was significantly more during IMC + CS.
3. CS versus IMC + CS: SBP, DBP, MAP, and RPP in males and SBP and MAP in females were significantly more during IMC+CS.

Table 5: Significance of differences (*P* value) in cognitive and cardiovascular parameters during various interventions

Parameters	HR		SBP		DBP		MAP		RPP		AVAS		SVAS	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
At rest versus IMC	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	000	0.00	0.00	0.00
At rest versus CS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.01
At rest versus IMC+CS	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01
At rest versus after 5 min	0.38	0.73	0.07	0.69	0.1	0.46	0.00	0.42	0.31	1.00	0.73	0.47	0.61	0.26
IMC versus CS	0.60	0.38	0.45	0.08	0.01	0.09	0.02	0.04	0.84	0.99	0.15	0.18	0.88	0.84
CS versus IMC+CS	0.30	0.12	0.03	0.01	0.01	0.11	0.00	0.02	0.05	0.89	0.34	0.60	0.14	0.14
IMC versus IMC+CS	0.14	0.02	0.02	0.56	0.90	0.80	0.33	0.98	0.02	1.00	0.90	0.06	0.07	0.13

IMC: Isometric contraction, CS: Cognitive stressor, IMC+CS: Isometric contraction with cognitive stressor, HR: Heart rate, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial blood pressure, RPP: Rate pressure product, AVAS: Anxiety visual analog score, SVAS: Stress visual analog score

DISCUSSION

In this study, males had significantly higher hand grip strength than females. This is in accordance with previous studies.[6,9,11,12] This finding can be due to increased bone mineral density and increased muscle mass in males when compared to females. The TTF was significantly more in males compared to that of females both during sustained submaximal (20% of MVC) contraction without and with CS sessions. This finding of this study is in accordance[11-13] and contrast[6,9,10] with previous studies. As proposed by Gaskell,[16] blood flow to the active muscle is a compromise between two opposing events: First, the dilation of its vasculature to provide increase blood flow and sympathoexcitation which in turn is a result of metabolic by-products of muscle contraction. Second is the impedance of this dilation by mechanical compression of vessels. Although active muscle becomes progressively more ischemic due to mechanical compression during a sustained IMC, vasodilation can occur via local metabolites acting on vascular endothelium and smooth muscle and stimulation of β-2 receptors via circulating epinephrine.[17] However, during the fatiguing isometric exercise, the reflex originating from under-perfused active muscle will cause rise in cardiac output and arterial BP,[18,19] which in turn results in increase blood flow but when the intramuscular pressure exceeds this arterial pressure there is cessation of blood flow and thus resulting in fatigue. Hence, the balance between vasodilation and vasoconstriction will determine the TTF under control conditions. Some other variables that influence the involved mechanisms include the type and intensity of contraction, the muscle groups involved, the limb support provided, and the physical environment, in which the task is performed.[1,7]

This study showed a positive correlation between the TTF and initial strength (MVC). The possible mechanism for longer TTF in men could be due to large muscle mass in males generate greater force during muscle contraction which in turn can increase sympathetic excitation causing an increase in cardiac output and vasodilation in active muscle due to the production of more local metabolites. Previous studies[20-22] demonstrated that during sustained contractions at 20% MVC, of more than 60% of total time to exhaustion, mean blood flow was higher in men compared to women. This suggests that while approaching toward fatigue, men required increase blood flow to maintain the same relative force as women and this, in turn, may be the reason for shorter TTF in women reported in previous studies. In this study, the possible role of local metabolites in increasing the perfusion of active muscle is suspected in prolonging TTF in males. Studies that address the issue by controlling for larger muscle size using current imaging technology to examine muscle blood flow to the fatigued muscle and with increased number of samples to reduce the inter-subject variability are warranted. Future studies should continue to examine the relative reliance on oxidative versus glycolytic sources in the working muscle of men and women and the precise role that differences in substrate utilization play in fatigue.

Furthermore, in this study, VAS score for anxiety in male subjects was significantly more than that of female subjects during IMC session. Studies also show that increase in anxiety was reliably associated with an increase in BP and HR on handgrip tasks, but the amount of change in negative emotion required to obtain a specific change in cardiovascular response may vary across individuals. Only small changes in emotion may be required to trigger specific cardiovascular response in some, but large changes may be required to trigger the same response in others.[23] Hence, the role of negative emotions on cardiovascular response to handgrip task and TTF has to be clarified.

The study demonstrated non-significant greater percentage reduction in TTF for women compared with the men when the CS was imposed. Women can have different functional neural networks during a CS and motor tasks compared with men.[24-26] Mental stress and performance of a motor task, for example, both involve the anterior cingulate cortex, which differs in activation in men and women in regulating cardiovascular responses.[26] The impact of such sex differences in functional neural networks is not

understood when a CS is imposed during a fatiguing motor task. Furthermore, the magnitude of the sex difference is specific to the task performed, and these differences can change across the lifespan.[7]

The increased VAS for stress and anxiety in this study indicated that both genders had increased levels of arousal to the CS task. An increase in arousal can result in activation of the sympathetic nervous system with the subsequent release of neuromodulators and hormones throughout the central and peripheral nervous system,[6,9] causing elevations of HR and BP. This study also indicated that perceived anxiety, HR, and BP were all elevated during IMC + CS task relative to resting levels and IMC session, demonstrating that sympathetic activation was likely to be elevated. The mechanism for the greater fatigability during IMC+CS, therefore, may be due to the stressor-induced sympathetic activation and increased vasoconstriction to inactive muscles.[6] The relative changes in blood flow due to sympathetic activity, however, could have influenced perfusion in both genders. In contrast, stressful mental math can cause vasodilation in upper limbs via similar local vasodilator mechanisms to contraction[17] although not always.[27] Hence, increased muscle perfusion during the CS could be expected to enhance rather than decrease the motor performance of a fatiguing task. Although the interactions are not fully understood, the balance of vasoconstriction and vasodilation could potentially alter the net perfusion of the active muscle in both genders during IMC + CS causing a reduced time to failure.

Finally, a clinically relevant finding of this study, also in agreement with previous studies[6,9,28] was that both the genders had an elevated RRP during all the three different stressor sessions that increased arousal compared to the resting levels. The RRP was significantly greater for males than the females during IMC + CS when compared to IMC and CS sessions. These gender differences are in agreement with previous studies[9,28] but in contrast with another study.[6] RRP is an indicator of cardiac work and myocardial oxygen consumption,[27,29] hence these findings can have significant clinical implications for both males and females who perform low-force, sustained contractions for prolonged periods under stressful work conditions.

CONCLUSION

The TTF was positively correlated with the initial strength of the subject and was paralleled by changes in cardiovascular responses that are the indices of sympathetic neural activity; and the CS increased cardiac work (indicated by RRP) during the fatiguing contraction, especially for males. Hence, it can be concluded from this study that exposure to a CS can increase fatigability for both genders when performing low-force fatiguing contractions, which are the foundations of many daily tasks.

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