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Fatigue differences between Asian and Western populations in prolonged mentally demanding work-tasks

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ABSTRACT

Introduction: With an increase in the number of mentally demanding jobs, as well as the increase in work performed while sedentary, there is a growing imbalance in the use of body resources. This often results in an increase in fatigue in the working population. The diversity of the workforce is also increasing, whereas physiological differences based on culture are important to consider. The objective of this study was to identify the differences in the levels of fatigue in the workplace experienced by Asian and Western workers in mentally demanding jobs.

Method: Eight Asian and eight Western participants completed an observation-based study. Each participant was observed for four hours in their workplace while they were working on highly mentally demanding work-tasks either computer programming or mathematical simulations. To balance the effect of time, half of the participants from each ethnic group were observed in the morning session and the other half in the afternoon session. Perceived fatigue was measured every 30 min using the single dimensional Borg and multidimensional SOFI scales. Workload was measured using NASA-TLX, and as a change in resting heart rate.

Result: Ethnicity and time interacted to significantly affect the perceived fatigue measured by Borg ($F(9,126) = 2.03$, $p = 0.0412$) and SOFI ($F(9,126) = 3.28$, $p = 0.0013$) scales. Asian participants reported significantly higher workload measured by NASA-TLX scores ($F(1, 14) = 3.68$, $p = 0.0024$) and change in resting heart rate ($F(1, 14) = 7.77$, $p = 0.0145$) was measured higher compared to Western participants. Unlike fatigue, no significant interactions were observed between time and ethnicity to affect either NASA-TLX scores or change in resting heart rate. Post-hoc analyses show that the rate of fatigue was higher for Asian participants. Correlations between the dependent variables were significant ($p < 0.0001$), with a stronger correlation identified for Asian participants.

Conclusion: As compared to the Western participants, Asian participants reported higher values in all dependent measures, including fatigue in both scales, NASA-TLX scores, and change in resting heart rate.

Relevance to industry: The significant growth in white-collar as well as mentally demanding jobs requires more cognitive resources, while reducing physical activities. The consequences of the imbalances in the use of body resources have yet to be studied. This study has been designed to investigate the issues of imbalance in the workplace.

1. Introduction

The experience of fatigue in the workplace has significantly increased in recent decades (van der Ploeg et al., 2013). During the same period, the negative health consequences of fatigue have also increased (van der Ploeg Hp, 2012). However, there is no clear

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Abbreviations

Ex	weekly exercise frequency
Sl	daily sleep in hours
DR	rest after work in hours
W	weekly working hours in primary occupation
TW	total weekly working hours in all of occupations
EDF	fatigue perceived at the end of a regular working day
Borg	one dimensional fatigue measured in Borg CR-10 scale
SOFI	multidimensional fatigue measured in Swedish Occupational Fatigue Inventory
ΔHR	change in resting heart rate
NASA	workload measured in NASA-TLX
Eth	ethnicity
I (or Asian)	study participants from first-generation Asian population
W (or Western)	study participants from Western population, excluding the 2nd or 3rd generation Asian.
T	experimental clock time or assessment point
ANOVA	analysis of variance using repeated measure design
F	F-value from appropriate F-statistics
p	P-value associated with corresponding analysis
r	correlation coefficient
A	afternoon shift between 1:00p.m. and 5:00p.m.
M	morning shift between 8:00a.m. and 12:00p.m.
Sh	working shift, either afternoon or morning

understanding of fatigue in the workplace (DeLuca, 2005). Significant effort has been made toward understanding localized fatigue, such as muscle fatigue, resulting in a significant reduction in injuries associated with those types of fatigue. As physical workload has apparently decreased due to technological advances, the mental workload has increased (Cenedella, 2010). Mentally demanding jobs, mostly performed in sedentary positions, create an imbalance in the use of body resources, resulting in a higher level of perceived fatigue (Ahmed, 2013). Whether the perception of fatigue results solely from the mental, physical or both from a combination is unknown (DeLuca, 2005).

Objective 1: *Therefore, the primary objective of this study is to study fatigue in the workplace developed due to mentally demanding work-tasks.*

According to the Population Reference Bureau (PRB), the Asian population in the United States holds a much higher portion (14 percent) of jobs in science and engineering than do the white (5.3 percent), Black (2.7 percent), and Hispanic (2 percent) populations (Lee and Mather, 2008). A study conducted by the U. S. National Science Foundation (NSF) has observed that among graduate students in science and engineering fields, international graduate students comprise 28 percent of the total population (NSF, 2014). The vast majority of those graduate students are Asian. In the United States, the Asian population is contributing significantly to mentally demanding jobs in the workplace.

Objective 2: *Therefore, to further understand fatigue in the context of the working populations, the second objective of the study is to compare the Asian population living in the United States and the Western population.*

1.1. Fatigue in the workplace due to mentally demanding work-tasks

1.1.1. Change in work-task paradigm and fatigue

In the United States, in the 48 years between 1960 and 2008, approximately 30 percent of jobs shifted from work requiring moderate physical activity to sedentary jobs (U.S. Bureau of Labor Statistics, 2013). In the same period, task-dependent energy consumption decreased 140 calories for men and 124 calories for women per day (U.S. Bureau of Labor Statistics, 2013), which has been suggested as the primary cause of mean weight gain in the U.S. population (Church et al., 2011). In the Netherlands, a 4.7 h per week increase in sedentary work-tasks was observed between 1975 and 2005; however, the non-occupational sedentary period was observed to be unchanged (van der Ploeg et al., 2013).

Cenedella shows that white collar jobs, which are primarily mentally demanding and performed sedentarily, increased 18 percent to 60 percent of the workforce during the 20th century (Cenedella, 2010). Despite the consistent growth in mentally demanding jobs, few studies have been performed on how these stressful jobs could increase fatigue in this population. While physically demanding jobs cause physical fatigue and injury, mentally demanding jobs impose a high level of stress that may result in fatigue if conditions persist for a prolonged period (BLS, 1999). The change in paradigm of the jobs does not necessarily reduce the demand on the personnel; instead it could introduce some unknown consequences if not properly understood.

1.1.2. Etiology of fatigue

In general, fatigue in the workplace can be explained by the amount of work relative to time, and the workload from various sources, including, lifestyle, workstyle, health conditions, organizational structure, work environment, and the work itself. Fatigue has been reported at the end of a regular working day, and fatigue increases over time (Santos et al., 2015). Duration of work-tasks or number of hours spent in occupation at the workplace is one of the primary factors that significantly affects fatigue (El Falou et al., 2003; Jensen, 2003; Østensvik et al., 2009). In addition to the duration of the work-tasks, workload has been proven to be one of the primary causes of fatigue in working populations (Boksem et al., 2006; Dorrian et al., 2011; Finkelman, 1994; Guastello et al., 2013; MacDonald, 2003). Moreover, a recent study shows that a significant interaction-only hyperbolic-mathematical relationship exists between time and load (anything that affects or causes fatigue) to explain fatigue in the workplace (Ahmed et al., 2014). For this reason, including the duration of the work-tasks in a fatigue study is imperative because of not just the main effect of time, but also the interaction with the fatigue load or workload (Ahmed et al., 2014).

Most mentally demanding work-tasks are designed to be performed in sitting positions, which makes the jobs even more sedentary. Prolonged sitting multiplies the odds for mortality irrespective of other physical activity (van der Ploeg Hp, 2012). Lack of physical activity either in the occupation or in non-occupation activities, boosts the risk for bad health consequences (Mork et al., 2010; Taylor and Dorn, 2006). For example, a sedentary job with low physical demands significantly contributes to central and total obesity (Choi et al., 2010), which has been considered the etiology of many life-threatening diseases (Bray, 2004; Gilson et al., 2011). Moreover, prolonged sitting has also been observed as the primary cause of fatigue in lumbar and trunk muscles, which may add up to overall body fatigue (Areeudomwong et al., 2012; van Dieën et al., 2009). Sitting over an extended period of time introduces prolonged static postures resulting in discomfort (Ahmed and Babski-Reeves, 2009; El Falou et al., 2003; Pietri et al., 1992; Smith et al., 2003) and muscle fatigue even for low-exertion activities such as 5 percent maximum voluntary contraction (MVC) (Sjogaard et al., 1986) and 2 percent MVC (van Dieën et al., 2009). Fatigue has been reported throughout the literature for these low physically demanding work-tasks (Blangsted et al., 2005; Kroemer, 1997; Sjøgaard et al., 2000). Mental demands significantly affect the capability to recover from physical fatigue, which may increase overall fatigue (Santos et al., 2015).

In addition to the sedentary activities resulting in higher physical demand, the situation becomes even more unfavorable when the brain demands more resources to accomplish the mentally challenging work-task. In this way, the mentally demanding jobs inherently create an inequality in the use of body resources, which could cause fatigue. Nevertheless, a few or no evaluation research study has been performed that incorporates the real-world work-task scenario to understand fatigue due to the mentally demanding jobs in the workplace.

1.2. Fatigue in the context of the working populations

People who live with certain conditions or situations (e.g. lifestyle, workstyle, workload, and duration of work) show significantly different trends in the experience of fatigue in the workplace (Cordero et al., 2012; Santos et al., 2015; Wang and Chuang, 2014). For Asian people working in the United States, the significant lifestyle and workstyle differences and separation from their native cultures, families, and friends; present additional challenges compared to their colleagues. Asian populations, especially first-generation, working in the United States may have to cope with an extra challenge as compared to their colleagues who have lived in the United States since childhood (Ahmed, 2013). A study comparing Hispanics and non-Hispanic whites observed many significant differences in perceived fatigue (Cordero et al., 2012). The objective of this study is to investigate fatigue in members of the foreign-born Asian population (first-generation) living in the United States who are working in mentally demanding jobs, which are primarily sedentary.

The vast majority of fatigue studies found in the literature have been significantly context-specific due to the context-specific loads imposed by different situations and conditions. For example, fatigue studies have examined workers in various occupations, including, professional drivers (Brown, 1994; Uenishi et al., 2002; Williamson et al., 2013), nurses (Barker Steege and Nussbaum, 2013; Hughes and Clancy, 2008; Trinkoff et al., 2011), and assembly line workers (Sparks et al., 2001; Taylor et al., 2013; Williamson and Friswell, 2013). In addition to the studies in these workplaces, context-specific fatigue research has also been performed for people with various pathological conditions (DeLuca, 2005) such as cancer (Hann et al., 2000; Piper and Cella, 2010; Piper et al., 1998; Stein et al., 1998), fibromyalgia (Mork et al., 2010; Sephton et al., 2003), migraine, (Santos et al., 2015), and pregnancy (Åhsberg, 2000).

This trend in fatigue studies suggests the possibility that certain demographic groups could experience higher levels of perceived fatigue than others (Di Milia et al., 2011; Orlando and King, 2004; Taylor et al., 2003). For example, studies have observed significantly higher fatigue in ethnic minority groups than among members of the ethnic majority (Cordero et al., 2012). Other researchers have found gender-based differences: A study conducted in Bangladesh, India and Pakistan showed that working women experience significantly higher fatigue than their male counterparts (Bhui et al., 2011); researchers claim that women they studied experienced higher workload because their load included both professional and household work (Bhui et al., 2011). These studies, based on questionnaires demand more detailed research that includes evaluative observational studies in the field that contrast demographic differences.

In spite of the potential differences in perceived fatigue among various ethnicities, few studies have been published that compare ethnic groups with respect to fatigue (Dinos et al., 2009). Moreover, the categorizations of ethnic groups have not been performed methodically to determine the effect of ethnicity alone on fatigue (Dinos et al., 2009; Jason et al., 1999a,b; Njoku et al., 2005). Studies have found a significant difference between the ethnic minority and majority with respect to fatigue, which must not be considered as the independent effect of ethnicity (Dinos et al., 2009; Jason et al., 1999a,b; Steele et al., 1998). Minorities reported less fatigue in studies controlled by demographics, including only education and age (Cordero et al., 2012). Studies have reported no significant difference in ethnicity with respect to fatigue (Bhui et al., 2011; Buchwald et al., 1996; Yennurajalingam et al., 2008). In contrast to ethnicity alone, socioeconomic status, unemployment, and minority status significantly affect fatigue (Taylor et al., 2003). Yet too few fatigue studies comprising demographics and ethnicity have been performed to reach substantial conclusions (Di Milia et al., 2011; Noy et al., 2011).

Mentally demanding jobs, which are increasing in prevalence, are primarily sedentary, creating an imbalance in the use of body resources in the workplace, resulting in fatigue. At the same time, the increasing diversity in working populations, especially the growing Asian population in mentally demanding jobs in the United States, calls for more evaluation studies to meet the future challenge.

2. Methodology

2.1. Experimental design

An observational study in the field was performed to evaluate fatigue in prolonged, mentally demanding work tasks in western and eastern populations. However, the strategy of data collection has resulted in a repeated measure design of experiment. Participants were randomly selected, and each participant was repeatedly measured over a four-hour time period. Therefore, experimental clock-time (assessment points) was considered as a within-subject factor, while ethnicity was considered as a between-subject factor.

2.2. Independent variable

Ethnicity and time were studied as the independent variables of the research. Each participant was observed over a four-hour period of time with a 15-min break in the middle of the session. Therefore, the time variable consisted of ten levels, including assessments every thirty minutes and two baseline assessments at the beginning of each two-hour session. Two levels of ethnicity comprise an equal number of participants from western and eastern populations only.

2.3. Dependent variable

Multiple dependent measures, including both objective and subjective measures, were studied. The data collection, instrumentations and data cleaning procedures are discussed for each dependent variable in the respective sections below. Two subjective instruments, including the Modified Borg CR-10 scale

(Borg Scale) and the Swedish Occupational Fatigue Inventory (SOFI), were used to measure participants' subjective perceptions of fatigue. NASA-TLX and change in heart rate were used as the subjective and objective measures of workload, respectively.

2.3.1. Selection of fatigue measures

The two subjective scales, (1) Borg and (2) SOFI have been used in many previous studies to evaluate fatigue in the workplace for numerous types of jobs, including both mental and physical (Åhsberg et al., 2000; Østensvik et al., 2009). However, most objective measures for fatigue used in the previous studies have been observed to be intrusive to the jobs and, oftentimes, they are less reliable. To keep the work-task less intrusive for an eight-hour period of study only increasing resting heart rate and NASA-TLX were used to measure workload both objectively and subjectively. As the higher workload for a long period of time have been observed to be a cause of fatigue, the subjective and objective measure for workload would provide information about the development of fatigue over time without intruding the study participants (Ahmed et al., 2014).

2.3.2. Modified Borg CR-10 scale to measure fatigue

Both the Rating of Perceived Exertion (RPE) scale and the Category Ratio (CR-10) scale have been widely used to measure both perceived exertion and overall fatigue (Åhsberg et al., 2000; Borg, 1970; Chien and Ko, 2004). A modified Borg CR-10 (modified because perceived overall fatigue was solicited instead of perceived exertion) scale was used to measure perceived fatigue every 30 min over a four-hour study period. A total of 10 assessments were performed including the baseline measurements at the beginning of each two-hour session before and after a short 15-min break. Participants rated their perceived fatigue for specific body parts presented in random order. Perceived fatigue was collected for: (1) leg, (2) buttock, (3) lower back, (4) upper back (5) shoulder- neck, (6) eyes, and (7) whole body. The body parts were chosen based on many previous studies (Åhsberg, 2000; Åhsberg and Gamberale, 1998). As it has been suggested in the literature, a total fatigue score for each 30-min block was calculated by adding fatigue ratings for each body part, including the whole body (Equation (1)) (Borg, 1982; Loge et al., 1998).

$$\begin{aligned}\text{Fatigue Rating in Borg Scale (Borg)} &= \text{Fatigue}_{\text{leg}} + \text{Fatigue}_{\text{buttock}} + \text{Fatigue}_{\text{lower back}} \\ &\quad + \text{Fatigue}_{\text{upper back}} + \text{Fatigue}_{\text{shoulder neck}} + \text{Fatigue}_{\text{eye}} \\ &\quad + \text{Fatigue}_{\textit{whole body}} \qquad (1)\end{aligned}$$

2.3.3. Swedish Occupational Fatigue Inventory (SOFI)

The short version of SOFI was used, and participants completed the survey every 30 min. A total multi-dimensional fatigue score for each 30-min block was calculated by adding the fatigue ratings for five dimensions of SOFI (Equation (2)) (Åhsberg et al., 2000; Loge et al., 1998). The short definition for the five dimensions of SOFI is given within the parenthesis: (1) physical exertion (breathing heavily, out of breath, sweaty, palpitations), (2) physical discomfort (aching, stiff joints, numbness, tense muscles), (3) lack of motivation (uninterested, indifferent, passive, lack of concern), (4) sleepiness (sleepy, yawing, drowsy, falling asleep), and (5) lack of energy (overwork, drained, spent, worn out). The detail definitions for the five broad dimensions of SOFI can be found in the original article (Åhsberg and Gamberale, 1998; Wang and Chuang, 2014).

$$\begin{aligned}\textit{Fatigue Rating in SOFI Scale(SOFI)} &= \textit{Fatigue}_{\textit{physical exersion}} + \textit{Fatigue}_{\textit{physical discomfort}} \\ &\quad + \textit{Fatigue}_{\textit{lack of motivation}} + \textit{Fatigue}_{\textit{sleepiness}} \\ &\quad + \textit{Fatigue}_{\textit{lack of energy}} \qquad (2)\end{aligned}$$

2.3.4. NASA-TLX

Subjective perceptions of workload were measured using the NASA-TLX. While fatigue and workload are generally considered two distinctly different concepts, they have been found to be related in previous studies. A total workload score for each 30-min block was measured by adding the scores for six dimensions of NASA-TLX (Hart and Staveland, 1988). Similar studies have not identified any significant difference between weighted and un-weighted scores of NASA scores (DiDomenico and Nussbaum, 2005; Ikuma et al., 2009). Therefore, simple un-weighted scores were used to calculated total workload measured by NASA-TLX (Equation (3)).

$$\begin{aligned}\text{Workload Rating in NASA(NASA)} &= \text{Workload}_{\text{mental demand}} + \text{Workload}_{\text{physical demand}} \\ &\quad + \text{Workload}_{\text{temporal demand}} + \text{Workload}_{\text{effort}} \\ &\quad + \text{Workload}_{\text{performance}} + \text{Workload}_{\text{frustration level}} \qquad (3)\end{aligned}$$

2.3.5. Change in heart rate

Change in heart rate was observed to be related to both physical (Borg, 1970, 1982) and mental workload (Roscoe, 1993). As this study views this highly mentally demanding work-tasks performed in prolonged sitting imposes both mental and physical workload for the workers, heart rate would be a potential measure for workload. Change in heart rate was continuously collected over the four-hours period of the study (Duchon et al., 1997). A Polar RS 400 heart-rate monitor (Polar Electro Oy, Professorintie 5, Fl-90440 Kempete, Finland; www.polar.fi) was used to measure heart rate continuously at a sampling rate of 1 Hz. Raw heart rate data was downloaded to the Polar Pro-Trainer 5 software (Polar Electro Oy, Professorintie 5, Fl-90440 Kempete, Finland; www.polar.fi) for analysis at a later time.

The heart-rate monitor was placed across the chest so that the sensor sits right of the sternum. A wrist watch was worn on either hand or placed on the working desk to minimize interference, but close enough to the chest sensor for continuous heart rate monitoring. To start the experiment, resting heart rate was calculated in a sitting position while participants were requested to sit back and relax until they reached a steady state resting heart rate defined to be 2 consecutive heart rate readings within 5 bpm. This procedure took 2–5 min. After recording resting heart rate, the heart rate wrist watch clock was started to begin the experiment. Average heart rate was also calculated during the steady state condition by collecting three heart rate readings. Change in heart rate (ΔHR) was used in all analyses. To compute ΔHR, the task heart rate was averaged for each 30-min block and the resting heart rate was subtracted from the average, heart rate for the 30-min block.

2.4. Participants

Sixteen self-reported healthy participants with no medical conditions (back pain, shoulder or neck pain, buttock pain, or headache) and 20/20 natural or corrected eye vision volunteered for the study. No other exclusion criteria were used. Demographic statistics are provided in Table 1.

The mean weekly working hours in the primary occupation (W) was self-reported to be 46.88 h with a standard deviation of 8.48 h. The mean overall daily sleep was self-reported to be 7.31 h with a standard deviation of 0.73 h. The demographic statistics demonstrated that Asian participants possess worse conditions (e.g. lower amount of sleep and higher working hours) as compared to the Westerners. However, there was no trend observed between participants completing the experiment in the morning or afternoon sessions.

2.4.1. Sample size

Similar studies have used fewer or less number of participants (Kim et al., 1994; Rose et al., 2014).

2.4.2. Definition of Asian and Western participants for this study

A study participant was considered Asian if he/she was originated from Asia (e.g. China, India, and Bangladesh). All Asian participants in the study were born in Asia, later they moved to the United States, making them the first-generation Asians in the United States. A study participant was considered Western if he/she was born in the United States. The western participants included in the study were White, African-American, and Biracial. Second-generation Asian participants were not included in the study.

2.5. Procedure

Each participant was given a verbal and written description of the experiment and was required to complete an Informed Consent document approved by the Institutional Review Board (IRB) for Research Involving Human Subjects at Mississippi State University. Participants were asked to complete a demographic questionnaire after the informed consent procedure (summarized in Table 1). The heart-rate monitor was then attached according to manufacturer guidelines, and a resting heart rate assessment was conducted. At each 30-min interval within each two-hour testing block, the subjective fatigue and workload assessments were collected. After the end of the first two hours of testing, a 15-min break was provided, and all dependent measures were collected. Procedures for the first-two-hour test session were replicated for a second-two-hour testing session.

2.5.1. Subjective questionnaire data collections

The dimensions for each subjective questionnaire, including the SOFI and NASA-TLX, were randomized within a participant at each data collection point, meaning that every participant was asked another random order in the next data collection time point or every 30-min. The body-parts for the Borg scale was randomized in each data collection point, similar to the SOFI and NASA-TLX scales. The dimensions were also randomized between participants. As the participants were busy with their regular work, the researcher collected the responses by asking the participants about their current experience on each dimension of the questionnaire instrument according to the prior random orders created utilizing the MS Excel random order generator function. All data were collected using printed questionnaires.

2.6. The work-tasks

The data were collected in one two national research centers under a research University. All participants were full time programmers or mathematical simulators. One group of employees were involved in coding using C# (pronounced as see sharp), MySQL, SFRS Reporting Service, and Share Point Technology, to develop state wide longitudinal data system. In another research center, employees were using Matlab and ANSYS Fluent software for Computational Fluid Dynamics. Both ethnic groups were recruited from both research centers.

2.7. Data analysis

Appropriate descriptive statistics were calculated for all dependent variables with respect to all independent variables. ANOVA was conducted to determine the effect of independent variables and their two-way interaction with time on all dependent measures. Moreover, interaction means were analyzed using Tukey Post-Hoc LSD analyses when appropriate. In addition spearman correlations were also performed. Statistical analyses were performed using Statistical Analysis System (SAS) version 9.3, and were considered significant at a significance level of 0.05.

2.7.1. Correlations

Spearman's rank correlation coefficient or Spearman's rho is considered more appropriate for Likert scale type data. All

Table 1
Demographic statistics.

	Variable	N[a]	Mean	St Dev	Min	Max		Variable	N	Mean	St Dev	Min	Max
Overall	Age (Yr.)	16	28.69	4.43	23	39	Overall	EDF	16	3.69	1.41	1	7
	Sl (hr.)	16	7.31	0.73	6.5	9.5		MMF	16	0.25	0.66	0	2
	W (hr.)	16	46.88	8.48	30	60		Ex	16	2.25	1.61	0	4
	TW (hr.)	16	56.94	10.51	35	74		DR	16	2.44	0.61	1	3
Asian	Age (year)	8	29.25	2.35	25	32	Westerners	Age (year)	8	28.13	5.77	23	39
	Sl	8	7.00	0.50	6.5	7.5		Sl	8	7.63	0.79	6.5	9.5
	W	8	50.00	8.71	40	60		W	8	43.75	7.00	30	50
	TW	8	63.00	8.89	50	74		TW	8	50.88	8.29	35	64
	EDF	8	4.38	1.33	3	7		EDF	8	3.00	1.13	1	4
	MMF	8	0.25	0.67	0	2		MMF	8	0.25	0.67	0	2
	Ex	8	2.13	1.70	0	4		Ex	8	2.38	1.50	0	4
	DR	8	2.25	0.67	1	3		DR	8	2.63	0.49	2	3
Morning	Age (year)	8	30.75	4.69	23	39	Afternoon	Age (year)	8	26.63	2.97	23	31
	Sl	8	7.50	0.87	6.5	9.5		Sl	8	7.13	0.49	6.5	7.5
	W	8	43.75	8.62	30	60		W	8	50.00	7.12	40	60
	TW	8	54.13	11.43	35	74		TW	8	59.75	8.68	48	70
	EDF	8	3.75	1.40	2	7		EDF	8	3.63	1.42	1	5
	MMF	8	0.50	0.87	0	2		MMF	8	0.00	0.00	0	0
	Ex	8	2.13	1.70	0	4		Ex	8	2.38	1.50	0	4
	DR	8	2.50	0.50	2	3		DR	8	2.38	0.70	1	3

[a] N = Sample Size, St Dev = Standard Deviation, Min = Minimum, Max = Maximum.

subjective assessment instruments used in this study could be considered as Likert scale data. For example, on a 0 to 10 scale, the response from a participant is perceived more as a rank than as purely numeric. Therefore, Spearman's rank correlation coefficient was used for all correlation analyses. Correlation matrices were generated for all pairs of dependent variables. A raw correlation matrix was developed using the 30-min block data. In addition to the overall correlation, correlation matrices were generated for each assessment time point separately to determine the micro-relationships.

3. Result

3.1. Descriptive statistics

Descriptive statistics tables are provided in Fig. 1 and Fig. 2. Asian participants reported higher levels of perceived fatigue and workload, and had a larger change in heart rate, ΔHR. These findings were more pronounced if the testing occurred in the afternoon. The Mean total fatigue for Asian participants in Borg and SOFI scales were observed to be 9.36 and 5.65 respectively, while the Western participants reported 5.05 and 2.66 correspondingly. The mean total scores for both subjective (NASA-TLX) and objective (ΔHR) measures of workload were observed to be 22.04 and 11.63 respectively for Asian participants. In contrast, western participants only reported correspondingly 18.88 for NASA-TLX and 10.2 for ΔHR.

Fig. 1 shows the increase in trend in fatigue scores measured in both Borg and SOFI scales, with the expectation of sudden decrease in fatigue after the short 15-min break. However, both workloads measured by NASA-TLX and change in resting heart rate were observed to be relatively unchanged during the two-hour working sessions before and after the break.

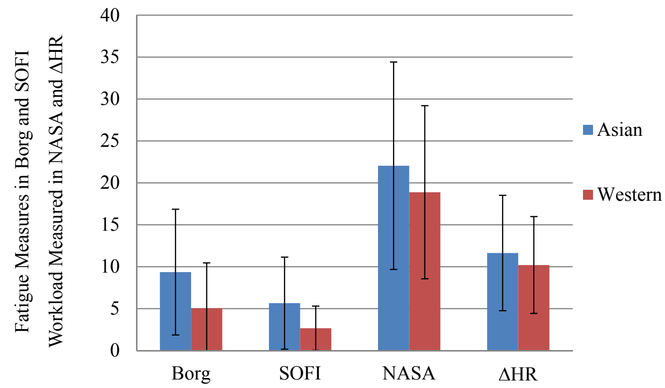

Fig. 2. Descriptive statistics for Borg, SOFI, NASA and ΔHR by ethnicity.

3.2. Effect of ethnicity and time

Table 2 describes the results from the repeated measure analyses of variance (ANOVA) to determine significant effects of

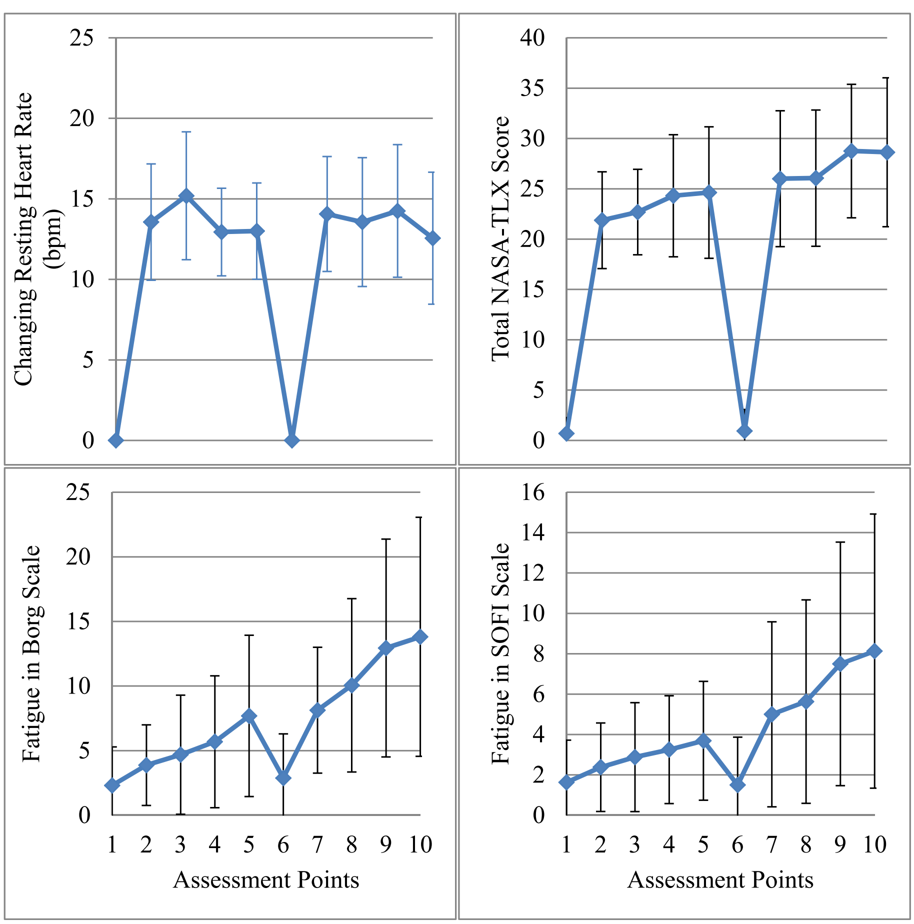

Fig. 1. Descriptive statistics: (1) top-left, (2) top-right, (3) bottom-left, (4) bottom-right figures represent the changing hear rate, NASA-TLX scores, fatigue scores measured in Borg and SOFI respectively.

ethnicity, time and their interaction. Ethnicity and time were found to significantly interact to affect Borg ($F(9,\ 126) = 2.03,\quad p = 0.0412$) and SOFI ratings ($F(9,\ 126) = 3.28,\quad p = 0.0013$). In contrast to fatigue measures, only the main effects of ethnicity ($F(1,\ 14) = 13.68,\quad p = 0.0024$) and time ($F(9,\ 126) = 61.33,\quad p < 0.0001$) were observed to be significant in affecting workload measured subjectively by NASA-TLX. Similarly, only ethnicity and time main effects were significant for workload, measured by change in resting heart rate.

Tukey adjusted post-hoc analyses for the Borg, SOFI, NASA and ΔHR are represented in Fig. 1. Due to the significant interaction between time and ethnicity, mean comparisons between ethnicities were performed for each time segment or assessment point. Statistically, there were no significant differences observed between ethnicities for the assessment points 1, 2, 3 and 6. However, Asian participants reported significantly higher fatigue scores measured in both Borg and SOFI for assessment points 5, 7, 8, 9 and 10. Moreover, post-hoc analysis also showed that fatigue scores in Asian participants were significantly increasing over time as compared to the Western participants.

Post-hoc analyses were performed separately for time and ethnicity for NASA scores and ΔHR because of the absence of interactions. Both NASA scores and ΔHR were observed to be significantly elevated during working with respect to the baseline measurements before and after the two-hour sessions. Asian participants significantly reported higher NASA scores and ΔHR (bottom picture in Fig. 3).

3.3. Correlation analysis

Table 3 shows the correlation analysis for four response variables, which were measured every 30-min. All response variables were significantly correlated (p-values < 0.0001), though the strength (ranges from r = 0.23 to r = 0.81) of the correlation ranged from poor to strong. Correlations between the response variables were observed to be stronger for the Asian participants than Westerners.

The objective (change in resting heart rate) and subjective (NASA-TLX) measures for workload were only correlated approximately 50% for overall, Asian and Western populations. However, the correlation between the single dimensional Borg and multidimensional SOFI scales was measured significant (p-value < 0.0001) and moderately high to strong (r-value ranges between 0.62 and 0.81) (Table 3).

4. Discussion

The objective of this study is to quantify and contrast human fatigue between the Asian and the Western populations working on prolonged mentally demanding work-tasks. The researcher performed an evaluation study in the field observing eight (8) Asian and eight (8) Western participants for a four-hour period (half session of a regular day) both in the morning and afternoon sessions in their workplace. Each participant of this study was working for either computer program or simulation, which have been observed to be mentally demanding according to NASA-TLX measures. To balance the effect of time in fatigue between ethnicity, an equal number of participants from each ethnicity was observed both in the morning and afternoon sessions.

ANOVA results demonstrated that all response variables, including fatigue measured in single dimension Borg and multidimension SOFI scales, and workload measured subjectively by NASA-TLX and objectively by ΔHR, were significantly affected by ethnicity and time. As expected, fatigue increased over time for both populations (Santos et al., 2015). More interestingly, ethnicity significantly interacted with time to affect fatigue for the Asian participants experiencing fatigue faster than Westerners. The post-hoc analysis shows a significantly faster increasing trend in the change of fatigue over time for the Asian participants as compared to the Westerners. Generally, previous studies demonstrated that ethnic minority groups reported significantly higher fatigue (Taylor et al., 2003). In this study, the personal and work-related factors such as daily sleep, everyday rest, exercise, effort during the work, workload in the primary occupations, and workload in all occupations have been observed to be significantly worse for the Asian participants to increase fatigue. For example, both subjective and objective workloads measured by NASA-TLX and change in resting heart rate were observed to be significantly higher for the Asian participants as compared to the Westerners. In addition to the worse conditions (e.g. lower amount of sleep) in all personal and tasks-related factors, the significantly higher level of workload could explain the increase in fatigue in the Asian participants. Therefore, according to this study, it is difficult to justify the effect of ethnicity alone to significantly affect fatigue. Studies have observed that when these factors are adjusted for, either no difference (Buchwald et al., 1996; Yennurajalingam et al., 2008) or less (Cordero et al., 2012) fatigue was reported by the ethnic minority groups. Future studies should confound these factors to determine the effect of ethnicity alone.

Generally, the correlations between the dependent variables were observed to be significant and moderate to high in strength. The correlations between the dependent variables in the Asian participants were observed to be significant and moderate to high in strength. In contrast, the western participants showed poor to moderate correlations only. The lower correlations between the workload and fatigue for the western participants indicated that the western participants had experienced lower fatigue for the same level of workload. These lower correlations also imply that the western participants may possess better strategies for managing fatigue, while performing the exact same work-tasks. For an example, in this study, all personal fatigue inducing factors for western participants have been observed to be better than for the Asian participants. Many previous studies have observed that fatigue risk managing strategy helps to reduce the level of fatigue (Åhsberg, 2000). Future studies could focus on these fatigue management strategies specifically directed towards a particular ethnicity.

To use the promising findings from this study effectively, important limitations of this study are disclosed here. Firstly, all subjects were recruited from two research centers at a rural research University. Although each participant was working as a full time programmer or computer simulator with mathematically intense work, these participants may not represent the workers in

Table 2
ANOVA results for Borg, SOFI, NASA and ΔHR.

Dependent variable	Effect	F(df1, df2)	=Value	P-value > F
Borg	Ethnicity	F(1, 14)	=26.86	**0.0001**[a]
	Time	F(9, 126)	=09.51	**<0.0001**
	Ethnicity × time	F(9, 126)	=02.03	**0.0412**
SOFI	Ethnicity	F(1, 14)	=28.22	**0.0001**
	Time	F(9, 126)	=06.90	**<0.0001**
	Ethnicity × time	F(9, 126)	=03.28	**0.0013**
NASA-TLX	Ethnicity	F(1, 14)	=03.68	**0.0024**
	Time	F(9, 126)	=61.33	**<0.0001**
	Ethnicity × time	F(9, 126)	=01.04	0.4091
ΔHR	Ethnicity	F(1, 14)	=07.77	**0.0145**
	Time	F(9, 126)	=51.47	**<0.0001**
	Ethnicity × time	F(9, 126)	=00.74	0.6692

[a] Bold faced p-values indicate significant results.

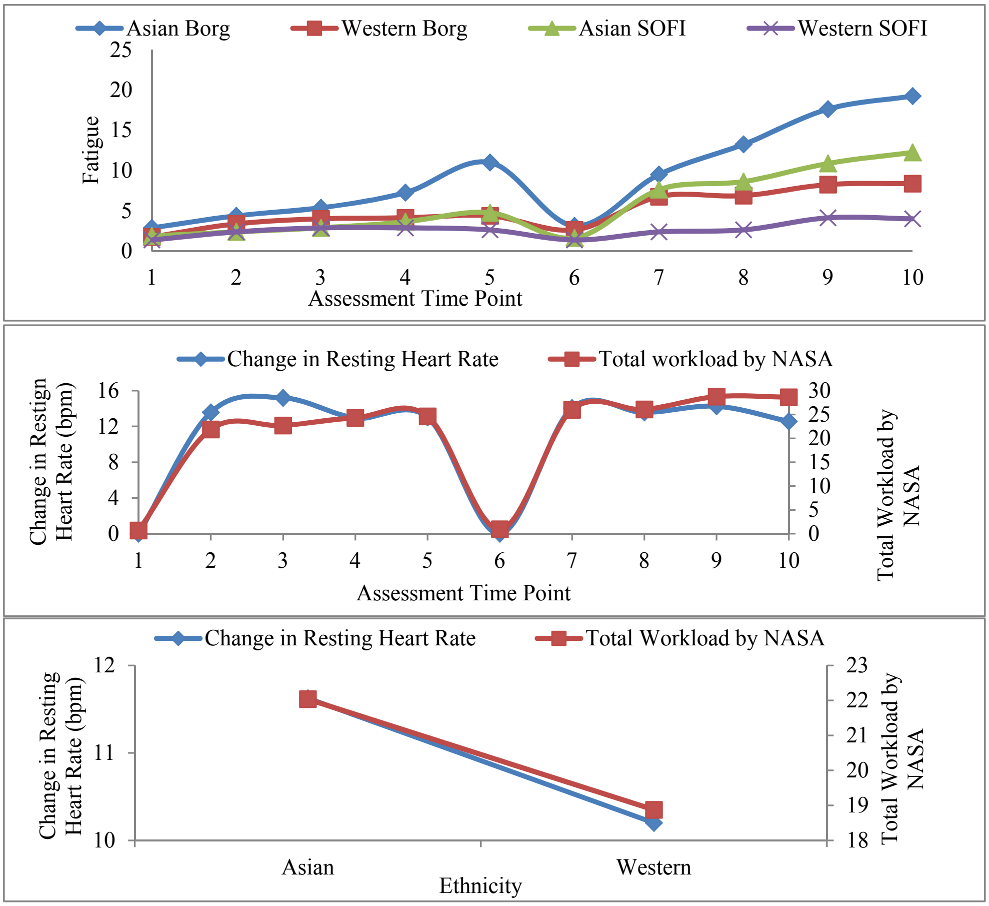

Fig. 3. Top: Time and ethnicity significantly interact to affect fatigue on both measurement scales; Middle: Change in resting heart and NASA scores over time; Bottom: Change in resting heart rate and NASA scores over ethnicity.

Table 3
Correlation matrix.

	Overall				Asian				Western			
	Borg	SOFI	NASA	ΔHR	Borg	SOFI	NASA	ΔHR	Borg	SOFI	NASA	ΔHR
Borg	1.00	0.78	0.64	0.38	1.00	0.81	0.63	0.45	1.00	0.62	0.56	0.24
SOFI		1.00	0.51	0.36		1.00	0.47	0.37		1.00	0.37	0.26
NASA			1.00	0.54			1.00	0.50			1.00	0.49
ΔHR				1.00				1.00				1.00

an industrial setting.

Secondly, participants were requested to perform their regular activities as usual, which did not allow the researcher to have any control across the study participants. Therefore, the findings from this study could possibly adhere to those particular working environments. Future studies could focus on confounding the working environment to eliminate this bias from the results.

5. Conclusion

The aim of the study was to evaluate and contrast fatigue between Asian and Western Populations working for mentally demanding work-tasks. The study observed a significantly higher perceived fatigue in the Asian population as compared to the Western population. Fatigue over time was also increasing significantly faster for Asian participants as compared to the Westerners. Moreover, workloads measured by NASA-TLX and change in resting heart rate were observed significantly higher for the Asian population. The correlation between dependent variables, including both fatigue and workload measures were observed to be higher for the Asian participants. Personal and work-related factors that cause fatigue were also observed higher for the Asian participants. While working for the exact same job, the western participants experiencing less fatigue could provide some insight into fatigue management.

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