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Effect of Exercise and Heat-Load on Simple Reaction Time of University Students

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Visual and auditory simple reaction times for both right and left hands of young university male students were recorded with a simple reaction timer, before and after an exercise schedule without and with elevated temperatures in a climatic chamber. The results indicated a decrease in both visual and auditory reaction times after the exercise, but a marked increase in them was noticed when exercise was performed at elevated temperatures. The difference in reaction times in preferred and nonpreferred hands was negligible at rest, i.e., without any exercise and elevated temperature. However, the difference was significant when exercise was performed at elevated temperatures. Visual reaction time was longer than auditory reaction time in all conditions. The results suggest that in hot industries, increased temperature has a specific rather than general effect on cognitive processes, perception and attentiveness, leading to increased chances of human errors, fatal accidents and loss of productivity.

reaction time   exercise   heat stress   cognitive performance

1. INTRODUCTION

Reaction time (RT) is the elapsed time between the presentation of a sensory stimulus and the subsequent behavioral response. RT is often used in experimental psychology to measure the duration of mental operations, an area of research known as mental chronometry. RT is fastest when there is only one possible response (simple reaction time, SRT) and becomes slower as additional response options are added (choice RT). According to Hick's law, choice RT increases in proportion to the logarithm of the number of response alternatives. The law is usually expressed with the formula $RT = a + b \log_2 (n + 1)$, where a and b are constants representing the intercept and slope of the function, and n is the number of alternatives [1]. RT is quickest for young adults and gradually slows down with age [2].

The Persian scientist, Abū Rayhān al-Bīrūnī, was the first person to describe the concept of RT [3]. The first scientist to measure RT in the laboratory was Franciscus Donders. Donders found that SRT was shorter than recognition RT, and that choice RT was longer than both [4]. Donders also devised a subtraction method to

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analyze the time it took for mental operations to take place. By subtracting SRT from choice RT, e.g., it is possible to calculate how much time is needed to make the choice [5]. SRT is the time required for an observer to respond to the presence of a stimulus. For example, a subject might be asked to press a button as soon as a light or sound appears. Mean SRT for young adults is ~215 ms to detect visual stimulus, and ~160 ms to detect an auditory stimulus [6]. Due to momentary attentional lapses, there is a considerable amount of variation in an individual's RT. To control for this, researchers typically require a subject to perform multiple trials, which are then averaged to provide a more reliable measure.

In SRT experiments, there is only one stimulus and one response. For ~120 years, the accepted figures for mean SRTs for college-age individuals were ~190 ms for light stimuli and ~160 ms for sound stimuli (Galton F, 1899†[1]; von Fieandt K, Huhtala A, Kullberg P and Saarl K, 1956†; Welford AT, 1980†).

Laming DRJ's (1968)† pioneer studies showed that SRT was on average 220 ms but recognition RTs averaged 384 ms. Thereafter many studies in this line concluded that a complex stimulus (e.g., several letters versus one letter in symbol recognition) elicited a slower RT (Teichner WH and Krebs MJ, 1974†). An example very much like our experiment was reported by Surwillo WW (1973†) in which reaction was faster when a single tone sounded than when either a high or a low tone sounded and the subject was supposed to react only when the high tone sounded.

Miller JO and Low K (2001)† determined that the time for motor preparation (e.g., tensing muscles) and motor response (in this case, pressing the spacebar) was the same in all three types of RT tests, implying that the differences in RT were caused by processing time.

Many researchers have confirmed that reaction to sound was faster than reaction to light, with mean auditory RTs being 140–160 ms and visual RTs being 180–200 ms (von Fieandt K, Huhtala A, Kullberg P, et al., 1956†; Welford AT, 1980†; Woodworth RS and Scholoberg H, 1954†; Brebner JT, 1980†). Perhaps this is because an auditory stimulus only takes 8–10 ms to reach the brain (Kemp BJ, 1973†), whereas a visual one takes 20–40 ms (Marshall WH, Talbot SA and Ades HW, 1943†). RT to touch is intermediate, at 155 ms (Robinson MC and Tamir M, 2005†). Differences in RT between these types of stimuli persist whether the subject is asked to make a simple or a complex response (Sanders AF, 1998†).

Researchers have reported modest, but statistically significant correlations between measures of RT and intelligence. Although there are numerous exceptions, there is an overall tendency for individuals with higher IQ to be slightly faster on RT tests. One study found a weak association between SRT and intelligence ($r = -.31$), and a moderate association between choice RT and intelligence ($r = -.49$). This relationship may be due to more efficient information processing or better attentional resources in more intelligent people [8].

RT reflects speed of information processing in humans and has been found to be related to measures of cognitive abilities. It is a good index of psychometric reaction and is thus directly related to speed and consistency of processing RT tasks. Even very small decrements in one or more components of cognitive performance such as concentration, attention, RT, and cognitive processing speed may affect individual performance. The specific effects of heat stress on physiological processes have been widely studied [9]. It has been shown that high ambient temperature increased the physiological reactions to exertion [10].

Laboratory studies documented the adverse effects of extreme atmospheric conditions on RT. The studies showed that extreme variations in hotness and coldness led to decrements in cognitive performance as well as RT [14]. As a result, all types of human performance, whether mental work [11] or strenuous physical work [12] are affected. In general, a heat-stressed person takes longer to processes information and makes wrong decisions [13, 14, 15].

[1] All citations indicated with a dagger (†) are after Kosinski [7].

Numerous studies investigated the effects of heat stress on mental performance. Many of these studies reported some form of decrement in performances (Wing JF and Touchstone RM, 1965, and Iampietro PF, Melton CE, Higgins EA, et al., 1972, as cited in Vasmatzidis, Schlegel and Hancock [16]; [17, 18]). A strong correlation was shown between hot environment and unsafe behaviors [19]. The effects of exercise on cognitive processes have been mainly approached, in recent years, through the study of RT tasks ([20]; Legros P, Delignières D, Durand M, et al., 1992, Paas FGWC and Adams JJ, 1991, as cited in Delignières, Brisswalter and Legros [20]). These studies showed that exercise led to a decrement in SRT, but to an enhancement of choice RT, especially with collective and combat sports experts. These contrasting effects seemed related to a complex interaction between a specific influence of exercise on some cognitive processes (Arcellin R, Delignières D and Brisswalter J, 1995, as cited in Delignières and Brisswalter [21]), and a mental effort mobilization under exertion [20].

In the present study an attempt was made to evaluate the effect of moderate exercise and graded heat load with exercise on SRT for both auditory and visual stimuli on healthy young adult males since RT is a direct index of cognitive performance.

2. MATERIALS AND METHODS

2.1. Place of Experiment

This investigation was conducted in the climatic chamber of the Work Physiology and Ergonomics Department of Central Labour Institute, Sion, Mumbai. A climatic chamber (a closed and insulated chamber) is a closed room where the temperature can be artificially increased to a desired level. Table 1 shows the temperature indices at the beginning of the experiment in the climatic chamber.

TABLE 1. Thermal Indices of Climatic Chamber During the Experiment

Parameters	Room Temperature	1st Heat Load	2nd Heat Load
DB (°C)	32.4	34.7	37.8
NWB (°C)	26.7	28.6	30.6
GT (°C)	33.1	35.6	38.4
WBGT (°C)	28.6	30.6	33.2
RH (%)	61	62	61

Notes. DB—dry bulb temperature; NWB—natural wet bulb temperature; GT—globe temperature; WBGT—wet bulb globe temperature; RH—relative humidity.

2.2. Selection of Subjects

Fifteen male postgraduate students of Calcutta University were randomly selected for this study. Their mean age was 24.45 ± 1.34 years, their height was 162.87 ± 5.33 cm, and they weighed 62.85 ± 12.79 kg. They had no history of any illness, they were healthy, and they did not smoke or partake of alcoholic drinks.

2.3. Instruments Used

2.3.1. Bi-cycle ergometer

A bicycle ergometer is a magnetic brake ergometer constructed in the Max Plank Institute (Germany). The working rate with which the subjects perform work can be adjusted with a handle, which keeps the magnets at a suitable position of the disc with a simple gear mechanism. The calibration of scale was set to 60 rotations of the pedal per minute.

2.3.2. Simple reaction timer (Anand Agency, Pune, India)

An electrical reaction timer is used for measuring RT to auditory and visual stimuli. It gives RT data in milliseconds.

2.3.3. Sling psychrometer

Dry and wet bulb temperatures were measured with a whirling psychrometer or a Sling psychrometer (NovaLynx, USA) that houses both the dry and wet bulb thermometers in wooden grooves. A handle is attached at one end, around which the psychrometer can be rotated at 60 rpm. This is essential for measuring dry and wet bulb temperatures.

2.3.4. Globe thermometer

Radiant heat was measured with a Vernon globe thermometer (NovaLynx, USA). The temperature can be read from a standard mercury-in-glass thermometer inserted into a 15-cm diameter copper globe whose outside surface is painted with a matte black finish.

The wet bulb globe temperature (WBGT) index can be calculated with the following formulas [22]:

- for outdoors with a solar load (in sunshine)

$$WBGT_{out} = 0.7\ NWB + 0.2\ GT + 0.1\ DB;$$

- for indoors or outdoors without a solar load (in shade)

$$WBGT_{in} = 0.7\ NWB + 0.3\ GT;$$

where NWB—natural web bulb temperature, GT—globe temperature, DB—dry bulb temperature.

2.4. Experimental Protocol

The subjects reported in the laboratory after a light breakfast without any stimulant like tea or coffee. They were required to rest for 45 min to acclimatize themselves in the environmental condition of the laboratory until a steady-state baseline resting condition was achieved.

Baseline physiological conditions were monitored with a polar heart rate monitor (Polar Electro, USA), an ECG machine (BPL, India), and with blood pressure instruments (Omron Healthcare, Japan) following standard protocol.

1. Before the actual experiment, all the subjects were familiarized with the exercise in a bi-cycle ergometer and operated a simple reaction timer in several trials. Then each of them was allowed to rest, mentally and physically, in the climatic chamber for at least 30 min at room temperature (WBGT index 28.6 °C);
2. The subjects' individual SRTs for auditory and visual stimuli for both hands were recorded at room temperature (WBGT index 28.6 °C).
3. The subjects were made to perform light exercise on a bi-cycle ergometer for 5 min with the work load (60 kg·m/h) in the same temperature (WBGT index 28.6 °C). Their RT for auditory and visual stimuli for both hands were again measured immediately after exercise and recorded.
4. In the next step the subjects were asked to perform the same exercise for the same duration (5 min) in the climatic chamber (the protocol was already mentioned in phase 3) at two different heats load (34.7 and 37.8 °C) and their SRTs were measured as it was done previously.

Throughout the experiment dry bulb, wet bulb and globe temperatures of the climatic chamber were measured from time to time. Relative humidity (RH) was calculated from the dry bulb wet bulb nomogram and air velocity was measured with a kata thermometer (C.F. Casella and Co., UK).

The Departmental Human Research Ethics Committee, Department of Physiology, Calcutta University, Kolkata, India, approved the experimental protocol.

2.5. Statistical Analysis

A paired sample *t* test [23] was done with the collected data to find out the significant difference between the observed RT at different environmental conditions.

3. RESULTS AND DISCUSSION

Tables 2–5 show SRTs before and after exercise and also exercise with increased temperature in the climatic chamber.

TABLE 2. Visual and Auditory Reaction Time (RT) ($M \pm SD$) for Both Hands (Before Exercise)

Hand	Visual RT (ms)	Auditory RT (ms)	*p*
Left	252.2 ± 7.91	238.67 ± 11.93	>.05 (*ns*)
Right	250.0 ± 6.99	232.93 ± 12.59	<.05 (significant)
p	>.05 (*ns*)	>.05 (*ns*)	

TABLE 3. Visual and Auditory Reaction Time (RT) (*M* ± *SD*) for Both Hands (After Exercise)

Hand	Visual RT (ms)	Auditory RT (ms)	*p*
Left	248.45 ± 7.79	229.13 ± 10.85	<.05 (significant)
Right	233.80 ± 6.53	199.80 ± 17.30	<.01 (significant)
p	<.01 (significant)	<.01 (significant)	

TABLE 4. Visual and Auditory Reaction Time (RT) (*M* ± *SD*) for Both Hands With Exercise and Increased Temperature (1st Heat Load)

Hand	Visual RT (ms)	Auditory RT (ms)	*p*
Left	304.67 ± 10.42	288.33 ± 9.89	<.050 (significant)
Right	287.13 ± 7.57	256.07 ± 13.41	<.001 (significant)
p	<.050 (significant)	<.001 (significant)	

TABLE 5. Visual and Auditory Reaction Time (RT) (*M* ± *SD*) for Both Hands With Exercise and Increased Temperature (2nd Heat Load)

Hand	Visual RT (ms)	Auditory RT (ms)	*p*
Left	379.4 ± 7.38	356.73 ± 12.03	<.010 (significant)
Right	375.87 ± 6.99	314.20 ± 11.75	<.001 (significant)
p	>.050 (*ns*)	<.001 (significant)	

Table 2 shows SRT for both visual and auditory stimuli of both hands in the climatic chamber at rest/room temperature. Following exercise in the climatic chamber, the subjects' visual and auditory SRT decreased significantly (Table 3) in comparison to their resting SRT. But when the temperature in the chamber increased to 34.7 °C (first heat load) with the same exercise load a significant increase in their SRT (Table 4) was recorded. With a further increase in temperature in the climatic chamber to 37.8 °C (second heat load, Table 5) there was a further increase in SRT for both the auditory and visual stimuli of both hands.

Figures 1–2 illustrate a comparative assessment of the auditory versus visual stimuli. Figures 3–4 show the relationship between the preferred and nonpreferred hands.

The results of the present observation showed that visual SRT was significantly longer than auditory SRT in each condition. Many researchers reported the same observations; they confirmed that reaction to sound was faster than reaction to light, with mean auditory RTs of 140–160 ms and visual RTs of 180–200 ms (Galton F, 1899†; von Fieandt K, Huhtala A, Kullberg P, et al., 1956†; Welford AT, 1980†; Woodworth RS and Scholoberg H, 1954†; Brebner JT, 1980†). Perhaps this is because an

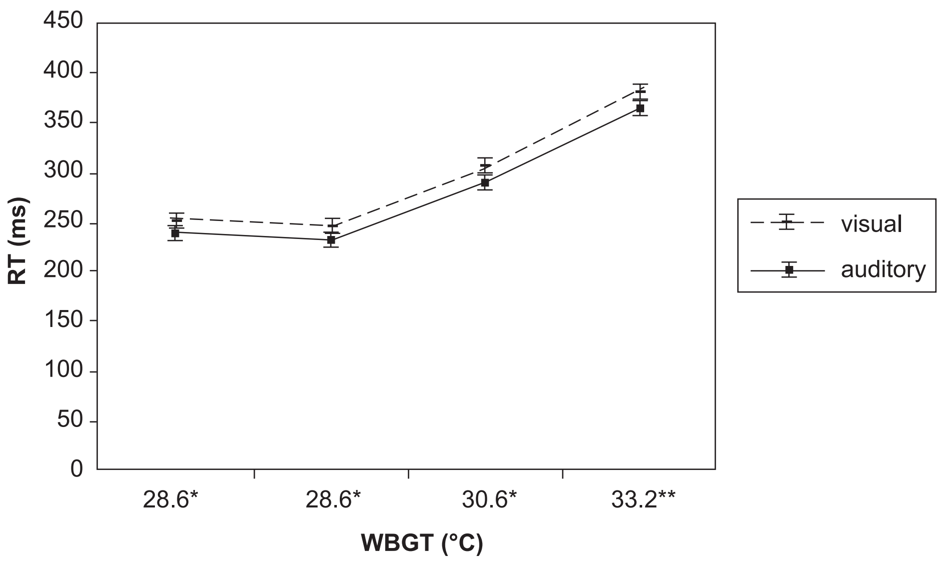

Figure 1. Reaction time (RT) for visual versus auditory stimulus (left hand). *Notes.* #—not significant, *$p < .05$, **$p < .01$.

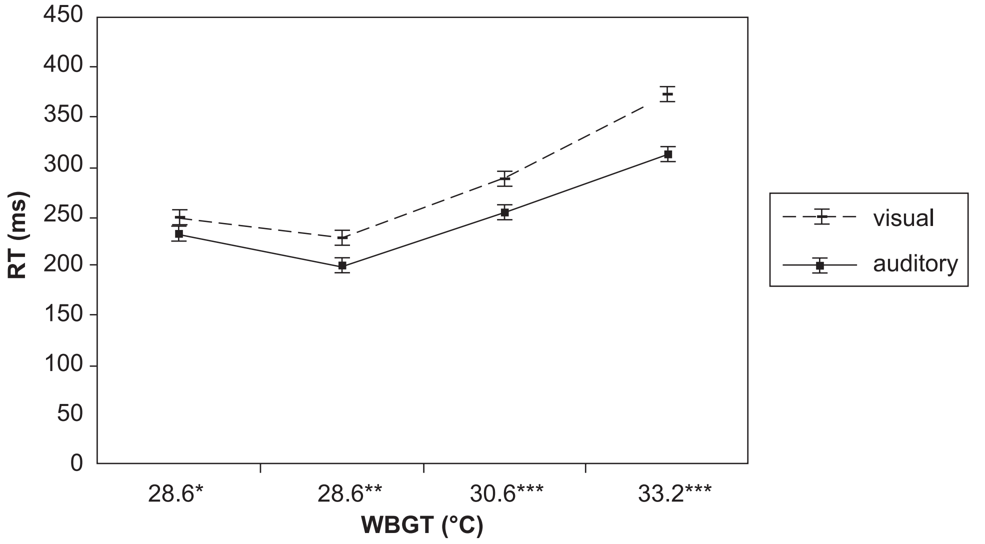

Figure 2. Reaction time (RT) for visual versus auditory stimulus (right hand). *Notes.* $^{*}p < .050$, $^{**}p < .010$, $^{***}p < .001$.

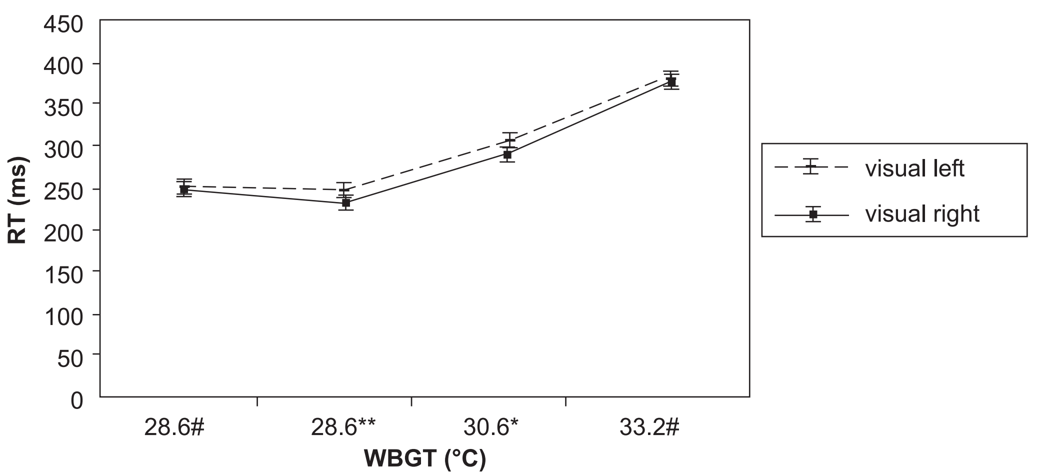

Figure 3. Visual reaction time for preferred versus nonpreferred hand. *Notes.* #—not significant, $^{*}p < .05$, $^{**}p < .01$.

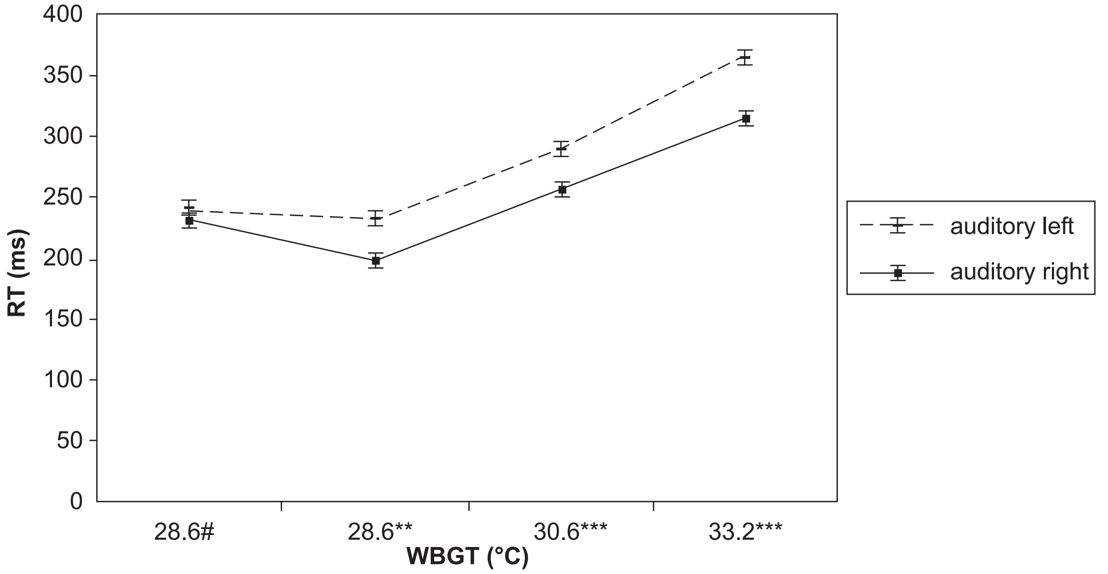

Figure 4 . Auditory reaction time for preferred versus nonpreferred hand. *Notes.* #—not significant, $^{**}p < .010$, $^{***}p < .001$.

auditory stimulus only takes 8–10 ms to reach the brain, whereas a visual stimulus takes 20–40 ms (Kemp BJ, 1973†; Marshall WH, Talbot SA and Ades HW, 1943†).

There has been controversy about SRTs of the left versus the right hand. The left hemisphere is regarded as the verbal and logical brain, and the right hemisphere is thought to govern creativity and spatial relations, among other things. It is well-known that the right hemisphere controls the left hand, and the left hemisphere controls the right hand. This has made researchers think that the left hand should be faster at RTs involving spatial relationships (such as pointing at a target). The results of Boulinguez P and Bartélémy S (2000)† and Bartélémy S and Boulinguez P (2001, 2002)† all supported this idea. Dane S and Erzurumluoglu A (2003)† found that in handball players, left-handed people were faster than right-handed ones when the test involved the left hand, but there was no difference between the RTs of the right- and left-handers when using the right hand. Finally, although right-handed male handball players had faster RTs than right-handed women, there was no such gender difference between left-handed men and women. The authors concluded that left-handed people had an inherent RT advantage. In an experiment using a computer mouse, Peters M and Ivanoff J (1999)† found that right-handed people were faster with their right hand (as expected), but left-handed people were equally fast with both hands. The preferred hand was generally faster. However, the RT advantage of the preferred over the nonpreferred hand was so small that they recommended alternating hands when using a mouse. Bryden P (2002)† testing right-handed people only, found that the difficulty of the task did not affect the RT difference between the left and right hands. Miller J and Van Nes F (2007)† found that responses involving both hands were faster when the stimulus was presented to both hemispheres of the brain simultaneously.

It was also found that RT to an auditory stimulus did not differ significantly for the preferred and nonpreferred hands. Woodworth RS and Schlosberg H (1954)† and Seashore and Seashore [24] performed similar studies. A comparison of SRT for preferred and nonpreferred hands did not show any significant differences between these two hands in a normal resting condition. However, there were significant differences in some cases after exercise in heat stress.

So while carrying out any hard intensive task in hot industries workers should take additional precautionary measures to prevent any unwanted incidents (that require a response to visual or auditory stimuli) with the nonpreferred hand.

Our study showed that visual and auditory SRT of the left hand changed from 252.20 and 238.67 ms to 248.45 and 229.13 ms, respectively, while in the case of the right hand visual and auditory SRT changed from 250.00 and 232.93 ms to 233.80 and 199.80 ms, respectively, following moderate exercise. Welford AT (1980)† reported a similar observation of faster RT of physically fit subjects. Levitt S and Gutin B (1971)† and Sjoberg H (1975)† showed that subjects had the fastest RTs when they were exercising sufficiently to produce a heart rate of 115 beats per minute.

Besides, Nakamoto H and Mori S (2008)† found that college students who played basketball and baseball had faster RTs than sedentary students. Davranche K, Audiffren M and Denjean A (2006)† concluded that exercise on a stationary bicycle improved RTs. They attributed this to increased arousal during the exercise.

So our observations of shortened SRT following exercise are in full agreement with the aforementioned reports. Several previous studies reported that light exercise stimulated SRT if there no environmental stressors were present [6], which our study also substantiated.

As suggested by our pre-experimental observations, heat stress seemed to widely enhance physiological reactions to exertion. This result, in accordance with specific literature, shows that even with fit young people, hot climates have a strongly detrimental effect on physiological performance.

In our case, an increase in SRTs followed exercise with increased heat load. This increment increased after a further increase in the heat load.

This result indicated that for SRT, the decrement in performance was related to thermal stress/ discomfort.

Several other researchers also reported that there were various other factors which could affect human SRT, with heat being crucial (Welford AT, 1980†; Brebner JT, 1980†; Levitt S and Gutin B, 1971†; Jevas S and Yan JH, 2001†; Luchies CW, Schiffman J, Richards LG, et al., 2002†; Der G and Deary IJ, 2006†; Rose SA, Feldman JF, Jankowski JJ, et al., 2002†; Adam J, Paas F, Buekers M, et al., 1999†; Noble CE, Baker BL and Jones TA, 1964†; Singleton WT, 1953†; Welfrod AT, 1968†, [25]).

Fraser and Jackson also suggested that there might be a negative correlation between SRT and temperature, but the results appeared to be rather inconclusive [26]. Longer exposures, particularly associated with physical exertion, could result in dehydration and have a specific effect on performance and RT [27], which appeared to be true for our observation as well.

4. CONCLUSION

Thus the present investigation also substantiates the widely accepted fact that SRT to a visual stimulus is longer than to an auditory stimulus. Physical exercise shortens SRT and when combined with graded thermal stress, this exercise has a negative impact (prolongation of SRT) on human SRT. This study also showed that there was no significant difference between SRT for preferred and nonpreferred hands in a normal resting condition but there was a significant difference after exercise both with and without heat load. However, it can be postulated from this investigation that during work in a hot environment cognitive demand becomes higher than in a normal environmental condition and visual SRT is more affected than auditory SRT. Thus the management of hot industrial sectors must adopt necessary preventive measures before increasing the work load (mainly for those tasks which involve an increase in visual demands) since it may ultimately lead to an increase in the likelihood of human error and fatal accident.

Considering the benefits of the working population, especially in the industrial sector, for their safety, further studies in this field along with the various other factors might throw some light in the future.

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