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The effect of black tea on human cognitive performance in a cognitive test battery

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Abstract

Background: Black Tea is a widely consumed drink in the world. Evidence suggest Black Tea has stimulatory effect on humans. We investigated the effect of Black Tea on cognition using a cognitive test battery.

Methods: Participants ($n = 32$) were fasted overnight for 10 h and restrained from caffeine and other stimulant drugs for 14 days prior to participation. We randomly assigned participants into either an experimental ($n = 16$) or a control ($n = 16$) group. Experimental group consumed 250 ml of Black Tea (BT) while control group was received equal volume of water (W). Participants were tested on the following cognitive tasks: executive function, sustained attention, memory (memory span, immediate, delayed, working memory) and arithmetic calculation task.

Results: We found that BT group performed significantly ($p < 0.05$) faster in the executive function task (BT: M = 1671, SD = 319; W: M = 1935, SD = 372); simple reaction time task (BT: M = 333, SD = 87; W: M = 361, SD = 101), identification of target location in the visual search task (BT: M = 925, SD = 50; W: M = 972, SD = 115). We also showed that BT group forgotten significantly ($p < 0.05$) lower number of words in the delayed memory recall test (BT: M = 1.12, SD = 0.15; W: M = 1.37, SD = 0.33) and made significantly ($p < 0.05$) fewer errors in the trail making task (BT: M = 0.31, SD = 1.01; W: M = 1.31, SD = 1.66).

Conclusions: BT consumption speeded the performance, improved memory, reduced number of errors in the various cognitive tasks. Our results further showed that even in small volume of BT consumption can speed up cognitive processing.

Keywords: Attention, Memory, Reaction time, Cognition, Visual search

Background

Tea is the second most extensively consumed beverages on the planet [1]. The popularity of tea could possibly be explained by its pharmacological action. For instance, the component of tea such as caffeine increases cortisol level in response to stress [2]. Drinking tea produced stimulation which further helps to overcome psychosocial stress [3], enhances cognitive performance [4] and improves attention [5]. Tea contains phenolic compounds that facilitates synaptic plasticity [6]. The principle constituents of black tea are caffeine and L-theanine. The amount of caffeine and L-theanine in one cup of tea varies. It is estimated that, 200 ml of black tea contain 35–61 mg of caffeine and 4.5–22.5 mg of L-theanine. Caffeine is quickly absorbed (30–40 min, half-life = 3 to 6 h) [7]. Importantly, the effect of caffeine on cognitive function is not limited to a particular type of tea [8].

Previous studies investigated the effects of caffeine and L-theanine on human cognitive performances and behavior. The effect of caffeine and L-theanine on cognition are summarized in Table 1. Higher consumption of tea is associated with a lower risk of cognitive impairment [9]. In elderly people (>60 years old), Black tea consumption improves cognitive performances [10]. Importantly, caffeine improves sustained attention [5], mood and reduces fatigue [11–13], improves motor-skill performance in tasks such as a simulated driving task [14] and improves handwriting [15]. Caffeine at a dose of 200–250 mg improves attention in visual search task [16]. Functional magnetic resonance imaging (fMRI) study reported that caffeine alters neuronal activity in

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Table 1 Summary of published findings on the effect of Black Tea on cognitive process

Study	Dose	Task type	Positive effect	Negative or No effect
Caffeine, ERP study [29]	250 mg	Auditory Go/NoGo	Global increases in P1, P2 and P3b amplitudes to Go stimuli	N1 or N2 (Go stimuli), any components (NoGo stimuli)
Caffeine, ERP study [16]	3 mg/kg	Visual search	Subjects reacted faster	Negative ERP deflection was unaffected
Caffeine [20]	400 mg	Visual search, Simple choice reaction time	Positive effect depends on the level of caffeine use.	
Green tea [9]	1 cup to 6 cups	Mini-Mental State Examination	Higher consumption is associated with a lower prevalence of cognitive impairment	
Breakfast cereal and caffeinated coffee [22]		Working memory, attention and mood		No effect on initial mood or working memory capacity
Caffeine [21]		Visual information processing		Does not affect cognition, learning & memory performance
Breakfast and caffeine [50]	4 mg/kg	Free recall and recognition memory and semantic memory		Impaired accuracy
Glucose & caffeine, fMRI study [53]	Glucose (75 g) + Caffeine (75 g)	Sustained attention	Increase the efficiency of the attentional system	
Caffeine [25]	4 mg/kg	Delayed memory, metamemory and sustained attention		Not affect the magnitude or accuracy of memory predictions
Caffeine, fMRI study [54]	100 mg	WM maintenance task		Detrimental effect on WM at higher levels of WM load
Caffeine, fMRI study[17]	250 or 500 ml	WM	Alters brain activity in DLPFC area	
Caffeine [55]	200 mg	'N-Back' WM paradigm	Heightened WM performance	
Caffeine, Review paper [56]				Does not improve learning and memory
L-theanine, caffeine [26]	L-theanine (250 mg) + caffeine (150 mg)	Simple reaction time, Numeric WM RT and sentence verification	Faster reaction time and improved sentence verification accuracy	
L-theanine, caffeine [28]	L-theanine (100 mg)	Target discrimination	Increase in hit rate and target discriminability (d') for the combined treatment	No effects were detected for l-theanine alone
L-theanine [27]	200 mg + 100 ml water	Attention test	Improves attention and reaction time response	

the DLPFC (dorsolateral Pre-Frontal Cortex) on working memory task [17]. Caffeine also modulates neuronal activity [18]. Caffeine improves low alertness during long drive [14]. Besides caffeine, Theanine improves attentional performance at a dose of 200 mg/100 ml water [19]. Important to notice, effect of caffeine is shown to be related to the habitual intake levels. It has been reported that higher caffeine consumers are more likely to perceive broadly positive effects of caffeine [20].

Surprisingly, caffeine does not always produces beneficial effects, especially at less than 100 mg dose. Caffeine does not affect cognition and memory performance, learning and initial mood [21, 22], long- and short term memory in a delayed recall verbal memory task [23, 24], and complex short-term memory task performance [4].

Aim of the study

We selected Black Tea (BT) since the principle constituent of black tea are two stimulating agents, namely caffeine and L-theanine. It is generally believed that caffeine containing black tea improves human cognitive functioning. However, previous studies reported inconsistent results. These studies used different tasks [25, 26], varied the dosage of caffeine and L-theanine in the tea [26–28], tested participants in different cognitive tasks [8, 20, 29, 30]. Therefore, we aimed to identify the influence of BT consumption on human cognitive functioning, testing the participants in a wide range of cognitive tasks with a low dose that is 50 mg and 15 mg respectively. This small dose have shown no effect on cognitive functioning due to the habitual

intake level [20]. In this study, we controlled habitual black tea consumption level of each participants' prior to the experiment (i.e., consumption of tea was completely restricted for 2 weeks prior to experiment). Moreover, previous studies used relatively simple tasks [14, 30–32] (although see [4] for a more complicated task). Therefore, we used relatively complex test procedures such as trail making tests [33], card sorting test [34, 35], calculation tasks etc.

We hypothesized that BT at a low dose [caffeine (50 mg) and plus L-theanine (15 mg)] would enhance cognitive performance. This enhancement could be due to the faster bioavailablity of caffeine to the brain which is 40 min following drinking [36]. Although cerebral blood circulation may affect cognitive performance, affecting several brain regions at the same time. Therefore, the consumption of BT was expected to influence cognitive processes during the series of behavioural tasks in the cognitive test battery (PEBL) [37].

Methods

Participants

Thirty two healthy volunteers (12 female; mean age = 21) took part in this study. Participants were recruited and controlled for the level of IQ measured by the National Adult Reading Test (mean IQ = 110.62); [38] and were naive to the purpose of experiment. Participants fasted for 10 h overnight and restrained themselves from consumption of tea, caffeine or other stimulant drinks and drugs for 14 days prior to participation in the experiment. All participants had normal or corrected to normal vision.

Procedure

Participants were instructed to sleep at least 8 h overnight and came at 6.30 AM to the test center (Department of Pharmacy, Jahangirnagar University, Savar, Dhaka, Bangladesh). Participants were divided into two groups; (i) experimental group consumed 250 ml of Black Tea (BT) 40 min before testing, assuming caffeine at a dose of 50 mg plus L-theanine at a dose of 15 mg while (ii) control group consumed 250 ml of water (i.e., drinking water; not boiled or distilled). Subjects were randomized to participate in this experiment. A person blind to the purpose of the experiment was involved in assigning subjects for each condition. Before starting the cognitive test battery, participants were shown the procedures for attending the battery of test by a projector as a training phase.

Preparation of drink

BT was purchased from Kazi and Kazi tea, Dhaka, Bangladesh and added to 250 ml of drinking water.

Immediate recall memory test

A list of 10 words was presented to the subjects at a rate of one every 2 second. At the end of the presentation, subjects were given 1 min to write down as many words as possible.

Delayed recall memory test

At the end of the test session (average 90 min test session) subjects were given 1 min to recall as many words as possible from the list shown at the beginning of the study. The number of words forgotten was calculated by subtracting number of words reproduced correctly from the total number of words presented to participants. The difference between numbers of words remembered in the learning trial versus the delayed recall was obtained as an estimation of forgetting.

Trail making test A and B

Participants were asked to connect circles in a specified sequence using pencil to draw lines as rapidly as possible. Condition A involved sequence for connecting the circles in a numeric sequence. Condition B involved circles with alternating numeric and alphabetic sequences.

The psychology experiment building language (PEBL) Version 0.13 [37] was used to test the performance of Visual search, Berger's card sorting test, Memory span, Sustained attention and Arithmetic calculation.

Visual search task

Participants were asked to find the target (odd colored "X" or "O") in a randomly displayed stimulus in the screen. In some trials the target was present and in other trials it was absent. Participants responded with left click of the mouse button. Following the mouse click, the targets were replaced by a mask. Participants were instructed to 'click' on the location of the target. If the target was absent on the screen, following the mouse click, the instruction was to 'click' on the 'none' button. Each participant completed 180 trials.

Berg's Card Sorting Test (BCST)

This is a computerized version of wisconsin card sorting test [39, 40]. Each participant had to complete 128 trials. BCST [41] assessed performance in various tasks: cognitive processing speed, concept formation, inhibition capacity and cognitive flexibility.

Simple reaction time task

Participants were asked to press the space button as quickly as possible every time the red 'dot' was presented on the monitor in 121 trials for the PPVT (PEBL Perceptual Vigilance Task) program of PEBL. The stimuli were presented with an inter-stimulus interval that

varied randomly between 1 and 3.5 seconds. Reaction Times (RTs) were recorded in milliseconds.

Memory span test

This test was used to measure the ability to remember a sequence of locations. In each of the trials nine blue squares were displayed on the screen and these squares lit up one at a time in different sequences. Participants were required to observe the sequence and memorize the order in which the squares lit up. After each trial, subjects were asked to replicate the sequence by clicking on corresponding squares in the right order.

Arithmetic calculation test

It was used to examine the ability to solve a number of simple addition and subtraction problems. Participants were asked to determine whether the answer of each arithmetic operation is greater or less than 5. Each testing block is 3 min long. In separate blocks the task of participants was to do one, two and three digit addition/subtraction operations, with equal number of trials in each block. Participants were asked to perform the task as quickly and accurately as possible.

Apparatus

Stimuli were presented on 15″ CRT (Cathode Ray Tube) screen monitor (SAMSUNG Syncmaster 794MG, made in Malaysia) with a 100 Hz refresh rate placed at a distance of 100 cm from an observer. Responses were gathered with a Logitech optical mouse (Made by Logitech Inc. in China). The whole experiment was programmed in PEBL software run on an Intel ® Core ™ 2 CPU 6700 @ 2.66 Ghz, 2CPUs) computer with Microsoft Windows XP Professional operating system.

Data analysis

Repeated measures ANOVA was used to check for effects of BT on cognitive performance in visual search and arithmetic calculation tasks. Independent sample t-test was conducted to analyze the results of simple reaction time, BCST, memory span, immediate/delayed recall memory and verbal fluency tests. In independent sample t-test, BT and water were grouping variables and all reaction time and other interval data were dependent variable. Reaction times above 1500 ms (too slow) or below 50 ms (too fast) were excluded during the data analysis of visual search, sustained attention, simple reaction time task. In case of BCST and "mathproc" test the upper cut off value for RT was 300 ms and lowest value was 50 ms since they are complicated task and participants required more time than comparatively other tasks. Moreover mean ± 2S.D. was used to exclude odd data. All analyses were carried out with the SPSS package (version 16.0). The difference was considered significant when p value was less than 0.05. Data were represented as mean ± SD (Standard Deviation).

Results

Demographic information

There was no difference in between control and experimental conditions in terms of age (21.5 ± 1.26 vs 20.88 ± 0.71) and IQ level (106.29 ± 23.34 vs 100.71 ± 31.22) (Table 2).

Immediate and delayed recall memory test

Independent samples t-test was conducted to compare the average number of words forgotten in the delayed recall test between BT and W group. There was a significant difference ($p < 0.05$) between the BT (M = 1.12, SD = 0.15) and W condition (M = 1.37, SD = 0.33); t(30) = 1.89, $p < 0.05$. Participants in W group forgot more words than BT group (Fig. 1).

Trail making test A and B

Independent samples t-test revealed no significant difference ($p < 0.01$) between BT and W groups. Mann–Whitney test was used due to the fact that values of standard deviations (SD) were larger than the mean in each of the groups. Error rates in trail making test A were significantly lower in BT (M = 0.31; SD = 1.01) than water (M = 1.31; SD = 1.66). Moreover, participants with BT made less error ($p < 0.01$).

Visual search task

Independent samples t-test was conducted to compare the Reaction Time for identifying the target between BT and W group. There was no difference in the RT between BT (M = 984, SD = 109) and W (M = 999, SD = 101) groups t(30) = −0.38, $p > 0.05$.

Independent samples t-test was conducted to compare the Reaction Time (RT) for identifying the location of the target between BT and W group. We found a significant difference in the RTs between BT (M = 925, SD = 50) and W (M = 972, SD = 115) condition; t(0.28) = −1.07, $p < 0.05$. Repeated measures ANOVA showed the main effect of stimulus size: a gradual increase in RTs with increase in set size for both groups $F_{(2,14)} = 5.6$, $p < 0.05$ (Fig. 2).

Berger's card sorting test

We found no difference between the BT (M = 8.81%, SD = 5.74) and W (M = 9.38%, SD = 5.99) groups in the error rates; t(30) = −0.271, $p > 0.5$). In other words, both groups made comparable number of errors in the test. However, there was a difference in RTs. BT group (M = 1671, SD = 319) was faster relative to the W (M = 1935, SD = 372) group; t(30) = −2.155, $p < 0.05$), although participants were not instructed to give a

Table 2 Demographic data and participant's performance in various cognitive tasks in PEBL test battery

		Black Tea (BT)	Water (W)	*P* value
Age	Year	21.5 ± 1.26	20.88 ± 0.71	>0.1
IQ level		106.29 ± 23.34	100.71 ± 31.22	>0.1
Memory Span	Average block	5.31 ± 0.89	4.90 ± 0.84	>0.1
Immediate Recall Memory Test	No. of words retrieved	8.06 ± 0.32	7.75 ± 0.22	>0.1
Delayed Recall Memory Test	No. of words retrieved	7.56 ± 0.93	6.50 ± 0.37	>0.1
	No. of words failed to recall	1.12 ± 0.15	1.37 ± 0.32	<0.05
Berger's Card Sorting Test	Persev_error	8.81 ± 5.74	9.38 ± 5.99	>0.1
	RT (ms)	1671 ± 319	1935 ± 372	<0.05
Simple Reaction Time Task to measure Sustained Attention	RT (ms)	333 ± 2	361 ± 2	<0.05
Visual Search (Target identification)	RT (ms)	984 ± 32	999 ± 37	>0.1
Visual Search (Target location)	RT (ms)	925 ± 12	972 ± 28	<0.05

Total subjects ($n = 32$); water ($n = 16$); Black Tea ($n = 16$); *RT* Reaction Time; Data were represented as Mean ± SEM; RTs were shown in millisecond (ms

speeded response. This may suggest that BT consumption could facilitate RTs in BCST task.

Simple reaction time task

Independent samples t-test was conducted to compare the Reaction Time in the sustained attention task between BT and W group. We found a significant difference in the RT for BT condition (M = 333, SD = 87) and W condition (M = 361, SD = 101); t(30) = −8.43, $p < 0.05$.

Memory span test

We showed no difference in the memory for BT (M = 5.31, SD = 0.89) and W conditions (M = 4.90, SD = 0.84); t(30) = −1.32, $p > 0.05$ following independent sample t-test analysis.

Arithmetic calculation test

Repeated measure ANOVA revealed no effect of BT on neither speed nor accuracy of arithmetic calculations task F 2, 14 = 6.4, $p > 0.05$.

Discussion

We investigated the influence of BT on the performance of a series of cognitive tasks, controlling for the habitual intake level of caffeine, complexity of the task and inter-participant differences in cognition. We used a lower amount of BT since several studies suggeste BT does not influence certain cognitive functions [28], particularly at the dosage of less than 100 mg [22, 23]. We found BT groupe sowed improved performances in a number of

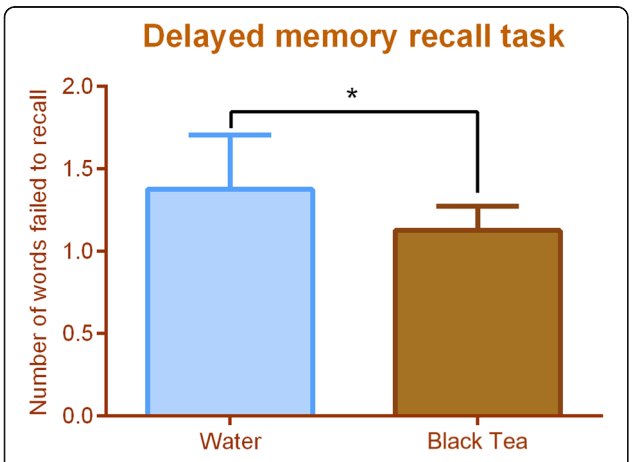

Fig. 1 Effect of Black Tea (BT) and Water on delayed memory recall task. *Vertical axis* represents number of words failed to recall in the delayed memory recall task while *horizontal axis* represents the treatment groups (water and BT). Data is represented as Mean ± SEM (Standard Error of Mean). * indicates *p* value less than 0.05

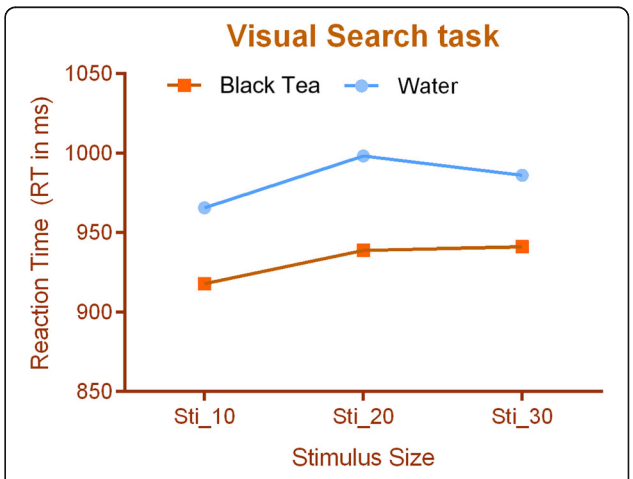

Fig. 2 Effect of Black Tea (BT) and Water on Visual Search task. *Vertical axis* represents Reaction Time (RT) in millisecond (ms) while represents various stimulus size namely, Sti_10: Stimulus Size 10; Sti_20: Stimulus Size 20; Sti_30: Stimulus Size 30. Data is represented as Mean value

cognitive tasks. In line with previous results, we have also shown facilitation effect of BT on cognition [2].

We showed drinking of BT facilitated cognitive functions in delayed recall memory test. BT group forgotten fewer words. It is presumable that drinking of BT accelerates the consolidation [36] and retrieval of memory. The memory traces could be stabilized during the experimental sessions which helped BT consumers to retrieve the words [42]. A revious study [17] suggest that caffeine alters neuronal activity in the DLPFC (dorsolateral Pre-Frontal Cortex) during performance on a working memory task [38]. Additionally, our study showed that this effect might already had at caffeine dose of less than 70 mg.

Further, BT consumers were more accurate in performing trail making test A. Trial making is a complex task that requires sustained attention, alertness, speeded motor activity to be activated at the same time. Previous studies showed a positive effect of caffeine on sustained attention [36] alertness [25] and motor activity [43] separately. Trail making test confirms our hypothesis that a merging of facilitation events might produce a combinatory effect on cognitive processing.

Another important finding of the present study is that BT consumers were faster in identifying target location in the visual search task. This effect is only possible when a combination of higher level cognition (e.g., attention, alertness, short term memory) is involved in the task. Identifying an object in their location is a hippocampal-dependent task. It is possible that BT consumers had learned better in this spatial learning task. This finding goes in line with the caffeine related improved performance in the *Berg's Card Sorting Test* (BCST) and simple reaction time tasks and supports previous findings that showed caffeine induced facilitation of attention [32, 44] and level of alertness [13, 45]. It is also consistent with other previous studies [2, 16, 19, 38] that linked consumption of tea to robust increases in alertness and information processing capacity [4]. As cholinergic mechanisms have been shown to be a necessary condition for memory formation in rats [46], we hypothesize that BT might also be able to influence the level of cholinergic mechanisms in humans, thus improving memory formation [46].

Caffeine facilitation in visual search task raises an important issue for the cognitive psychology research that greatly relies on reaction time (RT) data in visual search tasks. Since caffeine and L-theanine in tea are a regularly consumed drink by the students, it might influence behavioral results in cognitive experiments. Therefore, it could be recommended to additionally measure the level of caffeine consumption among participants of various RT experiments and use it as an additional factor during the statistical analysis.

Visual search task is an established neuropsychological tool for testing the iconic memory [47, 48]. It measures two parameters: the reaction time (RT) necessary to either detect or determine spatial location of the target. Both groups (i.e., BT and W) performed equally well in the first task – target detection. However, BT group showed facilitated identification of target location, relative to the control group. To our knowledge, we first report that BT is able to improve iconic memory. There are several non-exclusive explanations of this effect. Possibly, caffeine is able to facilitate attention allocation that is necessary to locate a target [49]. On the other hand, caffeine could facilitate the decision making stage of visual search, which allowed BT participants to perform faster [20, 50]. Additionally, overall stimulant effect of caffeine could possibly enhance motor processes that cause the improved performance [43]. This latter point is, however, less likely since previous studies showed no effect of caffeine on human motor functioning [51]; although see [14] for a different view. Further Electroencephalographic (EEG) experiment would be necessary to identify the stage of visual processing that is influenced by caffeine: attention allocation i.e., N2PC (N200 component of posterior contralateral) [52].

Arithmetic calculation task (ACT), memory span and iconic memory (target location identification) were for the first time tested in this experiment. We showed that BT does not affect arithmetic calculation and memory span, but enhances iconic memory.

Our study has several limitations. First, the number of participants was ($n = 16$ in each groups) relatively smaller and we used a lower volume of BT. Additionally, we measured only behavioral performance. Therefore, future studies should test larger groups of participants as well as employ Event Related Potential (ERP) methodology.

Conclusions

Tea is one of the most popular drinks because of having two stimulants, caffeine and l-theanine. Caffeine increases the level of alertness and improves cognitive functions. Previous studies showed that consumption of caffeine is able to facilitate certain cognitive processes (e.g., short term memory, simple RTs etc.). In our present study, we tested the influence of black tea on human cognitive performance in a battery of cognitive tests. We showed that BT improved the speed of attention allocation, speeded visual search and increased level of alertness. However, additional studies are required in order to identify specific stages of visual processing that are being influence by BT consumption as well as long term BT effects on human cognitive functioning.

Abbreviations
BCST: Berg's Card Sorting Test; BT: Black Tea; PEBL: Psychology experiment building language (PEBL)

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Authors' contributions
AR and MMAA designed the study. AR collected the data. AR, AZ, CO and MMAA analyzed the data. MMAA and AR prepared the manuscript. AZ and MSR revised the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Ethics approval and consent to participate
Participants signed an informed consent form. Participants and instructors were awarded with breakfast and snacks at the post test session. Experimental protocol was approved by Institutional Review Board of the Department of Pharmacy, Jahangirnagar University (Approval No. JU/LS/Pha/2013/1040).

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