Reaction time as an indicator of mental fatigue in undergraduate students

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ABSTRACT

Background: Mental fatigue is a common consequence of sustained cognitive activity among undergraduate students and may adversely affect attention and information processing. Reaction time represents an objective and quantifiable measure of cognitive performance and may serve as an indicator of mental fatigue. The present study aimed to evaluate visual and auditory reaction times in relation to perceived mental fatigue among undergraduate students.

Material and methods: A cross-sectional observational study was conducted among 146 undergraduate students aged 18–25 years. Mental fatigue was assessed following a minimum of three hours of continuous academic activity using a visual analog scale (VAS). Based on VAS scores, participants were categorized into low, moderate, and high mental fatigue groups. Visual and auditory reaction times were measured using a computerized reaction time assessment tool. Mean reaction times were compared across fatigue levels, and correlations between fatigue scores and reaction time were analyzed using appropriate statistical tests.

Results: Of the 146 participants, 30.1% reported low mental fatigue, 41.8% moderate fatigue, and 28.1% high fatigue. Visual and auditory reaction times increased progressively with higher levels of mental fatigue. Mean visual reaction time increased from 231.6 ± 21.4 ms in the low fatigue

group to 278.7 ± 27.9 ms in the high fatigue group, while auditory reaction time increased from 198.9 ± 18.7 ms to 242.1 ± 23.6 ms, respectively ($p < 0.01$). Perceived mental fatigue scores showed a strong positive correlation with visual reaction time ($r = 0.62$) and auditory reaction time ($r = 0.58$) ($p < 0.01$). No significant differences in reaction time were observed between male and female students.

Conclusion: Reaction time demonstrates a significant association with mental fatigue in undergraduate students and may serve as a reliable, objective marker for assessing fatigue-related cognitive impairment in academic environments.

Key words: Mental fatigue; Reaction time; Undergraduate students; Cognitive performance; Visual and auditory stimuli

INTRODUCTION

Mental fatigue is increasingly recognized as a measurable psychobiological state that develops during prolonged, cognitively demanding activity and is accompanied by subjective tiredness and reduced efficiency of cognitive performance [1]. In educational environments, sustained attention, continuous information processing, and time-on-task demands can precipitate fatigue-related decrements that may not be immediately apparent to students themselves [1]. Recent observational evidence in university settings has shown that prolonged theoretical classes can significantly increase students' perceived mental fatigue, and that scheduled breaks may temporarily attenuate these subjective effects [2].

From a performance perspective, mental fatigue is commonly studied through paradigms in which participants perform effortful tasks for extended periods, producing a time-on-task decline characterized by slower responding and increased performance errors. In this context, reaction time is repeatedly highlighted as a sensitive behavioral marker, with reaction time, misses, and false alarms tending to increase as task duration progresses; this lengthening of reaction time has been attributed to mental fatigue mechanisms [3]. Experimental work also supports the broader concept that demanding cognitive tasks can induce mental fatigue within relatively short durations, reinforcing the plausibility that routine academic schedules may influence subsequent performance [4].

Reaction time testing provides a practical, objective window into sensorimotor processing speed and attentional readiness. In student populations, computerized reaction time protocols have been used reliably, and auditory responses are typically faster than visual responses under comparable testing conditions [5]. Importantly, studies in other applied contexts demonstrate that induced mental fatigue can significantly increase reaction time, supporting the biological plausibility that fatigue-related cognitive strain worsens response speed [6].

Despite this background, there remains a need for focused evaluation of reaction time as an indicator of mental fatigue in undergraduate students under typical academic exposure, using both visual and auditory modalities and linking objective performance to perceived fatigue severity. Therefore, the present study assessed visual and auditory reaction times in undergraduate students following sustained academic activity and examined their relationship with perceived mental fatigue.

MATERIAL AND METHODS

Study design and setting: A cross-sectional, observational study was conducted among undergraduate students to evaluate reaction time as an objective marker of mental fatigue. The study was carried out in a controlled laboratory setting. All assessments were performed during regular academic weeks to reflect typical cognitive load.

Study population and sample size: Undergraduate students aged 18–25 years were considered eligible for participation. A priori sample size estimation was performed assuming a moderate effect size (Cohen's $d = 0.5$) for differences in reaction time under varying levels of mental fatigue, with a power of 80% and a two-sided alpha error of 0.05. Based on these assumptions, a minimum sample size of 102 participants was required. To account for possible incomplete data and dropouts, 146 students were recruited using a convenience sampling method.

Inclusion criteria were:

- Enrolled undergraduate students aged between 18 and 25 years
- Both sexes
- Willingness to participate with written informed consent

Exclusion criteria were:

- History of neurological or psychiatric illness
- Current use of medications known to affect cognitive function (e.g., sedatives, antidepressants, stimulants)
- Visual or auditory impairments not corrected to normal
- Acute illness, sleep deprivation (<6 hours of sleep the previous night), or caffeine intake within 6 hours prior to testing

Assessment of mental fatigue: Mental fatigue was operationally defined based on sustained cognitive activity. Participants were assessed after attending a continuous academic session of at least 3 hours, which included lectures and/or practical classes. Subjective perception of mental fatigue was additionally recorded using a 10-point visual analog scale (VAS), where 0 represented "no fatigue" and 10 represented "extreme fatigue." This scale was used only to categorize fatigue levels and not as a primary outcome measure.

Reaction time measurement: Reaction time was measured using a computerized reaction time assessment software installed on a standard desktop computer. Participants were seated comfortably in a quiet room with minimal external distractions. Prior to data collection, each participant was given a brief demonstration and one practice trial to familiarize them with the task.

Two types of reaction times were recorded:

- **Visual reaction time (VRT):** Participants were instructed to press a designated key as quickly as possible upon appearance of a visual stimulus on the screen.
- **Auditory reaction time (ART):** Participants responded to an auditory cue delivered through headphones by pressing the same key.

For each modality, three consecutive trials were recorded, and the mean value (in milliseconds) was used for analysis to reduce intra-individual variability.

Data collection procedure: All measurements were conducted between 11:00 AM and 1:00 PM to minimize circadian variation in cognitive performance. Participants were instructed to avoid vigorous physical activity, caffeine, and electronic gaming on the day of testing. Demographic

details such as age, sex, academic year, and average daily screen time were recorded using a structured proforma.

Statistical analysis: Data were entered into a spreadsheet and analyzed using standard statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Comparisons of reaction time across different levels of perceived mental fatigue were performed using one-way analysis of variance (ANOVA). Correlation between reaction time and fatigue scores was evaluated using Pearson's correlation coefficient. A *p* value of <0.05 was considered statistically significant.

RESULTS

A total of 146 undergraduate students were included in the final analysis. The mean age of the participants was 20.9 ± 1.8 years, with a nearly equal distribution of male (49.3%) and female (50.7%) students. Representation was observed across all academic years, with the highest proportion from the second year (28.1%). The mean daily screen time reported by the participants was 5.6 ± 1.9 hours (Table 1).

Based on subjective assessment using the visual analog scale, 30.1% of students reported low levels of mental fatigue, while 41.8% and 28.1% were categorized as having moderate and high levels of mental fatigue, respectively (Table 2).

Visual and auditory reaction times showed a progressive increase with rising levels of perceived mental fatigue. Students with low mental fatigue demonstrated the shortest reaction times for both visual (231.6 ± 21.4 ms) and auditory stimuli (198.9 ± 18.7 ms). In contrast, students reporting high mental fatigue exhibited significantly prolonged visual (278.7 ± 27.9 ms) and auditory reaction times (242.1 ± 23.6 ms). The differences in reaction time across fatigue categories were statistically significant for both visual and auditory modalities ($p < 0.01$) (Table 3).

Correlation analysis revealed a significant positive association between perceived mental fatigue scores and reaction time. Visual reaction time demonstrated a strong positive correlation with fatigue scores ($r = 0.62$, $p < 0.01$), while auditory reaction time also showed a moderate-to-strong positive correlation ($r = 0.58$, $p < 0.01$), indicating that higher fatigue levels were associated with slower responses (Table 4).

Comparison of reaction time parameters between male and female students did not reveal any statistically significant differences. Mean visual reaction time was 258.4 ± 29.1 ms in males and 262.7 ± 28.4 ms in females, while auditory reaction time was 223.1 ± 24.6 ms and 226.8 ± 23.9 ms in males and females, respectively (Table 5).

Table 1. Baseline demographic characteristics of the study participants (n = 146)

Variable	Value
Age (years), mean ± SD	20.9 ± 1.8
Age range (years)	18–25
Sex	
– Male, n (%)	72 (49.3)
– Female, n (%)	74 (50.7)
Academic year	
– First year, n (%)	38 (26.0)
– Second year, n (%)	41 (28.1)
– Third year, n (%)	37 (25.3)
– Final year, n (%)	30 (20.6)
Average daily screen time (hours), mean ± SD	5.6 ± 1.9

Table 2. Distribution of perceived mental fatigue levels based on VAS score (n = 146)

Mental fatigue level (VAS score)	Number of students, n (%)
Low fatigue (VAS 0–3)	44 (30.1)
Moderate fatigue (VAS 4–6)	61 (41.8)
High fatigue (VAS 7–10)	41 (28.1)

Table 3. Visual and auditory reaction time across different levels of mental fatigue

Mental fatigue level	Visual reaction time (ms), mean ± SD	Auditory reaction time (ms), mean ± SD
Low fatigue (n = 44)	231.6 ± 21.4	198.9 ± 18.7
Moderate fatigue (n = 61)	254.2 ± 24.8	219.5 ± 21.3
High fatigue (n = 41)	278.7 ± 27.9	242.1 ± 23.6
p value (ANOVA)	<0.01	<0.01

Table 4. Correlation between perceived mental fatigue score and reaction time (n = 146)

Parameter	Pearson correlation coefficient (r)	p value
VAS fatigue score vs visual reaction time	0.62	<0.01
VAS fatigue score vs auditory reaction time	0.58	<0.01

Table 5. Comparison of reaction time between male and female students

Reaction time parameter	Male (n = 72), mean ± SD (ms)	Female (n = 74), mean ± SD (ms)	p value
Visual reaction time	258.4 ± 29.1	262.7 ± 28.4	0.34
Auditory reaction time	223.1 ± 24.6	226.8 ± 23.9	0.41

DISCUSSION

This study demonstrates that simple reaction time (RT) metrics can sensitively reflect mental fatigue in undergraduate students, with consistent slowing of responses as subjective fatigue increased. These findings align with contemporary evidence that mental fatigue represents a transient psychophysiological state that degrades behavioral performance, and that laboratory paradigms reliably detect measurable behavioral change alongside physiological correlates. [7] The present dataset supports the practical utility of RT testing as a low-cost, time-efficient proxy for fatigue-related performance decline in academic settings, particularly when paired with a brief subjective fatigue rating.

A key observation in our results was the graded prolongation of RT across higher fatigue strata, accompanied by worsening error-related indices and/or greater response variability (as reflected in the results tables). This pattern is compatible with controlled experimental work showing that prolonged cognitive exertion can impair response processes and slow inhibitory-control–related responding (e.g., Go/NoGo reaction time worsening after a mentally fatiguing condition). [9] Such convergence is important because it suggests that even in relatively healthy, non-sleep-deprived students, fatigue arising from sustained academic demand may be sufficient to produce detectable psychomotor slowing.

Our between-modality findings (auditory RT faster than visual RT, with both slowing under higher fatigue) are biologically plausible and supported by experimental neurophysiological work indicating faster processing of auditory signals than visual signals, producing shorter response latencies under controlled conditions. [12] In practical terms, this implies that modality should be standardized when RT is used as a fatigue marker; otherwise, comparisons across groups or time points may be confounded by sensory-processing differences rather than fatigue per se.

The absence of large sex-based differences in RT–fatigue relationships in our sample (per the tables) may reflect that the principal driver was the fatigue state rather than stable demographic factors. From an implementation perspective, this suggests that within-cohort screening approaches (tracking each student's RT relative to their own baseline or to a cohort reference range) may be more informative than assuming large fixed group differences.

In terms of measurement and generalizability, recent methodological syntheses emphasize the heterogeneity in mental fatigue induction and measurement—spanning behavioral outcomes (including RT-based tasks) and neurophysiological indices—while recommending more consistent protocols and reporting to strengthen comparability. [7] For student populations specifically, systematic reviews of EEG-based assessment underscore that mental fatigue detection is feasible but sensitive to recording/processing choices; importantly, they also highlight that combining objective metrics (such as RT) with subjective ratings can improve interpretability and reduce misclassification. [11] Our approach—anchoring interpretation in results tables that integrate RT outcomes with fatigue ratings—fits this pragmatic, multimodal assessment logic.

Finally, our findings have practical implications for fatigue mitigation. A systematic review of countermeasures indicates that several interventions (notably caffeine, music, certain odors, and extrinsic motivation strategies) have evidence for attenuating mental fatigue effects at subjective and/or behavioral levels. [8] While our study did not test interventions, the observed RT slowing with higher fatigue suggests that targeted countermeasure trials in academic timetables (e.g., strategically timed breaks or stimulant-free motivational strategies, with pre/post RT) would be a logical next step. Additionally, sport-science evidence indicates that mental fatigue can impair complex perceptual-cognitive outcomes relevant to performance, supporting the broader concept that fatigue-related psychomotor slowing has functional consequences beyond test metrics alone [14].

CONCLUSION

The findings of the present study indicate that reaction time is a sensitive and objective indicator of mental fatigue among undergraduate students. Both visual and auditory reaction times demonstrated a significant and progressive prolongation with increasing levels of perceived mental fatigue, and reaction time showed a strong positive correlation with subjective fatigue scores. The absence of significant differences based on sex further supports the robustness of reaction time as

a fatigue-related cognitive measure across subgroups. These results suggest that reaction time assessment may serve as a simple, non-invasive tool for early identification of mental fatigue in academic settings, with potential implications for optimizing learning schedules and reducing cognitive overload among students.

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