POST-TASK P3-CHANGES FOLLOWING A BRIEF, RIGOROUS VISUAL TASK INDICATE INDIVIDUAL DIFFERENCES IN THE TASK-SPECIFIC ABILITY

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Abstract : The P3 latency in an auditory oddball ERP paradigm is known to get prolonged after a few hours of mental task. The present study shows that it takes merely a few minutes of challenging visual mental activity to produce significant changes in P3 latency in the visual oddball ERP paradigm. However, the mental activity results in a shortening of P3-latency almost as often as it results in its prolongation. Similarly, the post-task P3 amplitude is higher or lower with nearly equal incidences. Following the task, the reaction time shortens as often as it prolongs. It seems that the P3 changes and their variations through electrode sites signify individual differences in the amount and extent of additional neuronal resources tapped by the subject in coping with the challenging task, and that it leaves an aftereffect for several minutes after the mental workload is withdrawn. These aftereffects get indexed in the P3 wave characteristics of a much simpler ERP paradigm with more change occurring in the better performers. In the clinical context, these observations raise doubts about the diagnostic value of P3 latency or amplitude without knowledge of the immediate history of mental workload.

INTRODUCTION

It has been reported by Kaseda et al. (1) that when auditory event-related potentials (ERPs) are recorded before and after a mentally fatiguing task, a definite increase in the P3 latency is observed in the post-task record. Our experimental design accommodated the possibility that any P3 prolongation might be a reflection of the subject's mental ability, keeping in mind the anecdotal results of our preliminary experiments that suggested that the post-task latency prolongation was greater in

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high-IQ subjects (2) and the extensive literature related to brain electrical correlates of psychological measures beginning more than three decades ago (3) that have been elegantly summarized (4). We have performed experiments on similar lines ensuring that (a) the subjects' performance in the fatiguing task (which we prefer to call the challenge-task so as to be noncommittal about the effect it induces) can be objectively scored; (b) the challenge-task and the ERP paradigm are both visual; (c) the scalp topography of the ERP is recorded; and (d) the reaction-times before and after the challenge-task are recorded.

METHODS

Continuous 32-electrode electroencephalograms were recorded using NuAmps® and SCAN® (Neuroscan labs) in 22 intelligent and highly motivated volunteers with normal vision (medical students, all males aged between 18 and 24 years) while they performed psychomotor tasks generated through STIM® (Neuroscan labs) on the computer. The subjects were explained about the nature of the experiments and reassured that any difference in their psychomotor performance would be construed as a difference in a specific mental ability rather than a difference in I.Q. Two types of tasks were performed in three continuous sessions: a visual challenge-task (hereon called 'the task') for 15 minutes preceded and followed by 7½ sessions of the standard visual continuous performance tasks (hereon called the 'ERP task'). Overall, each recording session lasted 30 minutes comprising the sequence "ERP task – Task – ERP task". The ERP-task had

two cues: the frequent O's and the infrequent X's. The subject had to press '1' on the response key pad on seeing an X. The visual challenge task involved mental flipping or rotation of images (Fig. 1). The subject had to press '2' on the response key pad if, compared to the figure on the left, the right on the right was horizontally flipped, '3' if it was vertically flipped and '4' if it was rotated through 180°. Subjects were explained that there were points to be scored for both speed and accuracy and were encouraged to score as highly as they could. The subjects sat at a distance from the monitor which they found most convenient. The distance remained unchanged through out the recording session.
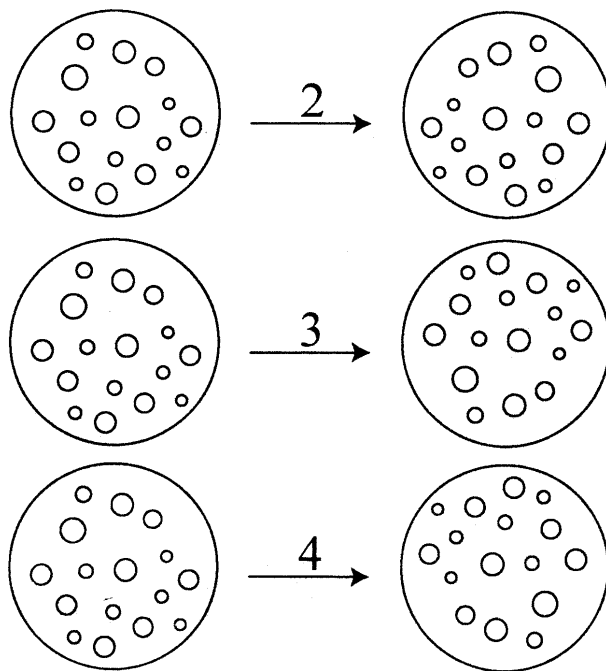

Fig. 1 : Visual 'challenge' task. Figure-A has been transformed in figure-B either by horizontal flipping, vertical flipping or by rotating through 180°.

The Reaction Time (RT) before and after the challenge task were compared using paired t-test separately for each individual. The latency and accuracy of the response to the task were recorded and a combined 'task score' was derived from the two. The score was arrived at by adding the average response time of the individual to each of his incorrect response time. Lower scores indicated fewer errors and quicker responses. The average response time as well as the task scores in the pre- and post-task ERP sessions were compared. For ascertaining any change in performance in the course of the task, the response time and the average scores were computed separately for the first 15 and the last 15 responses.

The EEG was recorded with chlorided silver electrodes from 32 standard scalp locations of the 10–20 International System, all referred to right mastoid electrode. The impedance was kept below 5 kOhms. The amplifiers were set to a high frequency cut-off of 40 Hz. The EEG was sampled continuously at 500 Hz. Eye movements (EOG) were recorded from above and below the right eye. Trials contaminated with EOG artifacts were excluded from the data and 70 artifact-free epochs of 2400 ms epoch beginning 400 ms prior to stimulus were averaged.

Averaged potentials derived from the pre- and post-task EEG and their P3 latency and amplitude were compared using paired samples *t* test. The latency change was also evaluated using cross-correlation of the most prominent part of the P3 waveforms (beginning at N2) recorded before and after the task. The latencies thus obtained indicated the shift of the overall contour of the P3 wave and were relatively resistant to location of its peak.

P300 amplitude was quantified by measuring the peak from the zero-voltage baseline. The search epoch ranged from 300–500 ms. The P3 latency and amplitude before and after the challenge task were compared using paired t-test, electrode for electrode, for each subject. Group averages were not calculated since, as was apparent on preliminary observation of results, the changes were bidirectional and would be lost on averaging across subjects. Correlation analysis was performed between each of the behavioral parameter (task-latency, task score, change in task score over 15 minutes, pre-task RT, change in RT) and each of the electroencephalographic parameter (Pre-task P3 latency, post-task P3 latency, increase in P3 latency, pre-task P3 amplitude, post-task P3 amplitude, increase in P3 amplitude). The latter were derived from global field power (GFP) as well as from individual electrodes in the median plane (Fz, FCz, Cz, CPz, Pz, Oz).

RESULTS

As already mentioned above, the data is described as individual rather than as group averages. This is because the comparison of P3 latency and amplitude before and after the task, which are mostly highly significant, could be in either direction, and would get obscured by group averages.

Visual ERP changes

At least 10 of the 22 subjects showed marked changes in the latency and

amplitude of the P3 wave (Fig. 2, 3). The amplitude changes were highly significant statistically when compared by paired t-test, in which the degree of freedom was derived from the number of epochs averaged. Overall, the post-task amplitude and latency changes at individual electrode sites were in both directions, representing either
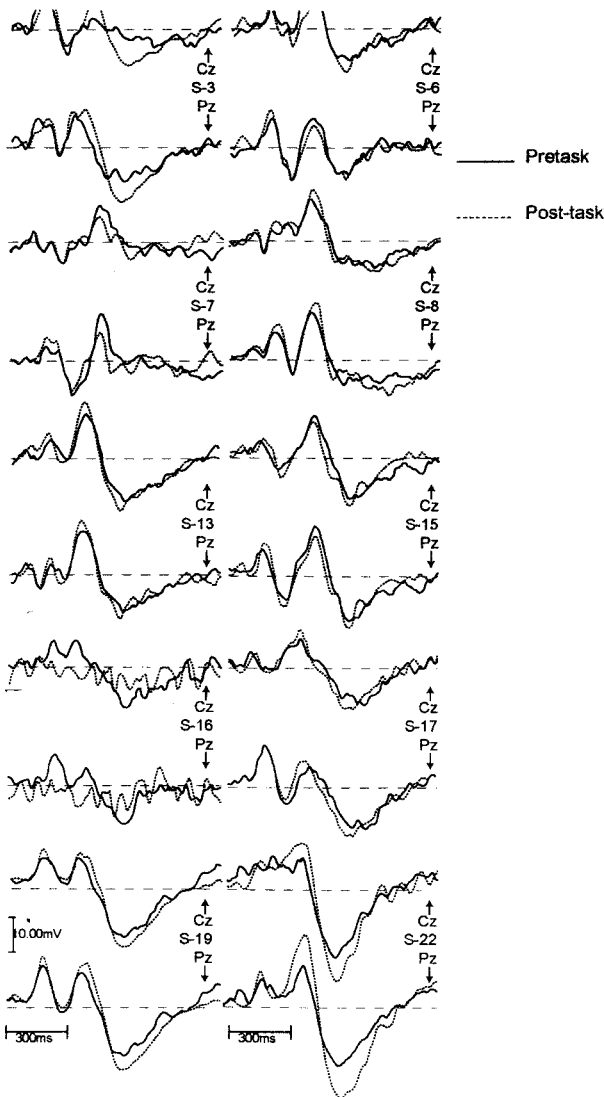
increase or decrease (Fig. 4). However, the global field power (GFP) showed mostly an increase in amplitude though the latency changes were once again bidirectional (Fig. 5a, b).

Visual response time changes

A few of the subjects showed significant

Fig. 2 : Visual ERP (in selected individuals) recorded at Cz and Pz before and after a visual 'challenge' task.
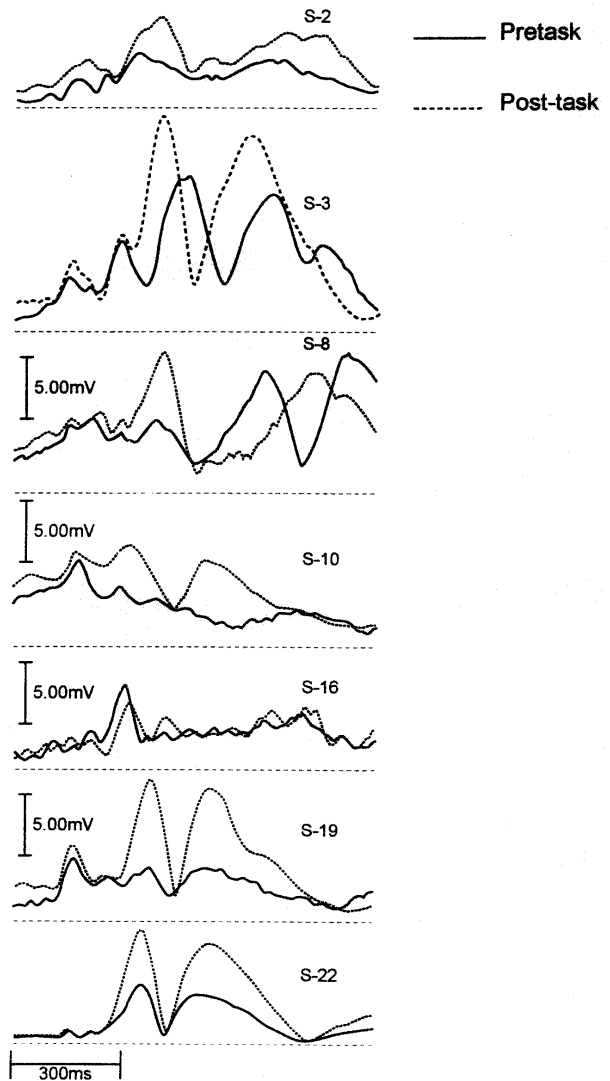
Fig. 3 : Global Field Power of Visual ERP (in selected individuals) before and after a visual 'challenge' task.
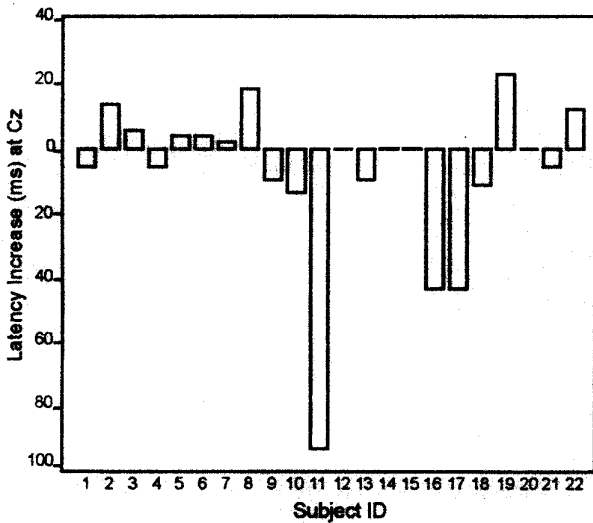
Fig. 4a. P3 latency increase at Cz
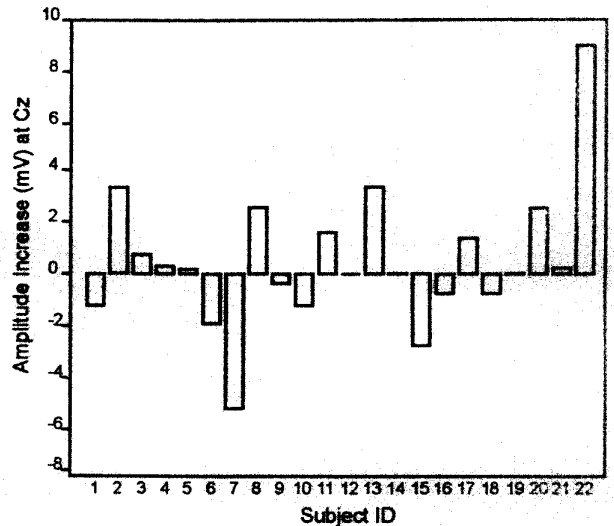
Fig. 4b. P3 amplitude increase at Cz

Fig. 4 :   Increase in P3 latency and amplitude after challenge-task recorded at Cz.
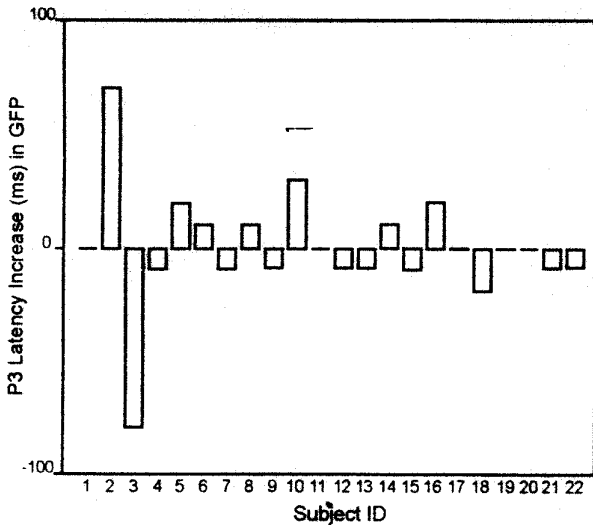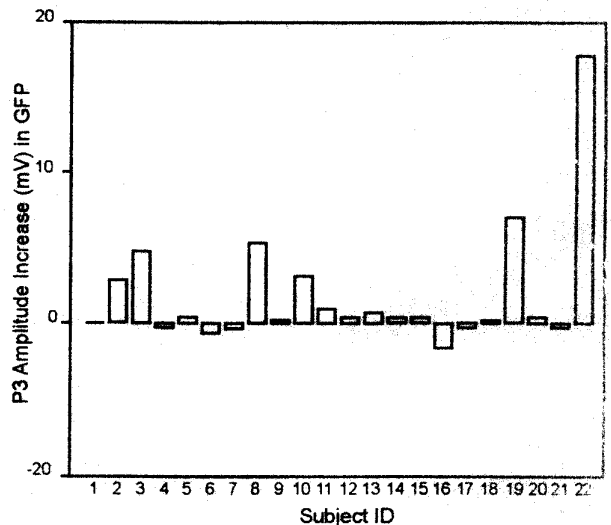

Fig. 5a. P3 latency increase in GFP

Fig. 5b. P3 amplitude increase in GFP

Fig. 5 :   Increase in GFP latency and amplitude after challenge-task.

changes in the visual RT after the challenge-task. Once again, they were in either direction. Similarly, changes in the response time to the challenge-task in the first and last 5 minutes were also in both directions (Fig. 7).
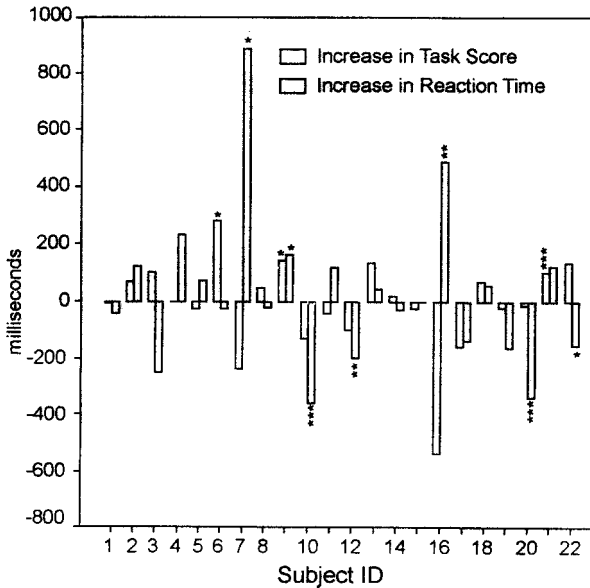
Fig. 6 :   (a) Increase in response time in course of the challenge task, and (b) increase in RT after the challenge-task in comparison to the pre-task RT.
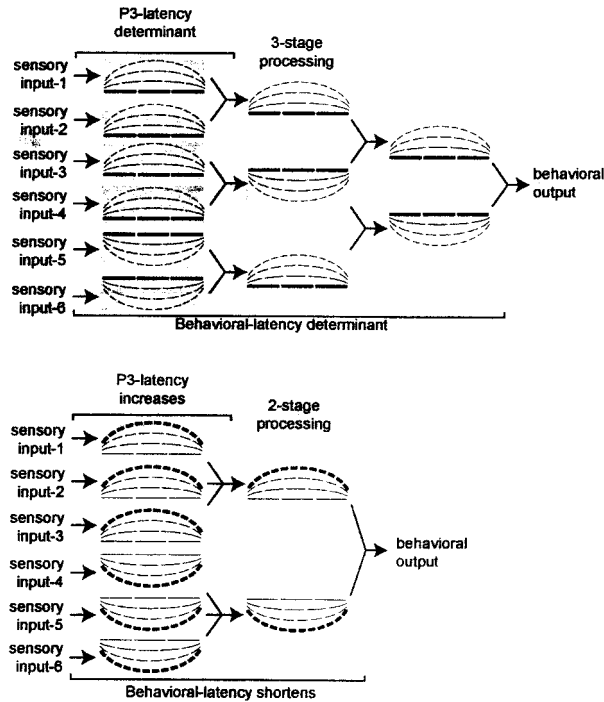

Fig. 7 :   Hypothetical neuronal mechanism to account for dissociation of the latency of behavioral output and the P3 wave. (MMS=major memory stations).

TABLE I :   Interbehavioral correlation analysis.

	Task score	Task score increase	Pre-task RT
Task score increase	−0.571**		
Pre-task RT	0.614*	−0.371	
Increase in RT	0.386	−0.545**	0.310

 * significance <0.05
** significance <0.01

Correlation analysis between interbehavioral parameters

Correlation analysis was done between each behavioral parameter with each of the other behavioral parameter (Table I).

TABLE II :   Correlation of electrophysiological and behavioral parameters.

	Task score	Task score increase	Pre-task RT	Post-task increase in RT
1. GFP Latency Pre-Task	−0.545*	0.366	−0.325	−0.238
2. GFP Latency Increase	0.164	−0.193	0.147	0.108
3. GFP Amplitude Pre-Task	−0.21	0.106	−0.184	−0.194
4. GFP Amplitude Increase	−0.251	0.275	−0.21	−0.348
5. Fz Latency Pre-Task	0.284	−0.02	−0.018	0.087
6. Fz Latency Increase	−0.331	0.407	−0.228	−0.145
7. Cz Latency Pre-Task	0.427*	0.094	−0.113	0.177
8. Cz Latency Increase	−0.617**	0.418	−0.185	−0.146
9. Pz Latency Pre-Task	0.062	0.112	0.394	0.151
10. Pz Latency Increase	−0.148	0.112	−0.137	0.085
11. Fz Amplitude Pre-Task	−0.339	0.362	−0.344	−0.064
12. Fz Amplitude Increase	−0.459*	0.436	−0.327	−0.536*
13. Cz Amplitude Pre-Task	−0.379	0.218	−0.235	0.148
14. Cz Amplitude Increase	−0.22	0.326	−0.349	−0.459*
15. Pz Amplitude Pre-Task	−0.254	−0.051	0.009	0.015
16. Pz Amplitude Increase	−0.31	0.515*	−0.439	−0.624**

Correlation analysis between electroencephalographic and behavioral parameters

Correlation analysis were done between every combination of electroencephalographic and behavioral parameter. Significant correlations were obtained between task latency (or score) and the global field power (GFP) latency. This correlation was reflected at some but not all electrode sites (Table II).

DISCUSSION

That mental workload induces changes in the post-ERP was reported earlier by Kasada et al. (1). However, they recorded such changes after 6 hours of simple calculations and showed significant correlations of those changes with the subjective feeling of fatigue. While our work is apparently similar, it is important to note that our subjects did rigorous visual task for only 15 minutes. Moreover, in our experiments, both the challenge-task and the ERP task are visual.

The results show that following the task, some of the subjects showed marked changes in the P3 waveform with little till the N2 wave. Some of the more prominent ones are shown in Fig. 2. Changes in the global field power are shown in Fig. 3 and 5. The P3 recording protocol was identical before and after the task and hence, the numerous studies on the effect of task difficulty on P3 are not relevant here. It shows that mental workload leaves its effect on subsequent cognitive processing even when the load is taken off. While fatigue and potentiation are known to occur in mental processes, a third possibility, one of 'cognitive recruitment' can explain why better performers tend to have higher P3-latencies. There is significant inverse correlation (P<0.05, r = −0.545) between task scores (lower, the better) and the GFP-P3 latency. The correlation becomes stronger (P<0.01, r = −0.555) after the task. It is unlikely that a fatigued neural pathway accounts for a better performance.

The hypothesis of cognitive recruitment (2) assumes that for any task, a parallel array of pathways is available and the brain recruits the pathway with processing power appropriate to the given task. It further assumes that it takes several minutes before the brain can step down the level of recruitment as a result of which the P3 characteristics recorded with a much simpler task immediately thereafter shows evidences of the preceding workload. The hypothesis therefore attributes the post-task ERP changes to the specific demands of the task rather than the more general possibilities of potentiation or fatigue. In any case, the commonly observed divergence between the post-task P3 latency and the post-task reaction time (RT) must be reconciled. Our hypothesis assumes that a task in performed in a series of strategic stages, each comprising a chain of neurons confined to a memory station (Fig. 8). Cognitive recruitment switches the processing in each stage from a chain with fewer neurons to a chain with larger number of neurons and the P3 latency varies directly with the length of the first chain recruited. The behavioral output will be delayed by both an increase in the length of the chain and an increase in the number of stages, but apparently by the latter by far. The amplitude of the P3 response is assumed to vary with the volume of signal traffic in the recruited neuronal pathway.

It is difficult to explain why the latency changes in GFP should occur in both

directions. In group averages, the GFP latency does not show any change at all: both the pretask and post-task averages are incidentally 352 ms. It seems that there are two processes that work at cross-purposes in changing the post-task latency. At least three observations weigh against fatigue as a cause (or at least, the only cause) for prolongation of P3 latency. One is that the latency prolongation is not uniform at different electrode sites in an individual. In some subjects, the latency prolongs at some sites and shortens at other in a rather smooth progression. The second reason is that at Cz, the latency prolongation is significantly and inversely correlated with the task score, i.e., directly with the task ability. It is unlikely that smarter performers are more fatigue prone. Finally, fatigue provides no explanation for the inverse correlation of the pre-task GFP latencies with the task-scores (Table II).

Recruitment of longer cognitive neuronal pathways would prolong the P3 latency but quickens the behavioral output as the task is accomplished in fewer stages. Since it takes some time before this recruitment can be scaled down, its effect shows up on subsequent simpler task as prolonged P3 latency. This is in line with the commonplace observation of fumbling with simple tasks following intense concentration on a difficult task. If however the recruitment is feeble and can be quickly reverted in accordance with the immediate requirement of the simpler task that follows the challenge task (as might be occurring in lesser performers), one would expect that the P3 latency either does not change at all, or shortens somewhat due to the potentiation induced by the preceding task.

The above hypothesis can explain why the smarter task performers have longer P3 latencies ($P<0.05$). The correlation becomes more significant following the task ($P<0.01$). Cognitive recruitment offers an explanation for the contradictory results in IQ-P3 correlations obtained by various workers. Task difficulty is mostly subjective, and low IQ subjects might find even the ERP-task to be difficult and respond with cognitive recruitment. The P3 latency would then be higher for low-IQ subjects, as reported by some workers (3, 5–9). Conversely, if the ERP task is difficult to both, both would muster cognitive recruitment. With high-IQ subjects having greater depth of recruitment, their P3 latency would be greater, as reported less often by others (10–13).

While the task scores did not show inverse correlations with the increase in GFP latency, the P3 recorded at individual electrode sites does reflect this trend, notably at Cz. One reason for this discrepancy is that the P3 prolongation varies at the different scalp locations. In quite a few, there is an increase in P3 latency at one site and a decrease at the other. These differences in P3 latencies (Fig. 6a-d) provide by far the strongest evidence that the post-ERP changes are not due to a global phenomenon like fatigue but are due to a regional redistribution of neuronal activity. It seems that the brain searches around for available neuronal substrates for recruiting to the challenging mental task and different brains seem to be doing it differently.

A relevant observation is that the subjects having low (better) task scores showed greater deterioration in the task performance towards the end. If fatigue is causing the slowing of task performance, it

would require some explanation as to why the smarter subjects are more fatigue prone. However, the differences in the task scores were mostly not significant statistically when considered individually (Fig. 7). Second, a decrease in the task score could signify a change in the strategy adopted for solving the problem rather than a lower level neuronal behavior. Even so, that some of the faster performers have slowed down towards the end of 15 minutes suggests that fatigue might be occurring in the shorter pathways as a prelude to the recruitment of longer pathways.

Fig. 4 shows that at Cz, the amplitude of the P3 wave in different individuals showed changes in either direction. This is true for other electrodes too. The same is however not true for the amplitude of global field power that mostly shows an increase, and the group average of post-task amplitude (7.62 mV) is significantly higher (P<0.05) than the pretask GFP amplitude (5.67 mV). The amplitude changes at midline electrode sites correlate best with the increase (deterioration) in task scores towards the end of the challenge session, suggesting that fatigue may be the main cause of the amplitude increase. The correlations are significant (<0.01) when the uncorrected task scores are considered. Amplitude changes show poor correlations (ranging from 0.20 at Fz to 0.003 at Pz and −0.09 in the GFP) with increase in P3 latency suggesting that an increase in path length *per se* is not responsible for the amplitude changes. A simple explanation could be that the amplitude changes are associated with the volume of axonal signal traffic which varies with the balance between fatigue and potentiation. Alternatively, amplitude changes could be due to fatigue along. Fatigue closer to the

sensory pathways (perceptual fatigue) could be causing a reduction in axonal traffic while fatigue at a more central site (cognitive fatigue) could be causing higher signal traffic as a compensatory response to synaptic fatigue. Finally, a greater axonal traffic could be the cause rather than the effect of fatigue, with more fatigue occurring in those who drive their neurons harder.

Given that the GFP mostly has higher amplitude after the task, it seems that the challenge task does cause fatigue and that after the task, the processing bases shift from the fatigued to the fresher areas of the brain. Higher behavioral scores are achieved only with higher signal traffic that tends to cause fatigue, and consistently high scores are possible when there is enough neuronal substrate to fall back upon. Thus, P3 latency prolongation is caused both by fatigue of shorter pathways (with slower conduction) as well as recruitment of longer pathways (with prolonged conduction). This would explain the delay in rolling back the recruitment to shorter pathways after the mental load is taken off. This is also in consonance with evidences from depth recordings of ERP, which suggest that 'the brain seems to adopt the strategy of engaging all potentially useful areas, even though the probability may be very low that they will contribute to immediate task performance' (14). It seems that the brain briefly activates all the areas that would serve as a backup in the event of fatigue of areas that are more directly engaged in the task.

In conclusion, it seems that the amplitude and latency changes in our experimental protocol occur due to different reasons. The amplitude changes are probably due to fatigue and/or potentiation

of neurons while the latency changes seem to be due to recruitment of newer processing pathways. It is possible, indeed likely, that the recruitment of newer pathways has its origin in progressive synaptic fatigue. The increase in P3 amplitude probably indicates the degree of mental effort put in by the subject, while the latency prolongation indicates the achievement potential of the subject. Finally, a high pre-task P3 latency probably indicates an ongoing mental workload even before the commencement of the test protocol. Our hypothesis is not in conflict with findings that P3 latency is prolonged in several psychiatric and neurological disorders. Organic disorders are likely to bring about qualitative and quantitative changes in the neuronal circuitry that may not be comparable with the normal.

ACKNOWLEDGEMENTS

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