Journal of Advances in Medical and Pharmaceutical Sciences

10(4): 1-12, 2016; Article no.JAMPS.29783

ISSN: 2394-1111

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Education Level is Associated with Specific N200 and P300 Profiles Reflecting Higher Cognitive Functioning

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Authors' contributions

This work was carried out in collaboration among all authors. Authors FR and TB designed the study, wrote the protocol, guided the data collection and performed the statistical analysis. Authors RAH and TB performed the data acquisition and literature review. Author RAH wrote the first draft of the manuscript. Authors TB and FR reviewed the final manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAMPS/2016/29783

Editor(s):

(1) Xiao-Xin Yan, Department of Anatomy & Neurobiology, Central South University Xiangya School of Medicine (CSU-XYSM), Changsha, Hunan 410013, China.

Reviewers:

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Complete Peer review History: http://www.sciencedomain.org/review-history/16972

Original Research Article

Received 29th September 2016

Accepted 7th November 2016

Published 19th November 2016

ABSTRACT

Background: While different colors are commonly used during neuropsychological assessments, there is a general lack of information about the influence of education on color processing, which could affect the results of neuropsychological testing. Higher education is directly related to higher cognitive functions. Therefore, we investigated educational influences on color processing in different tasks using reaction times (RTs) in an event-related potential (ERP) study.

Methods: A 128-sensor net was used for the ERP study with participants from low (G1), medium (G2) and high (G3) educational groups (n=17 per group). Participants were asked by pressing button to indicate whether they 'liked' or 'disliked' colors displayed to them for consideration in the

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RT analysis. A 10-20 system (19 electrode channels) was used to analyze the amplitudes and latencies of the N200 and P300 ERP components.

Results: The mean differences for the like and dislike choices were calculated in terms of the amplitudes and latencies of the both components. RTs were significantly shortest in G3, then G2, and G1 reflected significantly longer RTs. Seven (out of 19) electrode locations clearly expressed N200 and P300 components. The G3 evoked the highest amplitudes (significant at T6) of both components at most of the electrode locations. The next highest amplitudes were in G2 and then G1. There was a trend toward the shortest latencies of both components being represented in G3, with G1 holding the longest latencies at most electrode sites, but this did not quite reach significance.

Conclusion: Faster RTs, higher amplitudes and shorter latencies of the N200 and P300 ERP components in G3 suggest that higher education improves attention, enables faster decision-making and facilitates cognitive function that is important for improved quality of life.

Keywords: Color; stimulus; N200; P300; education; cognitive function.

1. INTRODUCTION

To perceive color from our surroundings is an innate ability that becomes perfected with daily experiences. The human brain needs a complex visual network to achieve this color processing [1,2,3]. While it is true that color perception varies across different cultures [4,5], the use of colors is spreading in various fields. In medicine, different types of colors have been used to assess cognitive function for diagnostic purposes [6,7] that are important for patients' care plans. There are different types of neuropsychology tests related to colors. The Weigl Color-Form Sorting Test, Wisconsin Card Sorting Test, and Stroop Test are just a few examples of tests that are frequently used for neuropsychology assessments with different populations [8,9,10]. The Ishihara chart can detect impairment of color perception [11,12]. Color has also been used therapeutically in cancer patients [13,14]. However, patients come from different educational backgrounds, and the results of neuropsychology tests might vary depending on background educational levels. This could have implications for management strategies. It is therefore important to investigate the influence of education on color processing.

Education develops our skills, knowledge, problem-solving abilities, and other cognitive functions [15,16] by improving the brain's ability to adapt to new stimuli and challenges [17,18]. Higher education is associated with higher cognitive functioning [19], but this can decline in elderly populations [20]. Influence of education on theta [21] and delta [22] rhythms, as well as its influence on processing of different shapes and their arrangements [19,23], has been investigated previously. However, no study has investigated the influence of education on perception of different colors. Therefore, here we investigated the influence of education on color processing using reaction time (RT) analysis and ERP tools.

RT measures the time interval between stimulus presentation and the subject's response [24]. Researchers have studied three types of RTs. Simple RT can be measured with one stimulus and one response; recognition RT presents a stimulus, but requires no motor response; and choice RT has multiple stimuli with multiple responses [25,26]. Jain et al. [27] showed that RT was faster in males and those who exercised regularly, compared with females and those with a more sedentary lifestyle. It is possible that faster RTs are underpinned by a faster nervous system processing time, corresponding to a faster muscular movement [28], which could be interpreted as meaning that a person with faster RT has higher cognitive function [29]. For these reasons, we used RT as a marker of cognitive processing speed in the present study.

In addition to RT, we also measured ERP components to assess cognitive function. Electroencephalography (EEG) is non-invasive, painless, and relatively inexpensive compared with other neuroimaging techniques [30,31]. In contrast to the excellent anatomical resolution of brain imaging techniques (3–4 mm for fMRI) that allow the visualization of the brain networks involved in a certain task, electrophysiological tools such as EEG, give fine temporal resolution (in the order of milliseconds), allowing us to observe the various ERP components representing the cognitive stages used during performance of a task. Thus, decreased amplitude and/or delayed latency compared with normal values can be interpreted as representative of a cognitive deficit. Such findings should be interpreted by taking into account the cerebral area from which the ERP is recorded [32]. All areas of cognition, such as perception, attention, selective attention, attention switching, resistance to distractive interference and memory, executive function linked to problem-solving, planning, and decision-making, are associated with ERP profiles. Cognitive ERPs allow for the assessment of the different stages used in the information processing stream during performance of a task. Every cognitive function is associated with various cognitive stages. Each of these stages is implemented within separate neural processes to achieve normal function [33]. Indirectly, non-invasive ERP components can therefore convey information pertaining to the functional connections between brain areas, and represents a tool with which to investigate cortical activity [34].

The ERP signal can directly measure the neural activity related to a specific event [35,36]. The recorded signal is mainly influenced by the electrical field of the head scalp, which comes from the current of the extracellular regions [37,38]. In response to visual stimuli, six ERP components have been identified: C1, P1, N1, P2, N2 and P3 [39]. Higher amplitudes of the N1 (N170) reflected increased attention in a study of different shapes and their organizations [19], and in a separate study of other race faces [40]. The N200 ERP component is a negative-going waveform that is evoked at 200-350 ms post-stimulus, and reflects executive cognitive function [41]. The N200 has subcomponents of *N2a*, *N2b*, *N2pc* that mainly reflect activity in occipital-temporal regions. Higher N200 amplitudes are thought to reflect increased intention [42]. The P300 ERP component is a positive deflection, usually ranges from 250 ms to 900 ms, is typically evoked between 300-400 ms [43], and reflects activity at Cz and Pz areas [44]. The P300 has been identified as a marker for response inhibition [45], which involves the activation of the executive system of the frontal lobes [46]. The neural basis for this executive system is believed to be a distributed circuitry comprising prefrontal areas and anterior cingulate gyrus [47], the orbitofrontal cortex [48], the ventral frontal regions [49], and the parietal, dorsal, and ventral prefrontal regions [50]. Elevated amplitudes and shorter latencies of P300 components are related to higher attention [51] with increased consciousness [52]. P300 deficits have been reported in many disorders, but there is also an abundance of literature implicating other ERP components, such as mismatch negativity, sensory P50, and N400 (linked to language and semantic processes) [53,54]. Nevertheless, because both the N200 and the P300 ERP components are related to cognitive functions [23], we analyzed these two components to assess visual cognitive function. There is currently a lack of information regarding how education influences processing of different color stimuli in the human brain on an electrophysiological level. The main aim of this study was therefore to investigate the impact of education level on color processing (as an index of cognitive processing) using RT and ERP.

2. METHODS

2.1 Ethical Permission

Approval for this study was granted by the ethical committee of Universiti Sains Malaysia (USM) (USMKK/PPP/JEPeM (232.3(8)).

2.2 Study Population

The required sample size was calculated by a statistician using Power and Sample size (PS) software. Participants were recruited via e-mail advertisements, personal communications, and/or internet advertisements. Subjects were stratified according to their highest educational qualification, and accordingly grouped as low (G1, mean age±SD; 30.91±5.32 years, 8M and 9F), medium (G2, 29.89±8.54 years, 10M and 7F) or high (G3, 27.01±2.97 years, 8M and 9F) education. The educational groups were established according to the Malaysian educational system. The low educational group (mean education±SD; 8.93±2.63 years) had completed SPM (Sijil Pelajaran Malaysia), the medium educational group (12.79±0.80 years) had completed STP (Sijil Tinggi Pelajaran Malaysia) and the high educational group (15.88±1.36 years) had completed higher educational qualifications such as a diploma, Degree, Master's, or PhD.

2.3 ERP Net/Cap

A 128-electrode sensor net was used for data acquisition. This net was connected to a headbox or amplifier, and the net was elastic to stabilize the electrodes on the head. Each Ag/AgCl electrode was covered by small plastic pedestal with a sponge contained within. Prior to each participant using the net, we soaked it in an electrolytic mixture of KCl solution and baby shampoo. Spontaneous electrical activity can sometimes pass through the wet sponge of the net to the scalp, and we measured this activity in terms of ERP amplitudes and latencies on another computer located to another room.

2.4 RT and ERP Stimuli and Recording

RT and ERP recordings were performed in the MEG/ERP laboratory at Hospital Universiti Sains Malaysia (HUSM). The ERP recordings were made in a dimly lit, electrically shielded and sound-treated room. Subjects were comfortably seated 1 m in front of a 22" LCD computer. Different color stimuli were presented using E-prime software (v 2.0 software (Psychology Software Tools, Inc., Sharpsburg, Pennsylvania, USA). ERP recordings were made with a 128-channel sensor net. 20 different colors were used as stimuli (13 × 17 cm): they were presented randomly on a white background for 1.4 s, with a 1.0 s inter-stimulus interval (ISI). Fig. 1 depicts the experimental paradigm used. Subjects were instructed to push 'button 1' for like and 'button 2' for dislike. All data were recorded on Net-Station software 5.2 (Electrical Geodesics, Inc., Eugene, OR, USA). Amplitudes and latencies of the N200 and the P300 ERP components were analyzed. For our purposes, we considered the observed RTs to represent "decision time". The experimental task used here differs from standard paradigms, in that it does not require the subject to make a correct/incorrect response.

2.5 Data Analysis

The band pass filter used was 0.3–30 Hz, with a stimulus rate of 0.5 Hz. Electrode impedance was within 0–50 KΩ. Using Net-Station software, we collected the mean differences between 'liked' and 'disliked' stimuli for the amplitudes and the latencies of the N200 and the P300 ERP components. Values from 19 channels were analyzed (FP1, FP2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, T3, T4, T5, T6, O1, and O2 electrodes). Values falling within the -100–800 ms ranges were incorporated in the final analyses; the baseline was corrected to 100 ms before stimulus onset. Eye blinks, eye movements and movement artifacts were removed using the artifact detection tool in Net-Station software. Results were analyzed in Statistical Package for the Social Sciences 22 (SPSS22) software, using a one-way analysis of variance (ANOVA) analysis. The significance level was set as $p \leq 0.05$.

3. RESULTS

The grand average waveforms of the amplitudes and the latencies of the N200 and the P300 ERP components are shown in Fig. 2a (G1), Fig. 2b (G2) and Fig. 2c (G3). Mean differences for the

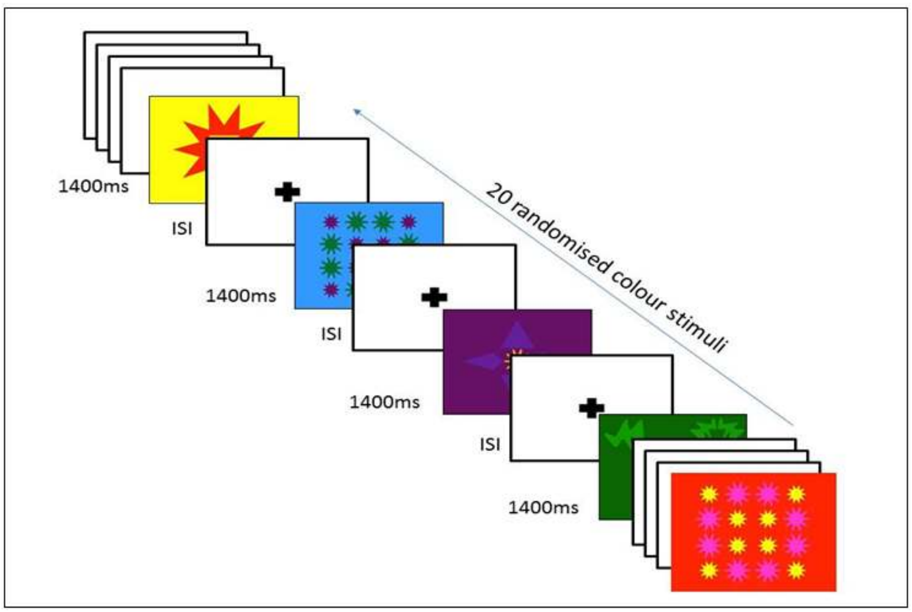

Fig. 1. The experimental paradigm incorporating 20 randomized different color stimuli, presented for 1400 ms with a 1000 ms inter-stimulus interval

'like' and 'dislike' color stimuli were collected for the amplitudes and the latencies of the N200 and the P300 ERP components (Tables 1 and 2).

3.1 Reaction Time (RT) Analysis

Our experimental paradigm did not allow for the assessment of correct vs incorrect responses; instead, participants chose whether they liked or disliked the different colors that they were presented with. Therefore, we were only able to analyze reaction times (RTs) and not task performance. RTs were compared across the three groups. A one-way ANOVA showed a main effect of group, $F(2, 48) = 8.449$, $p = 0.001$. Between-group contrasts revealed that RTs in the higher education (G3) (mean±SD, 763.8±239.53 ms) group were significantly lower than those in the medium (G2) ($p = 0.03$, 907±242.50 ms) and low (G1) ($p = 0.0002$, 1145.52±416.59 ms) education groups (Fig. 3). G2 showed reduced RTs compared with G1 ($p = 0.03$).

3.2 The N200 Component

N200 amplitudes were clearly seen at seven electrode sites: T4, T5, T6, P3, P4, O1 and O2. Higher amplitudes were evoked in G3 compared with the G2 and the G1 groups across all channels, but these were only significantly different at the T6 site, $F(2,48) = 4.497$, $p = 0.036$). Conversely, G2 had higher N200 amplitudes at 6 of the 7 sites (T4, T6, P3, P4, O1 and O2) compared with G1 (Table 1). In terms of the N200 latencies, G3 possessed the shortest latencies of the three groups at most of the locations (5 out of 7 locations: T4, T6, P4, O1 and O2). The next shortest latencies were in G2 (5 out of 7 locations: T4, T5, T6, P4 and O2; see Table 1).

3.3 The P300 Component

The P300 results were consistent with those observed for the N200 component. Again, G3 expressed the highest P300 amplitudes at most of the sites (6 out of 7 locations: T4, T5, T6, P4, O1 and O2) compared with the G2 and G1 groups (Table 2). G2 had the next highest amplitudes at most of the locations (5 out of 7: T4, T6, P4 and O2) compared with G1. A significant group effect was observed at T6, $F(2,48) = 3.186$, $p = 0.047$ (Table 2). There was no consistent relationship between group membership and latencies of the P300 component (Table 2).

4. DISCUSSION

In this study, we investigated the influence of education on color processing (indexed by RTs and ERPs) in low (G1), medium (G2) and high (G3) educational groups. G3 displayed significantly shorter (i.e. faster) RTs than the other groups, and G2 had faster RTs than

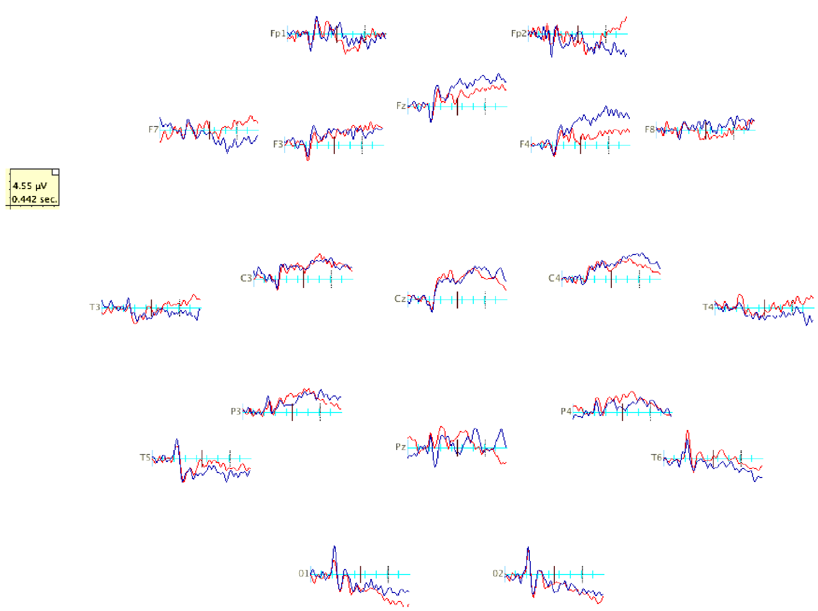

Fig. 2a. Grand average waveforms of the N200 and P300 ERP components at 19 electrode positions in the low education group (G1). Blue represents 'like' and red represents 'dislike' in relation to the colors displayed

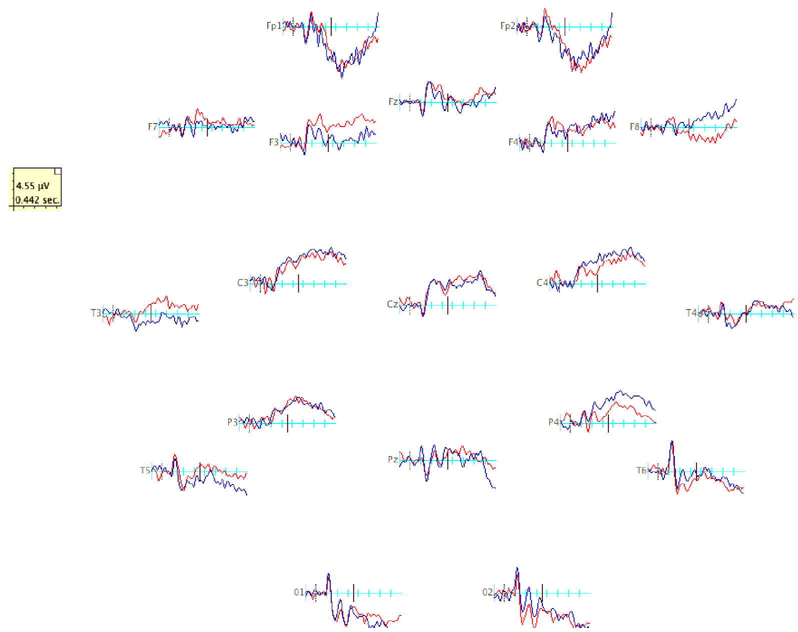

Fig. 2b. Grand average waveforms of the N200 and P300 ERP components at 19 electrode positions in the medium education group (G2). Blue represents 'like' and red represents 'dislike' in relation to the colors displayed

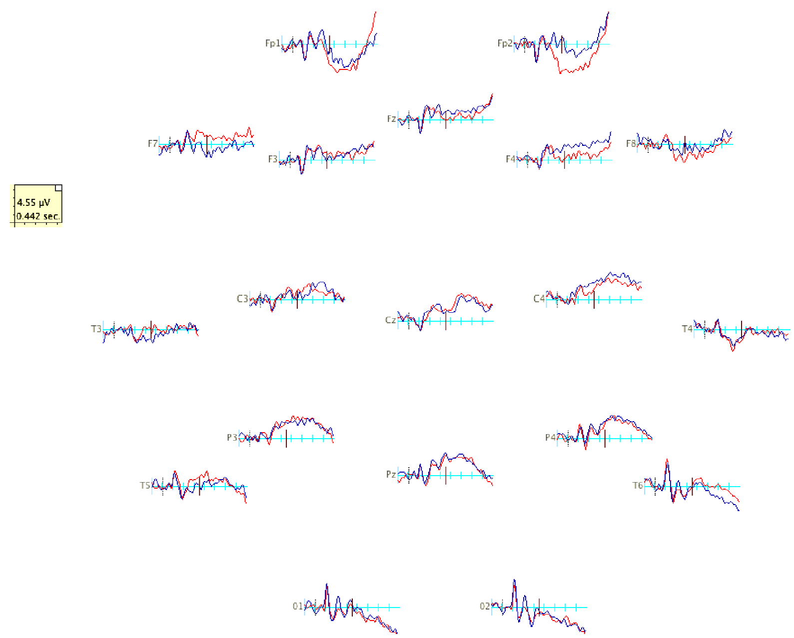

Fig. 2c. Grand average waveforms of the N200 and P300 ERP components at 19 electrode positions in the high education group (G3). Blue represents 'like' and red represents 'dislike' in relation to the colors displayed

G1.The highest amplitudes and shortest latencies of the N200 and P300 ERP components were evoked mostly in the G3 and G2 groups. The T6 area showed a significant group effect for amplitudes of both the N200 and the P300 components (Tables 1 and 2). Subjects in G1 (low education level) displayed the shortest amplitudes and the longest latencies for both components across most of the sites.

Participants in G3 had significantly faster RTs than those in G2 and G1. G2 participants had longer RTs than those in G3, and G1 had the longest RTs of all groups. There was a significant main effect of group on RT, as depicted in Fig. 3. Faster RTs are directly associated with faster decision-making [55]. As a corollary of this, we suggest that higher education is associated with faster decision-making.

Being an early ERP component, the N200 reveals basic information about 'bottom-up' sensory processing of stimuli. The P300, however, reflects 'top-down' perceptual and cognitive processing of stimuli [56]. Higher N200 amplitudes are associated with higher attention [57], and P300 amplitudes are directly proportional to successful perceptual and cognitive processing [58]. Kok et al. (2004) found that higher amplitudes of the P300 component reflect higher levels of cognitive function, including, but not limited to orientation of attention, response modulation, and response resolution [59]. Increased attention results in

Table 1. The amplitudes and the latencies of the N200 ERP component across low (G1), medium (G2) and high (G3) education groups. Values represent mean differences in terms of 'likes' and 'dislikes' for the colors presented

Sites	Low education/G1 (mean ± SD)	Medium education/G2 (mean ± SD)	High education/ G3 (mean ± SD)	F (df)	P	Significance
			N200 ERP component amplitudes (in μV) (mean±SD)			
Fz	4.74±3.39	2.83±3.66	3.91±3.99	1.371(2, 48)	0.26 1	NS
Cz	2.76±2.25	3.38±3.53	3.13±2.31	0.96(2, 48)	0.745	NS
Pz	4.40±3.98	3.50±3.49	2.38±6.54	1.022(2, 48)	0.365	NS
Fp1	6.20±5.74	4.67±4.77	5.67±6.18	0.390(2, 48)	0.679	NS
Fp2	4.80±5.16	4.13±4.68	6.22±6.27	0.969(2, 48)	0.384	NS
F3	4.41±3.56	2.00±3.88	2.98±4.24	1.989(2, 48)	0.144	NS
F4	5.74±3.35	3.65±3.80	4.14±3.45	2.124(2, 48)	0.127	NS
F7	5.11±4.10	2.77±3.97	1.95±3.50	**4.566(2, 48)**	**0.014**	**S**
F8	4.65±3.64	4.87±4.55	4.31±5.06	0.098(2, 48)	0.907	NS
C3	3.17±2.61	4.21±4.02	2.62±4.18	1.119(2, 48)	0.332	NS
C4	3.58±3.09	4.15±3.41	3.60±2.75	0.242(2, 48)	0.786	NS
T3	4.12±2.73	2.21±3.73	2.86±3.94	1.594(2, 48)	0.210	NS
T4	2.66±2.27	3.10±3.36	3.64±3.79	0.583(2, 48)	0.561	NS
T5	2.45±2.47	2.12±2.70	3.08±4.13	0.546(2, 48)	0.582	NS
T6	1.16±2.75	3.74±2.71	4.90±7.12	**3.497(2, 48)**	**0.036**	**S**
P3	2.85±3.27	3.07±2.97	2.95±3.56	0.024(2, 48)	0.976	NS
P4	2.43±2.96	3.86±3.41	3.86±4.07	1.218(2, 48)	0.302	NS
O1	3.74±2.42	3.24±3.72	4.52±3.56	0.983(2, 48)	0.379	NS
O2	2.50±3.27	4.00±3.13	4.54±3.45	2.528(2, 48)	0.087	NS
			N200 ERP component latencies (in ms) (mean±SD)			
Fz	285.64±63.28	275.40±60.00	291.38±76.69	0.333(2, 48)	0.718	NS
Cz	288.00±70.80	285.80±66.95	304.38±76.07	0.534(2, 48)	0.589	NS
Pz	320.00±66.77	305.40±74.44	293.50±72.66	0.898(2, 48)	0.412	NS
Fp1	268.91±46.81	272.40±55.21	278.63±68.67	0.185(2, 48)	0.831	NS
Fp2	296.55±63.21	267.00±54.32	284.75±79.31	0.979(2, 48)	0.381	NS
F3	288.73±67.18	307.40±58.07	306.25±67.49	0.592(2, 48)	0.556	NS
F4	279.45±58.35	269.40±70.06	274.50±69.12	0.120(2, 48)	0.887	NS
F7	290.91±65.46	309.40±65.25	312.50±65.15	0.769(2, 48)	0.467	NS
F8	316.36±70.52	262.60±73.44	279.88±74.84	3.026(2, 48)	0.055	NS
C3	301.45±68.55	301.20±67.46	311.50±64.03	0.214(2, 48)	0.808	NS
C4	288.55±55.88	275.40±61.15	287.50±66.77	0.298(2, 48)	0.743	NS
T3	294.18±52.31	328.00±62.24	326.50±52.83	2.734(2, 48)	0.072	NS
T4	308.36±74.43	273.60±70.00	296.50±72.60	1.244(2, 48)	0.295	NS
T5	303.45±58.88	297.00±73.51	311.38±60.65	0.323(2, 48)	0.725	NS
T6	317.45±65.02	315.80±74.19	293.50±60.64	1.129(2, 48)	0.329	NS
P3	289.64±59.03	312.80±72.39	304.38±66.70	0.671(2, 48)	0.514	NS
P4	299.64±60.54	287.20±73.69	293.38±62.62	0.191(2, 48)	0.827	NS
O1	310.73±54.82	316.60±64.45	291.50±63.10	1.226(2, 48)	0.300	NS
O2	327.45±66.32	319.80±68.54	309.75±68.46	0.457(2, 48)	0.635	NS

Note: ns: nonsignificant, s: significant, p≤05

Table 2. The amplitudes and the latencies of the P300 ERP component across low (G1), medium (G2) and high (G3) education groups. Values represent mean differences in terms of 'likes' and 'dislikes' for the colors presented

Sites	Low education/G1 (mean ± SD)	Medium education/G2 (mean ± SD)	High education/G3 (mean ± SD)	F (df)	P	Significance
			P300 ERP component amplitudes (in µV) (mean±SD)			
Fz	6.37±4.29	4.99±4.77	5.16±3.73	0.723(2, 48)	0.489	NS
Cz	5.36±4.20	4.20±4.06	4.22±2.76	0.781(2, 48)	0.462	NS
Pz	6.95±5.78	5.43±5.86	4.67±4.96	1.142(2, 48)	0.325	NS
Fp1	7.84±8.35	7.84±7.37	7.04±4.99	0.128(2, 48)	0.880	NS
Fp2	6.36±7.72	8.85±7.82	8.15±7.13	0.637(2, 48)	0.532	NS
F3	5.52±3.94	3.00±4.77	4.80±5.10	1.599(2, 48)	0.209	NS
F4	6.92±4.68	5.39±5.20	5.43±4.27	0.807(2, 48)	0.450	NS
F7	6.97±8.17	4.74±5.27	4.00±5.37	1.485(2, 48)	0.233	NS
F8	6.34±4.87	7.20±5.90	5.74±6.27	0.394(2, 48)	0.676	NS
C3	4.44±3.05	5.55±4.28	4.15±5.57	0.589(2, 48)	0.558	NS
C4	5.28±4.60	4.45±3.41	4.49±3.32	0.354(2, 48)	0.703	NS
T3	4.67±3.96	3.31±5.55	4.62±4.78	0.569(2, 48)	0.569	NS
T4	2.82±2.78	4.14±4.29	4.90±4.82	2.039(2, 48)	0.138	NS
T5	3.13±3.94	2.91±3.31	4.98±5.11	1.842(2, 48)	0.166	NS
T6	2.26±3.46	4.17±2.04	6.42±8.48	**3.186(2, 48)**	**0.047**	**S**
P3	4.85±3.66	3.74±3.44	4.29±3.66	0.496(2, 48)	0.611	NS
P4	4.43±4.18	5.17±3.61	4.69±4.53	0.170(2, 48)	0.844	NS
O1	5.72±4.31	4.13±3.77	6.08±3.73	1.609(2, 48)	0.207	NS
O2	4.05±3.70	4.86±4.12	5.84±4.00	1.384(2, 48)	0.257	NS
			P300 ERP component latencies (in ms) (mean±SD)			
Fz	534.18±165.73	608.40±178.06	515.13±154.24	2.064(2, 48)	0.134	NS
Cz	633.82±137.05	532.20±179.17	555.00±166.58	2.380(2, 48)	0.100	NS
Pz	602.00±153.78	518.60±161.03	596.00±159.94	1.863(2, 48)	0.163	NS
Fp1	461.64±132.74	591.80±158.99	490.88±154.71	**4.391(2, 48)**	**0.016**	**S**
Fp2	491.45±155.67	578.60±159.43	487.13±154.47	2.413(2, 48)	0.097	NS
F3	517.27±165.20	547.40±160.20	577.75±150.91	0.968(2, 48)	0.385	NS
F4	512.73±173.99	529.00±162.02	563.63±146.77	0.721(2, 48)	0.490	NS
F7	565.27±185.38	611.60±168.55	568.75±148.88	0.524(2, 48)	0.594	NS
F8	508.36±177.70	555.20±153.47	560.13±166.66	0.698(2, 48)	0.501	NS
C3	574.91±131.56	594.00±170.72	564.25±150.07	0.240(2, 48)	0.788	NS
C4	564.55±167.09	576.20±158.52	539.88±160.43	0.344(2, 48)	0.710	NS
T3	592.36±168.56	595.40±159.18	570.63±150.15	0.197(2, 48)	0.822	NS
T4	483.27±155.48	494.00±144.24	577.13±168.78	2.867(2, 48)	0.063	NS
T5	555.45±172.02	528.60±158.66	588.38±156.42	0.869(2, 48)	0.424	NS
T6	603.45±165.39	565.60±152.44	547.13±167.79	0.783(2, 48)	0.461	NS
P3	649.27±120.21	564.60±155.40	641.38±137.17	2.485(2, 48)	0.091	NS
P4	601.45±136.04	554.80±162.85	581.63±182.35	0.423(2, 48)	0.657	NS
O1	600.91±157.85	505.80±146.17	588.50±161.95	2.331(2, 48)	0.105	NS
O2	565.82±163.33	564.40±137.02	579.50±157.86	0.079(2, 48)	0.924	NS

Note: ns: nonsignificant, s: significant, p≤05

quicker decision-making [55] and makes use of higher cognitive functions [29]. Taken together, these findings suggest that education improves attention, cognitive processing and improves cognitive functioning in general, which is associated with faster decision-making. Higher amplitudes for both components were evoked in the high education group (G3). However, we note that shorter amplitudes were recorded at some locations in G3, and our results should be interpreted with caution. On the other hand the low education group took the opposite interpretation of the high education group.

The N200 latency has an expression on the basis of the discrimination and classification of the visual stimuli that means on the basis of the rapid registration of the visual input which has positive correlation with the latencies of the N200 [60]. Applied to the present study, this suggests that participants in the high education group were able to rapidly register the color stimuli they were presented with: G3 evoked the shortest latencies at most of the electrode positions compared with G2 and G1. Indeed, G1 had the longest latencies, suggesting much slower registration in this group.

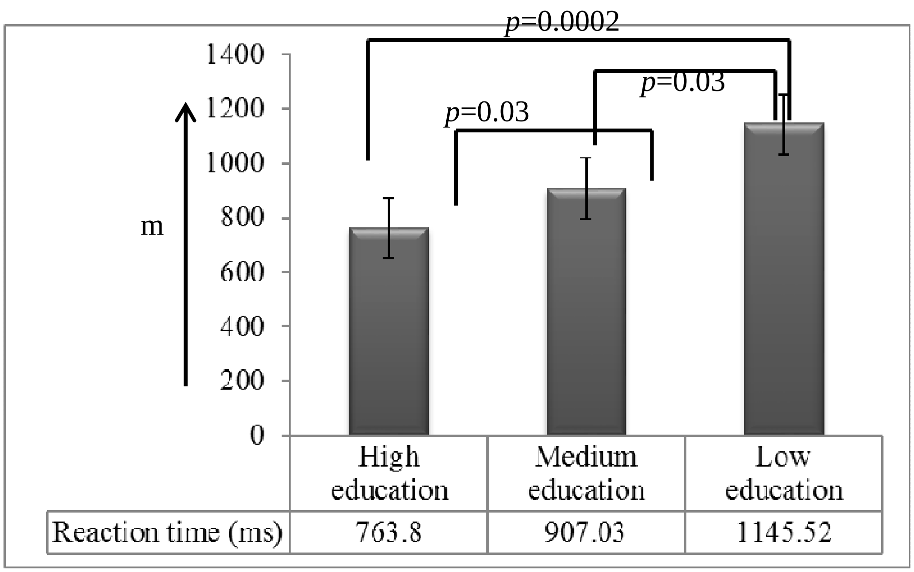

Fig. 3. Reaction times (ms) across high, medium and low educational groups

The P300 latency reflects the time taken to attend to and process a stimulus [61], relying on cognitive processes comprising attention, learning, and decision-making. The fact that there were (albeit non-significantly) longer latencies of the P300 component at most of the electrode locations in the lower education group could reflect longer processing times underpinned by attention, learning and decision-making processes in this group. The higher education might made the G3 and then G2 groups in more quicker timing process of cognitive functions with the evidence of the significant and non-significant shorter latencies of the P300 component (Table 2). However, higher and lower amplitudes, and longer and shorter latencies were expressed in a mixed manner across all three groups, making it difficult to find a parsimonious interpretation of the results.

5. CONCLUSION

We investigated the influence of education (indexed as low, medium or high) on color processing (indexed by RTs and ERPs). Results suggest that participants in the high education had higher attention and cognitive functioning, as well as improved learning and decision-making. Additionally, the high education group was able to process stimuli faster than those in the other groups, presumably because of their increased attention. To conclude, higher education is associated with increased attention, which itself is related to faster decision-making. This ultimately leads to higher cognitive functioning and improved quality of life.

6. LIMITATIONS

ERP studies are associated with certain limitations with poor spatial resolution and inter-individually there are big differences of amplitudes and latencies of the ERP components [32]. Though electrophysiological components analysis alone can give us information about heterogeneity among the groups, but together with endophenotype analysis could reduce the impact of heterogeneity [62,63]. Another limitation of our study was small sample size. Larger sample of participants might be more reliable to generalize the results to a larger population.

CONSENT

It is not applicable.

ACKNOWLEDGEMENTS

This work was supported by a short-term grant from Universiti Sains Malaysia (USM) (304/PPSP/61311092) awarded to TB. We thank Dr. Izmer Ahmed and Miss Siti Nor Quamariah Binti Ismail for their technical supports.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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