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Concurrent effects of attention and colors on the cerebral hemisphere processing speed of Arabic words

Efectos simultáneos de la atención y los colores en la velocidad de procesamiento en los hemisferios cerebrales de las palabras árabes

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Abstract
It has been debated whether attention or colors may modulate cerebral hemisphere processing speed of visual modalities. Electrophysiological studies have demonstrated that either attention or colors modulates the early stages of brain neural activity when these stimuli were processed. However, the concurrent effects of attention and color on the speed of Arabic word processing in both cerebral hemispheres have not been investigated. The current study investigated the combined effects of attention and colors in the right and left cerebral hemisphere. In two experiments, word stimuli were presented in different length, and colors on the right and left hemifields randomly. Participants were instructed to detect specific word color using index fingers. Results reported that the reaction times "RTs" were increased, when letter words decreased, and longer RTs in the right than left hemifield for white and green colored words. An opposite pattern was reported for red and blue colored words, in that RTs were longer in the left than right hemifield. These findings suggested that colors may modulate cerebral hemisphere processing speed of these visual modalities. Additionally, attention may change the way that the cerebral cortex is responding to visual-colored words with different length. In conclusion, these findings suggested that combined effects of attention and colors modulate the cerebral hemisphere processing speed.

Keywords: word processing, colors, cerebral hemisphere, attention, reaction times

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Resumen

Se ha debatido si la atención o los colores pueden modular la velocidad de procesamiento de las modalidades visuales en los hemisferios cerebrales. Estudios electrofisiológicos han demostrado que la atención o los colores modulan las primeras etapas de la actividad neuronal cerebral cuando se procesaron estos estímulos. Sin embargo, no se han investigado los efectos simultáneos de la atención y el color sobre la velocidad del procesamiento de textos árabes en ambos hemisferios cerebrales. Estudiamos los efectos combinados de la atención y los colores en el hemisferio cerebral derecho e izquierdo. En dos experimentos, los estímulos de palabras se presentaron en diferentes longitudes, y los colores en los hemicampos derecho e izquierdo al azar. Se instruyó a los participantes a detectar el color específico de la palabra usando dedos índice. Los resultados informaron que los tiempos de reacción „RTs" se incrementaron cuando las letras de las palabras disminuyeron, y fueron más largos en el hemicampo derecho que en el izquierdo para palabras de color blanco y verde. Se informó de un patrón opuesto para las palabras de color rojo y azul, en que los RTs eran más largos en el hemicampo izquierdo que derecho. Los hallazgos sugieren que los colores pueden modular la velocidad de procesamiento del hemisferio cerebral ante estas modalidades visuales. Además, la atención puede cambiar la forma en que la corteza cerebral está respondiendo a palabras en colores con diferente longitud. En conclusión, estos hallazgos sugirieron que los efectos combinados de la atención y los colores, modulan la velocidad de procesamiento en los hemisferios cerebrales.

Palabras clave: procesamiento de textos, colores, hemisferio cerebral, atención, tiempo de reacción.

INTRODUCTION

One of the prominent features in the brain is the cerebral hemisphere specialization, referring to the way that the cerebral hemisphere is responding to different cognitive functions such as, language, attention, and emotion (Behrmann & Plaut, 2020; Burt & Hausmann, 2019; Inamizu *et al.,* 2019). Several lines of evidence suggested that words recognition show a stronger selectivity to the left than the right hemisphere (Inamizu *et al.,* 2019; Taylor *et al.,* 2017; Peleg & Eviatar, 2015; McClelland & Johnston, 1977)), demonstrating that the left hemisphere has a major role in language, which is well acknowledged in the right-handed participants (Taylor *et al.,* 2017, Peleg & Eviatar, 2015, Cousin, Perrone & Baciu, 2009).

Neuroimaging studies identified specific regions respond to visual words than other visual modalities such as posterior fusiform gyrus, and anterior fusiform gyrus (Yang *et al.,* 2011; Che *et al.,* 2000; Noble, Truest & McCarthy, 1994; Nobre, Truett & McCarthy,

1994). Additionally, it has been suggested that cerebral hemispheres have an important role in the processing of different visual modalities, in particular words, evidence has come from investigations using functional magnetic resonance imaging "FMRI" and stated cortical regions with selective response to written words such as, the visual word form area (Coch, 2021; Moret-Tatay *et al.,* 2021; Zaho *et al.,* 2021; Price & Mechelli, 2005; Cohen & Dehaene, 2004; Noble, Truest & McCarthy, 1994), which is located on the left hemisphere (Behrmann & Plaut, 2020).

Taha, Ibrahim & Khateb (2013) showed that words are composed of 2D structures with each letter, that sometimes are connected mandatory to each other such as in Arabic words, and they change in form due to the place of letters (i.e., the beginning, middle and the end). This unique form of Arabic words suggested that words are processed uniquely than other words in different languages. This phenomenon has raised a question whether Arabic words such as other visual modalities processed holistically as one unit or part based depending on the word composed letters.

It has been controversial in the literature whether Arabic words are processed holistically (i.e., one unit) or part based (i.e., letters) like some other visual modalities (e.g., faces vs. objects). In one hand, Behrmann & Plaut (2020) demonstrated that that words processed in a part based, in that words are recognized by letters not as a whole unit.

However, recent studies have provided new evidence that skilled reader are processed written visual words holistically, like human faces (Coch, 2021; Wong *et al*., 2019; Carlos et al., 2019; Martin et al., 2012), and suggested that words are processed in a combination of two mechanisms (i.e., part-based, and holistic mechanisms). It seems that both holistic and part-based mechanisms are required to process words in general, which associated with different cortical regions in the human brain, are specialized for word recognition.

Earlier studies consider that words are a specific category which is processed differently from other visual modalities and activate specific regions in the left cerebral hemisphere (Amenta *et al.,* 2021; Cohen & Dehaene, 2004; Noble, Truest & McCarthy, 1994). Additionally, recent studies have suggested that selective attention may modulate word processing speed in both cerebral hemispheres, when attention was manipulated by increasing the word length (Mohamed, 2018a,b; Ellis; Young & Anderson, 1988), in that longer reaction times were observed when words letters were increased (Mohamed, 2018a), suggesting that selective attention influences the word lexical decision in the left hemisphere. These findings suggested that words are processed by two different mechanisms; first which is seen at left hemisphere, and operates independently of word length, while the second is observed in the right hemisphere, that depends on word length.

Several studies have been reported that selective attention to speech in complex auditory input could show top-down modulation of cortical regions linked to the perception of

spoken, and written words, and selective attention increases the activity in the fusiform area of visual words (Moret-Tatay *et al.,* 2021; Yoncheva *et al.,* 2009).

However, selective attention is not the sole factor that affected the word recognition, colors of the words are consider as another factor which facilitate the word recognition. Recent research uncovered the effect of colors on human brain activity, in that both left and right inferior gyrus responsible for stored colors information (Chao & Martin, 1999; Kellenbach, Brett & Patterson, 2001, Siok *et al.,* 2009, *Schalk et al.,* 2017). Colored words recruit specific brain regions related to the visuospatial processing, suggesting that color information facilitate object recognition (Bramão *et al.,* 2010). The same observation was reported in the study of Siok *et al.* (2009), in that colors provoked faster response in the left hemisphere, and activated the visual areas 2/3, much stronger to the right visual field It has been observed that human brain modulates the activation of the visual cortex by top-down mechanism when stimuli from different linguistic groups are processed, in compared to Stimuli from the same linguistic groups (Mo *et al.*, 2011). In addition to, colored words interfere both cerebral hemispheres, and occur in the left lateral prefrontal cortex, the left anterior cingulate, and the left parietal-occipital cortex (Adleman *et al.,* 2002; Dyer, 1973).

Overall, it seems that both attention and colors influence the cerebral hemisphere processing speed of visual and auditory modalities. Therefore, the current study aimed at reassessing the concurrent effects of attention and colors on word processing speed in both cerebral hemispheres, by recording the reaction times when visual stimuli presented in the right and left visual hemifields (RVF and LVF) and presented ipsilateral versus contralateral.

In two experiments, attention was manipulated to Arabic words by presenting words in different lengths (i.e., two-letters words, four-letters words, six-letters word, and eight-letter words), and colors (i.e., White, red, blue, and green). All visual stimuli were presented in right or left visual hemifields randomly, and participants were instructed to detect colored words (e.g., Red and Blue). It is worth noting that attention was direct to the color information, while attention was indirect to the word length (i.e., selective attention condition).

In both Experiment 1 and 2, Considering the findings of word processing under selective attention conditions (Mohamed 2018a,b), I expected that the reaction times would be decreased with the increment of the words letters, irrespective of word colors (white vs. red) or (blue vs. green), and the colors of words would not have the ability to eliminate the effect of selective attention (word length). Additionally, the current study postulated that colors information might facilitate the word processing speed in both cerebral hemispheres, and ease word recognition, and the RTs for ipsilateral visual stimuli would be less than contralateral presentation of visual written words.

MATERIALS AND METHODS

Participants

102 students (51 females) aged between 19 and 24 years old (M= 22.3, SD= 1.07) contributed data to this study. Male and female Students from Sohag University, Egypt. All participants were right-handed, and they have normal or corrected-to-normal visual acuity, and completed a written informed consent. The study was conducted according to the declaration of Helsinki, and fellow the ethical guidelines regulations that approved by the scientific research committee at Sohag university.

Apparatus and materials

The experiment was run on a Dell Computer with the 19-inch color monitor set at 1024 X 768 pixels, and 64-bit color quality, using E-Prime Professional 2.0 Software (Psychology Software Tools, Pittsburgh, PA, Schneider, Eschman & Zuccolotto, 2012). Words Stimuli Presented in the right or left of the screen randomly on a black background, including colored words (white colored words vs. red colored words), and (4) word length categories (i.e., 2 letters words, 4 letters words, 6 letters words, and 8 letters words). To adjust contrast and luminance of different categories a Photoshop Professional 11.0 was used, and the visual angle was calculated and adjusted for all categories with 4.3º from a viewing distance of 90 cm, which kept constant by using a chin rest. Responses were made on a two-button response on the numerical part of the standard English keyboard, by using "6" button for the right hand to detect white colored words, and "4" button for the left hand to detect red color words.

Stimuli

A set of 80 Arabic words consists of (Two-letters words, four-letter words, Six-letter words, and 2 eight-letter words) were used, and obtained from database used in an earlier study of (Mohamed, 2018b). All stimuli were used in a block design, and counterbalanced randomly, and they placed in front of a black background. Word's stimuli in different categories were rated for frequency by the participants (102), using Likert scale (from 1 for non-frequent to 5 highly frequent), and the average frequency for each item in each group was then computed and values were statistically compared using ANOVA with all groups, showing that there is no significant difference of word frequency $F(3, 66) = 0.93$, $p = 0.19$.

Experiments

The present study, includes two experiments, to investigate the combined effects of attention (4 categories), and colors (4 categories) on the word processing speed in both

cerebral hemispheres. In the first experiment examined whether selective attention (i.e., word length manipulation), and word color (i.e., white vs. red) will influence the word processing speed in both cerebral hemispheres. Stimuli were presented in the right and left visual field randomly, and includes (3) different variables (i.e., Word length, Colors & Visual field). In experiment 2 words were presented in blue or green colors.

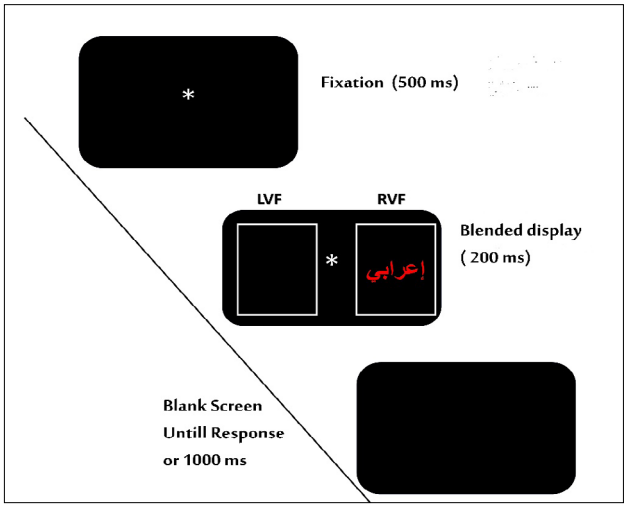
Procedures

Participants were seated in a light- and sound-attenuated room. Viewing distance was 90 cm from the computer screen. During each experimental trial, an initial White fixation on black background was replaced after 500 ms by blended display for 200 ms of word stimuli on the right and left hemifield randomly. A subsequent blank screen (1000 ms) allowed for responses until 1200 ms after stimulus onset (figure1). Participants were instructed to detect words colors (white vs. red, in Experiment 1) Or (blue vs. green in Experiment 2), using both index fingers, in that right index finger for White or Blue colored words and left index finger for red or green-colored words. Speed and accuracy were emphasized.

A 2 × 4 × 2 design included the factors word length (4 categories), colors (red vs. white), and Visual field (right vs. left). In total, 640 trials (40 trails per condition) were presented in randomized order, with breaks after every 160 trials. The total duration of each experiment is around 18 minutes.

Figure 1.

Examples of the stimuli. Participants had to perform two-alternate choice responses depends on the words color presented in the right or left visual hemi-field randomly.



Data Analysis

Repeated measure analysis of variance (ANOVA) was calculated for analyzing effects of selective attention "Word length" (four categories), Colors (White vs. Red), and Visual Field (RVF vs. LVF).

RESULTS

Reaction times (RTs) results of experiment 1

Incorrect responses (1.3%) and responses were slower or faster by 2SD of each subject mean (2.1%) were removed from the RTs analysis, using Tuckey's outlier corrections.

Repeated measure ANOVAs showed main effects of the Visual field, F (1, 101) = 4.87, $p < 0.05$, with longer RTs for LVF than RVF (M_{diff}= 4.44ms), and interactions of Colors by Word length F (3, 303) = 6.99, $p < 0.01$, and Colors by visual field, F (1, 101) = 99.64, $p < 0.001$ (Table 1).

A further analysis was conducted to solve-up these two-ways interactions, by collapsing over word categories or colors or visual fields.

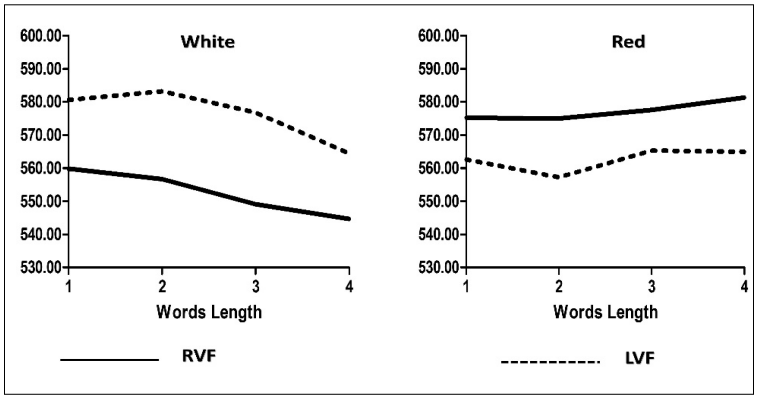
For the interaction of Colors by Word length, data was collapsed over the visual field and one-way ANOVA was conducted for each color (i.e., white vs. red). For white colored words there is a main effect of word length F (3, 303) = 7.32, $p < 0.01$, with faster RTs to eight-letters words than six-letter words, four-letters words, and Two-letters words (M= *1109.11, 1125.89, 1139.84, 1140.35*ms) respectively, while this effect was absent for red-colored words F (3, 303) = 1.55, p = 0.21 (Figure 2). An additional analysis was conducted to examine the effect of color (Fig.2) by collapsing the data over the word category and paired wise t-test was conducted and the result showed t (101) = 3.87, $p < 0.01$ longer RTs for red color words than white colored words (M_{diff}= 37.9ms).

For Color by visual field interaction, data was collapsed over the word-length and pairwise t-test was conducted and showed that RVF stimuli showed a main effect of colors t (101) = 6.09, p < 0.01, with longer RTs to red colored words than white colored words (M_{diff}= 98.76 ms). LVF stimuli showed a main effect of colors t (101) = 3.79, p < 0.0, with longer RTs for white colored words vs. red colored words (M_{diff} = 54.92 ms).

Table 1.
RTs results of experiment 1 for each conditions.

Colors		White				Red			
Length		2-letters	4-letters	6-letters	8-letters	2-letters	4-letters	6-letters	8-letters
RVF	Mean	559.82	556.69	549.10	544.69	575.20	575.01	577.55	581.30
	Std.Error	13.54	14.31	13.65	13.32	11.74	12.24	12.48	13.18
LVF	Mean	580.53	583.15	576.78	564.42	562.59	557.19	565.29	564.89
	Std.Error	13.19	14.01	12.99	12.42	11.99	12.12	12.47	12.71

Figure 2
RTs results of the right and left Visual hemifields for different words length which presented in white and red colors.



Overall, results of the first experiment reported faster RTs when the stimuli were presented in the RVF than the LVF (M_{diff}= 4.44ms), longer RTs for two- and four-letter words when they presented in white colored, longer RTs for red color words than white colored words (M_{diff}= 37.9 ms). Interestingly RVF stimuli showed longer RTs to red colored words than white colored words (M_{diff}= 98.76 ms) was reported while LVF stimuli showed longer RTs for white colored words than red colored words (M_{diff} = 54.92 ms). These findings suggested that colored words influence the word processing speed in cerebral hemispheres.

Results of experiment 2

Incorrect responses (1.1%), and responses that were slower or faster by 2SD of each subject mean (1.8%) from the RTs analysis were removed, using Tuckey's outlier corrections (Table 2). Repeated measure ANOVAs showed main effects of Colors F (1, 101) = 26.46, p

< 0.001, with longer RTs to blue colored words than green colored words (M_{diff}= 12.81ms), and Word length F (1, 101) = 3.44, $p < 0.05$, with faster RTs for eight-letters words than other categories (*M= 503.74, 507.63, 509.70, 509.33ms*) respectively (Figure 3), and a two-way interaction of Color by visual fields, F (1, 101) = 33.97, $p < 0.001$.

A further analysis was conducted to solve-up this two-way interaction by collapsing the data over the length (Table 2), and results reported a main effect of visual field t (101) = 3.19, $p < 0.01$, with faster RTs to LVF than RVF (M_{diff} = 33.24ms) for blue colored words. For green colored words there is a main effect of visual field t (101) = 5.51, p < 0.01, with faster RTs to RVF than LVF (M_{diff} = 53.98ms).

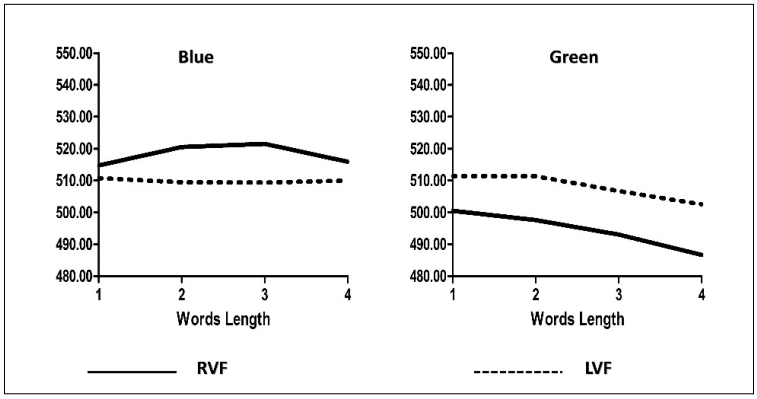
Table 2

The mean RTs results of experiment 2 for each conditions

Colors		Blue				Green			
Length		2-letters	4- letters	6- letters	8-letters	2-letters	4- letters	6- letters	8-letters
RVF	Mean	514.72	520.53	521.49	515.89	500.49	497.59	493.03	486.70
	Std.Error	9.36	10.33	10.68	10.82	11.17	13.02	11.39	11.38
LVF	Mean	510.72	509.41	509.34	509.93	511.39	511.27	506.68	502.46
	Std.Error	11.45	10.63	10.93	11.61	10.42	11.06	10.66	10.77

Figure 3

RTs results of the right and left Visual hemifields for different words length which presented in Blue and green colors.



Overall, the results of the second experiment reported longer RTs to blue colored words than green colored words (M_{diff}= 12.81ms), faster RTs to eight letter words than other categories, longer RTs for blue colored words in RVF than LVF (M_{diff} = 33.24ms), and the

opposite pattern was reported for green colored words, with faster RTs to RVF than LVF (M_{diff} = 53.98ms). These findings suggested that colors specialized areas were distributed between right and left hemisphere.

DISCUSSION

The current study investigated concurrent effects of attention and colors on cerebral hemispheres processing speed of Arabic words by measuring the reaction time when visual written words with different lengths, and colors were presented in the right or the left visual hemifield randomly.

In the first experiment, words with different length and colors (i.e., Red vs. white) were presented in the RVF and The LVF randomly, and results reported faster RTs for RVF stimuli than LVF stimuli, and longer RTs for red colored words than white colored words. These findings suggested that words are processed in the left hemisphere which reflects faster RTs for RVF than LVF stimuli, In particular, when these stimuli appeared in the RVF, it was processed automatically in the left hemisphere, while the LVF stimuli were processed in the right hemisphere, which required to be transferred via corpus callosum to the left hemisphere to be processed in word specialized areas, leading to increase the RT. Consistent with neuroimaging and electrophysiological studies, in that words process in the left hemisphere, due to the existence of the word processing area located in the left cerebral hemisphere (Taylor, Evans, Greer, Senior, Coventry & Ietswaart, 2017, Peleg & Eviatar, 2015; Yang, Wang, Shu, & Zevin, 2011; Cousin, Perrone & Baciu, 2009; Che et al., 2000).

Interestingly, results of the first experiment showed longer RTs to red colored words than white colored words (M_{diff}= 98.76 ms), when the written words presented in the RVF. In contrast, when written words presented in the LVF, longer RTs was recorded for white colored words than red colored words (M_{diff} = 54.92 ms). These findings suggested that red and white colors activated right and left hemisphere respectively, when red colored words presented the red color activated right hemisphere and the corpus callosum transfer these stimuli to word visual areas in the left hemisphere, this might explain why the RT is longer for red-colored words than white-colored words when these stimuli presented in the RVF, and the opposite might be occurred when stimuli presented in LVF.

In contrast, earlier findings reported that colors provoked stronger and faster response in the left hemisphere, and activated the visual areas 2/3, much stronger to the right visual field stimuli from different linguistic group than from the same linguistic group (Siok et al., 2009), and color activates areas located in the left lateral prefrontal cortex, the left anterior cingulate, and the left parietal and parietal-occipital cortex (Adleman et al. 2002). Therefore, the current results suggested that color and words interfere each other and modulate cerebral hemisphere processing speed for colored words (Dyer, 1973). Another

possible interpretation for this color effect of word processing could be due to competitive responses of reading the colored words, which interferes with color naming led to increase the RT for colored words and suggesting that word recognition is faster when the words interfere with colors (e.g., Jensen & Rohwer, 1966).

Interestingly, experiment 1 reported faster RTs to eight-letter white colored words than other word categories (i.e., six-letter, four-letter and two-letter white colored words), suggesting an opposite pattern that has been reported in previous studies, that used a similar attentional manipulation (i.e., Mohamed, 2018a), in that RTs were increased with the increment of word length. One possible interpretation, that colors modulate cerebral processing speed for white colored words, and the competition between word length and colors reverse the effect of selective attention. Another possible interpretation in that Arabic words are processed holistically, when they presented in a color identification task, the eight letter-colored words are processed more efficiently than other word categories. However, these interpretations need to be clarified using neuroimaging techniques, to investigate the effect of color and word length on the processing speed of cerebral hemisphere.

Surprisingly, this effect of word length was completely absent for red-colored words, suggesting that red colored words eliminated selective attention influence. In other words, it seems that red color has a unique influence on Arabic words, when words presented in red color, the competition of red color and word inhibited the effect of selective attention. These findings reconcile with previous study of (Furey, Honey & Konig, 2008) showed that the influence of color on overt attention depends on the type of image, this might explain the variation of the effect of colors in word processing, in particular the effect of selective attention was reserved for white colored words and vanished for red colored words.

It is worth noting that the same finding was replicated in the second experiment, in that RTs were faster to eight letter words than other categories regardless of colors (i.e., blue vs. green), suggesting that white, green, and blue colors interfere word processing speed in cerebral cortex and modulate the influence of selective attention. These findings supported the previous interpretation of white colored words, by suggesting that the competition between specific colors (i.e., white, blue, green) and words lead to reverse the selective attention effect in cerebral hemispheres, and increase the RT with the increment of word length, suggesting that words are processed holistically (Ventura *et al.,* 2019; Wong *et al.,* 2019; Carlos *et al.*, 2019; Martin *et al.*, 2012; Maurer, Rossion & McCandliss, 2008), and colors modulate visual processing in the cerebral hemisphere (*Sun et al.,* 2020).

Moreover, results of the second experiment reported longer RTs for blue colored words in the RVF than the LVF, and the opposite pattern for green colored words. These findings suggested that blue colored words processed mainly in right hemisphere, while green colored words processed in the left hemisphere, suggesting that colors activated both cerebral hemispheres. Consistent with the previous experiment which showed that red color

activated the right hemisphere, while the white colored words activated the left hemisphere. It seems that both blue and red colors activated the right hemisphere, while green and white colors activated the left hemisphere, these findings in line with neuroimaging studies (Franklin et al., 2008) that proved that colored words activated both cerebral hemispheres, depending on the color and age. One possible explanation that red and blue colors sources located in the right hemisphere, while the source of green and white color in the left hemisphere.

CONCLUSION

The current study demonstrated that color modulates selective attention effect in cerebral hemisphere, in that RTs increased with decreased of word length. However, this effect was existing, when words presented in white, green, and blue colors, while this effect is completely absent when words presented in the red color. Interestingly, this effect that the current study reported is an opposite effect of selective attention that has been reported in may studies, in that RTs times increased with the increasing of words length. These findings concluded that colors modulate selective attention effect in cerebral hemispheres. In addition, the current study showed a main effect of colors in the RVF and LVF (i.e., faster RTs to blue and green colored words in LVF than white and Green colored words in the RVF). These findings demonstrated that colors activated both cerebral hemispheres.

Ethical aspects: The study was conducted according to the declaration of Helsinki, and fellow the ethical guidelines regulations that approved by the scientific research committee at Sohag university.

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