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Human cognition involves many mental processes that are highly interrelated, such as perception, attention, memory, and thinking. An important and core cognitive process is memory, which is commonly associated with the storing and remembering of environmental information. An interesting issue in memory research is on ways to enhance memory performance, and thus, remembering of information. Can colour result in improved memory abilities? The present paper highlights the relationship between colours, attention, and memory performance. The significance of colour in different settings is presented first, followed by a description on the nature of human memory. The role of attention and emotional arousal on memory performance is discussed next. The review of several studies on colours and memory are meant to explain some empirical works done in the area and related issues that arise from such studies.

Keywords: *attention, colour, long term, mental recall, short term***Introduction**

Memory refers to the mental process of encoding, retaining, and retrieving environmental information (1). How the human cognitive system deals with the memorization process remains the centre of research among cognitive psychologists. One of the most interesting and challenging questions in contemporary memory research is on ways to enhance human memory performance. Many variables have been proposed to contribute to the retrieval operations and one of the variables is colour, which will be discussed thoroughly in the present paper.

Colour is believed to be the most important visual experience to human beings (2). It functions as a powerful information channel to the human cognitive system and has been found to play a significant role in enhancing memory performance (3). Colour can be very effective in learning and educational setting, marketing, communication, or even sport. For instance, a marketing study has found that colour can increase brand recognition by up to 80% (4). Most advertisements use colour as one of the important element in influencing people's attention, attitude towards the product, and pressuring decision making (5). According to White (6), coloured advertisements can attract people to read the advertisement up to 42% more often than the non-coloured advertisement. This shows the importance of colour in making the information or message more attractive to

the public.

In the educational setting, higher demand is put on excellent academic achievement. The extent to which students utilize their cognitive abilities is also important and may contribute to better academic achievement (7). The cognitive abilities of the students refer to the way the students perceive, pay attention, remember, think, and understand the lessons. There need to be strategies to facilitate the learning process and colours can play a role in motivating students to learn and profit from their educational experiences.

In addition, in the clinical setting, specific interventions involving colours can be introduced to deal with memory-related problems such as learning difficulty, autism, dyslexia, and others. With the use of colour in the intervention, it can help patients to follow and understand the learning program better. Clinical intervention for patients with dyslexia using colour have been proven to be effective in reducing patient difficulties in reading (8). The same approach is also used to help autistic patients. An improvement of reading speed up to 35% was reported for autistic patients reading using a coloured overlay compared to autistic patients reading without using a coloured overlay (9). Colour is also used to treat patients with Alzheimer Disease. Alzheimer Disease is a neurodegenerative form of dementia which deteriorates memory abilities

(10). Recently, there is a growing interest in the role of the non-biological or environmental factors associated with Alzheimer Disease (11). Thus, the use of colours to improve the memory performance of Alzheimer Disease patients can be practised. In fact, research has shown that vivid colour cues can help to enhance the short-term memory performance of Alzheimer Disease patients (12).

A plethora of studies have been conducted to understand the role of colour in enhancing memory performance. Back in 1976, Farley and Grant conducted experiments on the influence of colour on attention and found that coloured multimedia presentations resulted in better attention and memory performance (13). More experimental works exploring the influence of colour on the human cognitive processes were conducted since then (14–16).

Models of Human Memory

Human memory is commonly dichotomised to involve a short-term and longer-term memory storage. This dualistic nature of memory was proposed by the early investigators of memory, such as William James, and Waugh and Norman (17). The model proposed by Waugh and Norman, retained the concept of a primary and a secondary memory originally proposed by William James. Their model was regarded as the first behavioural model of memory due to its quantifying properties of primary memory (17). The earlier work on memory was well extended to lead to one of the influential models of the human memory system proposed Atkinson and Shiffrin (18). In their model, memory is made up of three structures; sensory register store, short-term store, and long-term store. Environmental stimuli will first reach the sensory register store. This memory store can register a huge amount of information, but the information is retained there very briefly. Information that is subject to a certain amount of attention is then moved to the short-term store. Information will be transferred to the long-term store for more permanent storage as a result of various types of control processes. It is said that the use of control processes such as maintenance and elaborative rehearsal, heuristic, or other memorization strategies are important to allow the information to be transferred from the short-term store to long-term store.

An alternative to the model of memory proposed by Atkinson and Shiffrin is the model proposed by Craik and Lockhart (19). They argued that the processes involved in memory were more

important than the structures of the memory system. The memory processes are assumed to be on a continuum, from shallow sensory process to a deeper semantic memory process. The shallow memory processes involve a basic and surface analysis of the information, such as the physical and sensory characteristic of the information. Intermediate memory processing requires some degree of recognition and labelling and a deeper processing involves a higher degree of analysis like processing the meaning of the information and its link to the existing memory trace. It is assumed that deeper level of analyses contributes to a more lasting and longer memory ability. In other words, information will be stored in the long-term memory store as a result of the amount of analysis and processing done on the environmental input.

Therefore, it is important for the stimuli available in the environment to have the potential to activate the attention and to be involved in control processes or deeper level of processing in order for the stimuli to be better remembered. Previous studies have shown evidences that colour is one of the variables that has those potential. Colours can influence the level of attention and also give rise to emotional arousal which contributes to control processes that will later enhance memory performance (13,14,21–23).

Attention and memory

Attention refers to the cognitive process of selecting information that is available in the environment. When we pay attention to certain information, we are actually selecting and focusing certain amount of information to be processed in our cognitive system. The degree of attention attached to certain stimuli increase the probability of the information to be stored in memory (14,15,23,24). In other words, the information that we pay more attention to is more likely to be remembered than the information that we ignore and do not pay attention to. Numerous studies have reported that attention can increase memory performance level in terms of the recall rates (14,15) and also faster reaction time (23).

Attention, memory, and colour

Colour helps us in memorizing certain information by increasing our attentional level. The role played by colour in enhancing our attention level is undisputable (14,23). The more attention focused on certain stimuli, the more chances of the stimuli to be transferred to a more permanent memory storage (18). As stated earlier,

colours have the potential to attract attention. Farley and Grant (13), were among the earliest who came out with a theory suggesting that colours have a greater effect on attention. This conclusion was based on their study on attention and cognition. They compared colour and non-colour multimedia presentations on memory performance. It was reported that the coloured multimedia presentation resulted in better attention than the non-coloured presentation. Greene, Bell, and Boyer (21), further explained that warm types of colours such as yellow, red and orange have been found to have a greater effect on attention compared to the cool type of colours like brown and gray.

Pan (23) found similar findings in his study on working memory and visual attention. In his study, participants were asked to identify whether the colour or the shape of the two objects that were presented were the same. In the first experiment, the colours of the two objects were the same but the shapes were different, while in the second experiment the conditions were reversed. The result showed that the participants' response times were faster in identifying the differences in colours compared to differences in the shapes of the objects in both experimental conditions (23). This finding can be interpreted to show that colours have a better and greater ability to capture attention than other variables.

Pan (14) extended his previous study by verifying the colours. He used visual geometrical shapes with various colours. The participants ($n = 22$) were asked to memorize both the colours and shape of the items. In the memory test, the participants were asked to recognize the colours and the shapes of the items that were presented earlier on. He found that participants performed better in recognizing the colour of the items than the shapes. The result supported his previous studies where colour had a stronger attention effect than the shape, $F(1, 21) = 4.984$, $P = 0.031$, $\eta^2 = 0.192$. This suggests that, colours can produce a higher level of attention and is effective to increase memory performance. Therefore, it can be concluded that colours have the tendency to capture better attention level, and thus, better memory.

Arousal and memory

Arousal refers to the state of being alert physically and internally. Various body system and hormones may contribute to alertness (20). The concept of arousal may include the physical,

psychological, physiological, and emotional arousal. In the study of memory, emotional arousal is focused on more than the other types of arousal. MacKay and Ahmetzanov (25) conducted a study on the relationship between emotional arousal and memory by using taboo stroop paradigm. They predicted better memory for taboo words (which were more emotionally arousing) than neutral words. It was found that the participants performed better in experimental conditions that were associated with emotionally arousing words (taboo words) than the conditions with neutral words (26). This result complements the study of Heuer and Reisberg (27), that found better retention in long-term recall with a high level of emotional arousal. Similarly, a high level of arousal leads to enhancement of both short-term and long-term memory. In an experiment conducted by Corteen (cited in 27), which used aurally presented words, it was reported that higher recall was found after 20 minutes and two week delays. The same result was reported in an experiment which used a single arousing word. Recall performance was found to be better with words that have arousal effect than non-arousal words. However, there was also evidence on the detrimental effects of arousal especially on short-term retention. For instance in learning, the participants who have high arousal effect remembered better in the delayed recall rather than shortly after learning process. According to Kleinsmith and Kaplan (28), words that can produce greater arousal effect were better remembered after one week than two minutes after the learning process. Thus, from the studies mentioned above, the level of arousal evoked by environmental stimuli can have a significant effect on memory performance in whether the short-term or long-term memory storage.

Arousal, memory and colour

Arousal, especially emotional arousal, can play an essential role in keeping the information in the memory system. Colours can enhance the relationship between arousal and memory. Kaya and Epps (22), asked their 98 college student volunteers in public institutions to associate colours with emotion. It was found that the majority of participants associated green colour with the feeling of calmness, happiness, comfort, peace, hope, and excitement. Black colour was associated with the feeling of sadness, depression, fear, and anger. This means that colours have an emotional arousing effect. However, the degree

of arousal level may differ depending on the type of emotion or feeling being attached to it (29). According to Jackson, Wu, Linden, and Raymond (29), some types of emotion may have a greater effect on arousal than the others. For instance, anger was found to have a greater arousal effect than happy or neutral type of emotion. Red colour is being attached with stronger emotion or feeling compared to the other type of colours. Based on the studies mentioned, it shows that colour can produce an emotional arousing effect but the degree or range of arousal varies depending on the emotional element that is attached with specific type of colour.

Colour and Memory Performance

Colour has been found to influence memory performance by increasing our attentional level and arousal. There exist robust evidences from several studies that have been conducted to explore the relationship between colour and memory performance. Those studies are reviewed in detail below.

Spence, Wong, Rusan, and Rastegar (16) examined the ability to recognise coloured and gray-scale images of neutral scenes with 120 participants. They reported that participants' recognition of the neutral scenes were approximately 5% higher in the coloured condition compared to the grey scale condition, $F(1, 112) = 47.0, P < 0.0001$. The same comparison was significant at the 0.05 level or better for different exposure durations. A similar finding was reached in a recall test conducted by Smilek and colleagues (15). Smilek, Dixon, and Merikle (15), carried out a study to investigate the influence of colour on memory performance. They used digit numbers with four different conditions; black, white, congruent, and incongruent colour conditions. They utilized the undergraduate students as their participants in the study. Three minutes were given to the participants to study the stimuli and another three minutes for them to recall the stimuli. The stimuli were exposed to the participants through a computer screen. Significant differences were found between recall conditions. The memory performance of the participants was found to be better in the congruent colour condition compared to the other conditions (26).

Wichmann, Sharpe, and Gegenfurtner (3), found a clear advantage of colour on visual memory. In their first experiment, they tested the colour recognition of the participants on the 50 milisecond to one second duration.

The participants reported 5% to 10% better performance on colours over black-and-white condition. In their second experiment, the same images were used but with the exposure duration of one second and in six different image contrasts; 5%, 10%, 20%, 40%, 70%, and 100%. These contrasts were applied in colour and black-and-white images. Colour images were reported to have better memory recognition over black-and-white, but the differences were small. However, there were no significant differences found at the lower contrast level (5% and 10%). According to the authors, the images in the low contrast level were hardly visible and seen. In their third experiment, the same procedure was used, but participants were tested in different conditions. Those images that were presented in colour were tested in black-and-white and vice versa. A significant interaction was found between study mode and test mode, $F(1, 30) = 8.209, P < 0.01$. However, the performance of the images that were presented in colour and tested in black-and-white was deteriorated. The same goes for the images that were presented in black-and-white and tested in colour. However, the performance was better with the colour images tested in colour, $F(1, 30) = 4.576, P < 0.05$. A similar finding was reported in the fifth experiment, where the images with the coloured frame show significant improvement (77.0% to 80.0%) in memory recognition than images with the black frame, $t(19) = 2.51, P < 0.05$.

Vernon and Lloyd-Jones (30) conducted a study to further explore the effect of colour in implicit and explicit memory performance. In one of their hypotheses, they expected a shorter response time to coloured stimuli in comparison to non-coloured/black and white stimuli. 30 coloured and 30 non-coloured objects were used in the study. In the study phase, the participants were involved in the naming task of those 60 experimental objects. While in the test phase, the participants were asked to recognize the objects which have been categorized in three different conditions; same colour, change colour and non-colour. 20 new objects (10 coloured and 10 non-coloured) were added in the test phase. Response time, percentage of the score, hit, and correct rejection rate were observed. The result revealed a significant effect on coloured object $F(1, 29) = 7.02, P < 0.05$. This means participants took faster time to recognise objects in the coloured than non-coloured condition.

The above studies indicated that colour can have a positive influence on memory

performance. A few studies have however found contradictory findings. Lloyd-Jones and Nakabayashi (31), carried out a study on the effects of colour on object identification and memorization, and found out that there were differences in memory performance in object-colour spatial integration and object spatial separation. Two hundred and thirteen undergraduate students from the University of Kent were involved in the study. All participants were non colour-blind. 75 coloured common objects were used as stimuli in the study. There were three conditions; correctly coloured (the object and its original colour), incorrectly coloured (the object not with its original colour) and greyscale condition. There were two experimental conditions; object-colour spatial integration and object-colour spatial separation. In the object-colour spatial integration, the colour object was placed on the grey background while in the object-colour spatial separation, the grey object was placed on the colour background. In the study phase, participants rated object-colour typicality on 7-point scale. In the test phase, participants were required to press certain buttons to indicate whether the object was correctly coloured or not. The speed of the response was measured. The result showed that there was a significant effect of the colour $F(1, 184) = 18.3, P < 0.0001$. Higher ratings were found for the spatially integrated condition ($M = 3.84$) than for spatial separated condition ($M = 3.13$). In terms of the reaction times, it was reported that shorter reaction times were found for correctly coloured than for incorrectly coloured in the spatial integrated condition, $t(83) = -2.58, P < 0.05$ but not for spatially separated, $t(83) = 0.70, P > 0.05$. Therefore, coloured object with non-coloured background have better memory retention and yielded faster respond time compared to coloured object with coloured background.

Another study by McConnochie (32) used alphanumeric characters and showed them to the participants through slideshow with three background colour conditions; white, blue and green. All the figure characters were in black. If the colours have positive effect on memory, performance was expected to be equal in these conditions. The result however showed that the slides with the white background resulted in higher retention rates both in immediate and delayed recall tasks than those with blue and green background. This result contradicts the previous studies in that only certain colours lead to better memory. Nevertheless, in this study, the colours chosen and the manipulation in the

figure and background colours may explain the result obtained.

Hall and Hanna (33), conducted a study on webpage text and background colour combination to memory retention. One hundred and thirty six university students participated in their study. They used two different types of websites; an educational website which contained information regarding a neuroscience subject and a website which was more commercial that had an advertisement of products. Hall and Hanna used four different types of ground and figure colour combinations for each of the websites; black on white background, white on black background, light blue on dark blue background and teal on black background. Each participant was randomly assigned to each of the four conditions and they were given 10 minutes to view the websites. After that, they were required to answer 10 multiple-choice questions used to measure the readability, retention, aesthetics, and behavioural intention level. It was expected that the condition with a higher contrast level of colour will result in a higher level of readability and also retention rate. The result obtained show significant differences in the four conditions and the post-hoc tests showed that the readability performance was highest on the black on white background condition. This condition was interpreted to have the highest contrast level compared to the others and this contributes to a better readability level. The significant result found for readability was however not found on retention rate. This means that the different contrast of colour combination used only effects readability level but not memory or retention rate (33).

Factors That Influence the Effectiveness of Colour on Memory Performance

The studies reviewed above showed that colours can lead to better memory performance. There are however studies that indicate an opposing effect of colour on memory. On the basis of the studies reviewed previously, it can be summarized that the effectiveness of colour on memory performance is based on a few factors. First is the consistency of the colours used during encoding and retrieval phases. This means the colour used or presented during the time when participants are asked to memorize should be the same with the colour shown to them at the time of retrieval. This rule is in line with the encoding specificity principle that highlights the close connection between these two memory

processes, encoding, and retrieval in determining the memory performance. The greater match of conditions in these two processes, the better is the retrieval outcome.

Another factor that needs to be taken into account is when few colours or combination of colours are involved (as in background and foreground conditions). The right combination of colours is important because it can produce higher level of contrast, and this can influence memory retention. Higher level of contrast may refer to the colour hue (the wavelength) and the luminance (brightness of the colour) of the colour (33). It was predicted that higher level of contrast will attract more attention and better visibility of an object or information. Stimuli with white foreground on red background can have a higher level of contrast compared to the other colour combination. Similarly, the use of a white colour background with black colour foreground has a better contrast level for memory retention for both short-term and long-term (32). This may be the reason for the top fast-food restaurants in the world to be associated and branded with vivid colour. For example, McDonalds used yellow and red colour in the logo, while Kentucky Fried Chicken is remembered with red and white colour combinations. Colour therefore played a very important role in influencing consumers psychologically, which is characterized by emotional attachment, attention, memory, and attitude that later increase the likelihood of buying behaviour.

Conclusion

An important aspect in successful and efficient cognitive functioning is the abilities to utilize the system to the fullest. Research on memory has provided a vast strategy that can be used to ensure successful retrieval. There appears to be a basis for associating colour and its significant effect on memory abilities. In other words, colour has the potential to increase chances of environmental stimuli to be encoded, stored, and retrieved successfully. The choice of colours and the manipulative aspects can, however, influence the extent to which colours can influence human memory performance.

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