The effects of eye closure and working memory capacity on memory performance

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ABSTRACT

Eye closure (EC) has been shown to facilitate performance on a range of cognitive tasks, including the recall of items previously studied. Additionally, working memory capacity (WMC) has been shown to influence memory performance. The present study aimed to combine these separate strands of research to assess whether EC and WMC interact with each other on a episodic memory task, for true and false memory with remember, know and guess responses outlined. The experiment assessed participants WMC using a reading span task and the median split was used to group participants into low vs. high. Following this, participants memory performance was assessed with eyes open and closed with a free recall task. Results from the separate ANOVAs found that EC facilitated memory performance for true memory overall and for remember and guess responses. Additionally, high WMC influenced memory performance for true memory overall and for remember, know and guess responses. The results highlight that EC effects are not critically dependent on WMC for true or false memory. Overall, the results obtained for this underexplored area of research provide the foundation for further contributions.

KEY WORDS:	EYE CLOSURE	WORKING MEMORY CAPACITY	COGNITIVE LOAD	EPISODIC MEMORY

Introduction:

There is a growing body of research surrounding the potential interaction between eye closure effects and memory performance (Vredeveldt & Penrod, 2012). Eye closure (EC) effects have been shown to be beneficial in both controlled environments and in real-life settings, such as aiding cognitive interviews for eyewitness testimonies (Vredeveldt, 2011) and hypnosis (Wagstaff, 2004). Expanding on this area of interest, this study explored the theoretical aspects of EC effects. This study is concerned with the relationship between two central constructs: EC and working memory capacity (WMC) – both of which arise from two separate bodies of literature and are combined by measuring the effects of EC and WMC on episodic memory performance. This exploration involved a number of factors including: (i) the theoretical background underlying EC effects on memory performance, and (ii) the mechanisms that explain the theoretical underpinnings of EC, and (iii) a new exploration of the potential interaction between EC effects and WMC.

Eye closure:

It is thought that when a person is deeply engaged in an activity that requires concentration, they may outwardly reflect this through their behaviour (Vredeveldt, 2011). 'These [visual displays] are often important sources of information' (Doherty-Sneddon, Bruce, Bonner, Longbotham and Doyle, 2002: 3), and one example considered as most informative is EC (Wagstaff, 2004; Vredeveldt, 2011) – a method that can enhance remembering and improve memory performance (Vredeveldt & Penrod, 2012). Glenberg, Schroeder and Robertson (1998) demonstrated this interaction, finding EC to be not only a physical effect of deep thought but also to have a functional purpose. Glenberg et al. (1998) assume EC to be a technique used to control the environment through disengagement of environmental stimuli that may be disruptive to the task at hand. This may help to explain why many individuals spontaneously avert their eyes or close them when trying to recall a memory of something specific (Buchanan, Markson, Bertrand, Greaves, Parmer and Paterson, 2014). Furthermore, when a cognitive task increases in difficulty, those instructed to close their eyes or avert their gaze showed significant improvement in performance compared to those instructed to keep them open (Glenberg et al. 1998; Perfect, Andrade & Eagan, 2011). In addition to previous research, Perfect, Wagstaff, Moore, Andrews, Cleveland, Newcombe, Brisbane and Brown, (2008) discovered that participants using EC could recall information more accurately than those who did not – further supporting EC effects.

In summary, it can be suggested there is a interaction between EC and episodic memory performance. This assumption, based upon a wide range of robust evidence, has highlighted the impact EC can have on facilitating remembering and increasing accurate recall (Vredeveldt & Sauer, 2015). Following previous research, 'there is much to gain from understanding the boundaries of this technique's potential' (Nash, Nash, Morris & Smith 2015: 1). In accordance to the potential benefits gained by understanding EC effects and their influence on episodic memory, various mechanisms have been hypothesised to explore the theoretical underpinnings of EC effects on memory performance. These have been attributed to two cognitive mechanisms: modality-specific interference and cognitive load (Vredeveldt, Hitch & Baddeley, 2011; Mastroberardino & Vredeveldt, 2014).

Modality-specific interference:

The first mechanism is the modality-specific interference hypothesis, which claims that distractions in the environment will only interfere with the concurrent task if in the same modality (Vredeveldt & Perfect, 2014) – these modalities referring to visual or auditory stimuli. An explanation for this is that impaired recall of information within the *same* modality is a result of stimulus competing for the same cognitive resource. Alongside this, Mastroberardino and Vredeveldt's (2014) findings found that EC increases concentration whilst also reducing visual distractions. This method enhances memory performance by improving recall of information, which is processed and perceived within the same modality. Phillips and Christie (2007) explored this and stated that visualisation and perception can interfere with one another when competing for the same resource, which has been shown to impair the recall of information. Additionally, Borst and Kosslyn (2008) found that visualisation and perception are processed in a similar manner and also have a very similar structure. Consequently, this can impair recall of information as they compete for similar underlying resources. Therefore, by reducing interference of competing resources within the same modality, information can be processed more efficiently. EC is an effective method in the reduction of modality interference by improving visualisation and mental stimulation, enhancing the processing of information and memory performance (Perfect, Andrade & Syrett, 2012).

Though a theory behind EC effects has been explored through the form of modality-specific interference, Vredeveldt (2011), among others, theorised an alternative hypothesis: cognitive load. This alternative theory looks at EC as a method that enhances recall of information on a general level, rather than specific to the modality.

Cognitive load:

The cognitive load hypothesis explains that closing of the eyes facilitates memory on a general level, rather than modality-specific, by freeing up cognitive resources in relation to working memory (Vredeveldt et al. 2011). It is believed that these working memory resources have been used to monitor the environment as well as process other cognitive inputs simultaneously. The cognitive load theory argues that there is a limited pool of resources that should be controlled and distributed based on the needs of the task. Therefore, disengaging from environmental stimulation, either through gaze aversion or through EC, can enhance the efficiency of cognitive processing (Glenberg, Schroeder & Robertson, 1998). This is a result of suppressing the awareness of environmental stimuli; lessening the demand on cognitive processes; allowing cognitive resources to focus solely on the complex cognitive process; and therefore improving memory recall (Doherty-Sneddon et al. 2002). Glenberg et al. (1998:657) defined this process as 'cognitive control over cognition'. This theory assumes that, when one takes part in a difficult task, there are numerous distractions within the environment that must be suppressed in order to have internal control over the current task. EC has been recognised as a method used to suppress this unwanted information from the environment, and helping to reduce cognitive interference to the task at hand (Vredeveldt, 2011; Vredeveldt & Penrod, 2012). Disengaging from the environment through EC makes cognitive resources available; hence improving the efficiency of processing information and influencing memory performance. This theory has acquired overwhelming support, demonstrating that reducing cognitive load through EC, gaze aversion or a blank screen can ultimately improve overall memory performance (Perfect et al. 2011).

Evidence provided is mixed in relation to the theoretical underpinnings of EC, and regrettably inconclusive as to whether EC reduces cognitive load or modality-specific interference. The cognitive load hypothesis predicts that EC improves memory performance for visual and auditory information, whereas the modality-specific interference hypothesis focuses mostly on improved memory performance of visual information. Both Perfect et al. (2008) and Vredeveldt et al. (2001) found support for the modality-specific hypothesis, however Vredeveldt also supported the cognitive load hypothesis. Vredeveldt et al. (2001) discovered (i) visual distraction impaired recall of visual information (modality-specific), and (ii) reducing environmental distraction with EC improved recall of materials in both modalities (cognitive load). Although evidence is mixed in terms of which is more credible, there is less support for the modality-specific interference hypothesis. This is a result of the overwhelming library of literature that supports cognitive load, whereas modality-specific is not as favourable in comparison. Ultimately, this has favoured consideration of the cognitive load hypothesis to underpin EC effects; information to be remembered will be recognised on a general level and EC will be seen to reduce load, which will allow ‘for more resources to be allocated to examining post-event information’ (Kies et al, 2013: 3).

Working memory:

To understand EC effects in more depth, other approaches within working memory provide a clearer insight. The working memory model provides a descriptive understanding into how visual, auditory and general information is maintained, stored and processed in both short-term and long-term memory (Baddeley, 2003; Cowan, 2005). Similar to modality-specific and cognitive load, Baddeley and Hitch’s (1974) multi-component model both accommodate two domain-specific subsystems; they process visual information through the visuospatial sketchpad and auditory information through the phonological loop. Additionally, there is a third component: the central executive – a domain-general system responsible for the allocation of general attention through the visuospatial sketchpad and the phonological loop. The central executive system is of most interest to this study. It not only determines how to process information through cognitive manipulation by expending specific cognitive resources, but also ‘regulates how to inhibit irrelevant information that would previously consume those resources’ (Baddeley, 1986). Tasks that require more complex processing, such as language comprehension, increase the level of individual performance as well as the demands made on the central executive to maintain relevant information and inhibit irrelevant information (Hester & Garavan, 2005). Just and Carpenter (1992) hypothesised that the processing, storage and regulation of this information is facilitated by activation, and that ‘cognitive capacity constrains comprehension, and it constrains comprehension more for some people than for others’ (Just & Carpenter, 1992: 122). In summary, differing levels of performance among individuals has been associated to having processing differences within the central executive, which have been correlated to individuals’ WMC (Hester & Garavan, 2005).

Working memory capacity:

WMC has often been misinterpreted for how many items an individual can store at a given time. Though a part of this is true, WMC is not exclusively about memory – it is also about attention and maintenance of this to avoid proactive interference, which is considered a primary function underlying working memory resources (Engle, 2002). Individuals with a high WMC span may not necessarily have a greater store for information; rather, they have a heightened ability to maximise and control attention, which is used to suppress extraneous information and maintain relevant information (Hester & Garavan, 2005:222). The first to devise a reliable and consistently valid measure of WMC was Daneman and Carpenter (1980), who conceived the reading span task (Conway et al. 2005; Engle, 2010). This task was developed based on reading comprehension being recognised as a crucial role in WMC. Previous measures such as digit span and word span were not seen as methods that challenged both the processing and storage functions of working memory (Daneman & Carpenter, 1980). Reading span, however, measured reading comprehension performance through assessing an individual’s ability to store and process information through functions within working memory. ‘In this task subjects must effectively encode, maintain access to, and/or recover the current set of words whilst trying to avoid interruption from the task itself and proactive interference’ (Kane et al. 2006: 749). The task, which is considered a true measure of WMC, reflects a variety of cognitive processes and abilities that are deemed appropriate functions of working memory.

Present study:

Preliminary studies have focused on EC effects and memory performance alone. The present study, however, aimed to extend this focus by combining two strands of research: EC effects and WMC. There is a great deal of research demonstrating that EC reduces cognitive load and enhances visualisation by disengaging from environmental stimulation. Additionally, there is much research on the topic that ‘WMC proposes that processing and storage are mediated by the amount of activation available’ (Just & Carpenter, 1992:122). Consequently, participants with a high WMC are able to efficiently process information and disengage from environmental distractions simultaneously. Participants with a low WMC, however, will find this difficult – based upon the notion that their WMC is smaller and their processing is limited, and therefore ‘activation available’ is reduced. This study explored the potential interaction between EC and WMC. On the basis of previous research, the following hypothesis is advanced; individuals with a low WMC will benefit more from EC on memory performance tasks in order to reduce cognitive load than those with a high WMC (this hypothesis does not negate the individual or main effect contributions of EC and WMC).

To incorporate both strands of research to assess the main aim of the study:

(i) A revised reading span task devised by Daneman and Carpenter was used (1980).

(ii) Subsequently, participants took part in a recall task in separate phases (with their eyes open and closed).

On the basis of previous research, these hypotheses have been advanced:

Main Effect: Predictions for True Memory.
H1a: Those high (vs. low) in WMC will correctly recall more studied items.
H1b: Those high (vs. low) in WMC will produce more Remember/Know responses to correctly recalled studied items.

H2a: Those in the eyes closed (vs. eyes open) condition will correctly recall more studied items.
H2b: Those in the eyes closed (vs. eyes open) condition will produce more Remember/Know responses to correctly recalled studied items.

Main Effect: Predictions for False Memory.
H3a: Those participants with high (vs. low) WMC will have fewer false memories for unstudied items.
H3b: Those participants with high (vs. low) WMC will produce fewer Remember/Know responses to incorrectly recalled studied items.

H4a: Those in the eyes closed (vs. eyes open) condition will have fewer false memories for unstudied items.
H4b: Those in the eyes closed (vs. eyes open) condition will have fewer Remember/Know responses to incorrectly recalled studied items.

Interactions: Predictions for EC & WMC.
H5: If EC enhances memory by freeing working memory resources then an interaction between EC and WMC is expected, with those low in WMC to benefit most from EC. This benefit will be expected in terms of higher true memory and lower false memory.

Methodology.

Participants

The experiment consisted of 60 participants, (Females, *n=34,* Males, *n=26);* participants' ages ranged from 18-30 years, with a mean age of 22. No further demographic details were collected. A combination of opportunity and snowball sampling was used to gather participants. Based on the two sampling methods employed, participants were gathered from Manchester Metropolitan University.

Design:

This study used a factorial experimental design with two independent variables and two dependent variables. The first independent variable was the WMC task (reading span); this was a between-subject variable with two levels: high capacity and low capacity (this was defined by the use of median split). The second variable was the eye condition; this was within-subjects with two levels: eyes open and eyes closed. Therefore, the design used was a 2 (working memory capacity: high vs. low) between subjects x 2 (memory performance: eyes open vs. eyes closed) within-subjects mixed design with repeated measures on the second variable. The second variable was counterbalanced to avoid potential order effects of the words to-be recalled

The dependent variables were (i) the number of studied words recalled and (ii) the number of non-studied (false) words recalled. Each of these was further subdivided into Remember, Know, and Guess responses.

Materials:

Materials for the Reading Span Task:

The first independent variable was measured using a complex span task: reading span task. This was administered similarly to Daneman and Carpenter's (1980) original version of the reading span, in which participants read aloud the sentences at the own pace and once they had read the sentence and the additional letter, the next sentence was presented. This task was administered individually with sentences ranging from 11-17 words, 20 to 22 syllables, with 41 to 73 letters. An adapted version of the reading span was modified to combine Turner and Engle's (1989) version, which used 12 items, 3 sets consisting of two, three, four and five. This task was adapted as Daneman and Carpenter's (1980) original version used 15 items, however, the results from Turner and Engle (1989) were found to be similar and subsequently less time was required with fewer items (Conway et al. 2005).

Similar to Turner and Engle's (1989) version, participants were asked whether the sentences were syntactically and semantically correct (e.g. "All parents hope their list will grow up intelligent"). This was used to prevent participants from using rehearsal techniques. Another point highlighted was participants relying on strategies that come from knowing the size of the sentence sets, such as the sentence sets being presented in ascending or descending order. As a result, Engle and colleagues' (1992) version was adopted. This required the set of sentences to be randomised in order to eliminate this concern. This was done using the randomising function of Microsoft Excel. These sentences were presented on slides using Microsoft PowerPoint, with a blank page to indicate the end of the sentence set and for the participants to recall the letters that were provided in order of presentation. All sentences were obtained through Engle Lab (Unsworth et al. 2005).

Partial credit unit scoring was used to calculate participants' WMC span; this type of unit scoring conveyed the mean of the correct letters recalled within a set (Conway et al. 2005; Redick et al. 2012). Proportion words were calculated by adding each correct letter in the set and dividing that number by the set size (e.g. 3 correct out of 4 equals 0.75 and once all sets are added together this is then divided by 12) This produced the participant's individual WMC score. (Appendix 3)

Materials for the Memory Task:

The materials for the subsequent memory test; the recall of the word list were constructed as follows: (i) Firstly, a pool of 50 four to five letters, one-or-two syllable words was constructed based on the Engle et al. (1999) task. The list of words was created using the MRC psycholinguistics database (Wilson, 1988). (ii) This overall pool of words was further divided into two sets of 25 for the purpose of counterbalancing. Two lists of words were provided for each of the two eye conditions. (Appendix 5).

The word recall task was administered verbally and participants responded verbally for each condition. The researcher was required to write down the participant's responses in the word-recall experiment form. This was provided in the participants' response booklet. (Appendix 2)

Procedure:

Reading Span Task:

Participants initially took part in the first experiment: the reading span task. The participants were prompted to read the instructions provided, which are similar to those described by Daneman and Carpenter (1980). The researcher elaborated on these instructions, if the participant required them to do so. The stimulus was presented on a computer using a PowerPoint presentation (Appendix 4). The participant read aloud each sentence within a set and the letter at the end of each sentence, and before proceeding on to the next. The participant verified whether the sentence provided was syntactically and semantically correct. After this, the next slide was shown. Once the set was completed, a blank slide was presented and this indicated the end of the set, and then the participant had to recall the letters provided, in the order presented to them. Once all 12 sets were completed, the participant proceeded on to the second phase of the experiment.

Memory Task:

The subsequent phase involved a memory recall task. Information was provided about the task and participants were required to read this. Once read, any questions the participant had were answered by the researcher. The researcher read aloud 25 words with two seconds given for each word. After the list of words were read, the participant was prompted to complete a 5-minute delay task, which required them to list towns and cities beginning with a specified letter. This was done to avoid rehearsal techniques. After the 5-minute delay, the participant was asked to verbally recall the list of words provided before the delay task. Participants completed this with either their eyes closed or with their eyes open. These conditions were counterbalanced to avoid potential effects. During recall, participants also informed the researcher on the characteristics of their recall by indicating if their recall was accompanied by explicit recollection (remember), recall without explicit recollection (know), or whether they believed they were guessing (guess). This procedure was elaborated on if needed. After a 5-minute interval, this procedure was repeated for the second condition that was not done initially, either with the participant's eyes open or eyes closed. This was also completed with a different list of 25 words. The condition and the word lists were counterbalanced to avoid potential order effects. All participants were verbally debriefed and given the opportunity to express any concerns or questions involving the experiment.

Ethics*:*

This study was given ethical approval and to ensure quality and integrity within this research, all ethics were addressed and adhered to in accordance with the code of ethics and conduct (British Psychological Society, 2010). (Appendix 1)

Results:

Overview of Results. The number of yes responses to studied items (true memory) and yes responses to non-studied items (false memory) were entered into separate ANOVAs. The analyses conducted were, 2(Working memory capacity; high vs. low) between-subjects by 2(Eye condition; Open vs. closed) within-subjects mixed ANOVAs. The division into the WMC group was done on the basis of a median split with those scoring above below the median (.615) into the high (low) groups respectively.

True Memory. The means and SDs for true memory comprised overall yes responses to studied items that were further assessed into Remember, Know and Guess response categories. The descriptive can be seen in Table 1 below.

Table 1: Means (SDs) of Yes Responses to Studied Items as a Function of Working Memory Capacity, Eye Condition & Response Type.

	Working Memory Capacity		
	High M (SD)	**Low M (SD)**	**Total M (SD)**
Response Type & Eye Condition			
Overall			
Open	4.97 (1.83)	3.97 (1.97)	4.47 (1.95)
Closed	5.97 (2.16)	4.57 (1.75)	5.27 (2.07)
Total	5.47 (1.59)	4.27 (1.66)	
Remember			
Open	3.90 (2.35)	2.80 (1.90)	3.35 (2.19)
Closed	4.90 (1.95)	3.00 (1.89)	3.95 (2.13)
Total	4.40 (1.73)	2.90 (1.66)	
Know			
Open	0.80 (1.35)	1.00 (1.20)	0.90 (1.27)
Closed	0.57 (0.86)	1.40 (1.57)	0.98 (1.32)
Total	0.68 (0.86)	1.20 (1.09)	
Guess			
Open	0.27 (0.45)	0.17 (0.46)	0.22 (0.45)
Closed	0.50 (0.63)	0.17 (0.38)	0.33 (0.54)
Total	0.38 (0.36)	0.17 (0.35)	

Separate ANOVAs for each of the dependent variables were completed. The main effect of overall WMC was significant, F (1, 58) = 8.17, p = .006. Overall, this indicates that more studied words were recalled from subjects with a high WMC. There was an overall significant main effect of EC, $F\ (1, 58) = 8.73$, $p = .005$. This indicates that those with their eyes closed recalled more than those with their eyes open. However, there was no interaction between eye condition and WMC for overall true responses, $F\ (1, 58) = 0.54$, $p = .46$.

The main effect of WMC for studied items receiving a remember response was significant $F\ (1, 58)$, = 11.66, $p = .001$. Overall, this indicates that there were more studied words responded with remember responses from subjects with a high WMC. There was an overall significant main effect of EC, $F\ (1, 58) = 4.34$, $p = .04$. This indicates that those with their eyes closed recalled more remember responses than those with their eyes open. However, there was no interaction between eye condition and WMC for true remember responses, $F\ (1, 58) = 1.93$, $p = .17$.

The main effect of WMC for studied items receiving a know response was significant $F\ (1, 58) = 4.14$, $p = .05$. Overall, this indicates that there were less Know responses from subjects with a high WMC. There was no overall significant main effect of EC, $F\ (1, 58) = 0.16$, $p = .69$. This indicates that there was no main effect between eyes open condition and eyes closed condition for know responses. Additionally, there was no interaction between eye condition and WMC for know responses, $F\ (1, 58) = 2.32$, $p = .13$.

The main effect for WMC for studied items receiving a guess response was significant $F\ (1, 58) = 5.44$, $p = .02$. Overall, this indicates that there were more studied words recalled and responded with guess responses from subjects with a high WMC. There was no overall significant main effect of EC, $F\ (1, 58) = 1.87$, $p = .18$. This indicates that there was no main effect between eyes open and eyes closed condition. Additionally, there was no interaction between eye condition and WMC for true guess responses, $F\ (1, 58) = 1.87$, $p = .18$.

False Memory. The means and SDs for false memory comprised overall yes responses to studied items that were further assessed into Remember, Know and Guess response categories. The descriptive can be seen in Table 2 below.

Table 2: Means (SDs) of Yes Responses to Non-Studied Items as a Function of Working Memory Capacity, Eye Condition & Response Type.

	Working Memory Capacity		
	High M (SD)	**Low M (SD)**	**Total M (SD)**
Response Type & Eye Condition			
Overall			
Open	1.83 (1.42)	2.03 (1.30)	1.93 (1.35)
Closed	1.63 (1.43)	2.03 (1.19)	1.83 (1.32)
Total	1.73 (1.24)	2.03 (1.00)	
Remember			
Open	0.93 (2.07)	0.57 (0.86)	0.75 (1.58)
Closed	0.53 (0.90)	0.63 (0.96)	0.58 (0.93)
Total	0.73 (1.15)	0.60 (0.64)	
Know			
Open	0.37 (0.67)	0.23 (0.57)	0.30 (0.62)
Closed	0.20 (0.48)	0.27 (0.45)	0.23 (0.46)
Total	0.28 (0.39)	0.25 (0.41)	
Guess			
Open	0.87 (1.14)	1.23 (1.01)	1.05 (1.08)
Closed	0.90 (1.10)	1.13 (0.86)	1.02 (0.98)
Total	0.88 (0.99)	1.18 (0.78)	

The main effect for overall WMC was not significant, F (1, 58) = 1.06, p = .31. This indicates that there was no main effect of WMC; this suggests that regardless of high or low WMC, subjects did not respond with more or less false responses to non-studied words (in spite of this there was a trend for lower error scores for those with high WMC). Additionally, there was no overall significant main effect of EC, F (1, 58) = 0.29, p = .59. This indicates that subjects, regardless of eye condition, did not respond with more or less false responses to non-studied words. Furthermore, there was no interaction between eye condition and WMC for overall false memory, F (1, 58) = 0.29, p = .59.

The main effect of WMC for non-studied items receiving a false remember response was not significant, F (1, 58) = 0.31 p = .58. Overall, this indicates that subjects regardless of WMC did not respond with more false remember responses. Additionally, there was no significant main effect of EC, F (1, 58) = .51, p = .48. This indicates that subjects, regardless of the eye condition, did not respond with more or less false remember responses to non-studied words. Furthermore, there was no interaction between eye condition and WMC for false remember responses, F (1, 58) = .99, p = .32.

The main effect of WMC for non-studied items receiving a false know response was not significant, *F* (1, 58) = .11, *p* = .75. Overall, this indicates that subjects, regardless of WMC, did not respond with more or less false know responses to non-studied words. Additionally, there was no significant main effect of EC, *F* (1, 58) = 0.47, *p* = .50. This indicates that subjects, regardless of eye condition, did not respond with more or less false remember responses to non-studied words. Furthermore, there was no interaction between eye condition and WMC for false know responses, *F* (1,58) = 1.05, *p* = .31.

The main effect of WMC for non-studied items receiving a guess response was not significant, *F* (1,58) = 1.70, *p* = .20. Overall this indicates that subjects WMC, did not respond with more or less false guess responses. Additionally, there was no significant main effect of EC for guess responses, *F* (1,58) = 0.06, *p* = .80. This indicates that was no difference between subjects false guess responses in both the eye conditions. Furthermore, there was no interaction between eye condition and WMC, *F* (1,58) = 0.25, *p* = .62.

Summary:

Overall, there were no interactions between WMC and EC for true or false memory, however there were main effects for these variables separately for true memory. True memory participants with a high WMC recalled more words correctly compared to individuals with a low WMC. Participants with a high WMC recalled more correct remember responses and fewer know responses compared to participants with a low WMC. Overall participants within the eyes closed condition recalled more studied items. Additionally, participants with their eyes closed produced more correct remember responses, but no main effects were presented for know or guess responses. In addition, the results for false memories for unstudied items with remember, know and guess responses, revealed that there were no main effects established.

Discussion:

Although the aims of this study were successfully explored within this investigation, not all of the outcomes from the separate ANOVAs aligned with previous predictions. The research conducted found that EC influences memory performance with regards to a number of variables, including: (i) overall true memory, EC-enhanced true memory for studied items overall; (ii) Remember, EC enhanced the number of remember responses towards studied items. However, (iii) Know and (iv) guess responses for EC had no significant effect. In addition, results indicated that WMC influences memory performance for a number of variables: (i) overall true memory, WMC enhanced memory for participants with a high WMC. (ii) Remember, WMC enhanced the number of remember responses for participants with a high WMC. (iii) Know, WMC reduced know responses for participants with a high WMC. (iv) Guess, WMC increased the number of guess responses for participants with a high WMC.

In addition to true memory, false memory was analysed. The research found that EC did not influence memory performance with regards to a number of variables: (i) overall false memory, EC had no significant effects for non-studied items. Likewise for (ii) Remember, (iii) Know and (iv) guess, EC had no significant effect. Results for false memory for WMC indicated no effect on memory performance with regards to a number of variables: (i) overall false memory, WMC had no significant effects for non-studied items. Adding to this, (ii) Remember, (iii) Know and (iv) guess responses indicated that WMC had no significant effect.

Overall, the results indicate that for true memory, significant main effects were found for the two separate variables, while for false memory there were no significant main effects. In addition, a common pattern was presented in both true and false memory; with results indicating that there was no evidence to suggest an ***interaction*** between eye closure and WMC for (i) remember, (ii) know, or (iii) guess responses. Utilising the results found, this section will consider the potential explanations for the lack of interaction between eye closure and WMC and subsequently the potential explanations for the main effects.

Observing the trends within the results, the non-significant effects do not support the hypothesis previously predicted – one that was based upon the theoretical premise that working memory resources underpin eye closure effects (Glenberg et al. 1998; Vredeveldt et al. 2011). However, though these findings were not significant, the reasoning for these results may be explained using two rationales: methodological and theoretical. For instance, the lack of interaction between EC and WMC could be due to methodological implications. The appropriate use of a measurement to assess individual differences within working memory is essential in providing a reliable and valid measure of WMC (Redick et al. 2012). But because it has been proven that it is much harder to find effects of WMC on elaborative inferences (Harley 2008), perhaps the complex span task used within this study may have been an inappropriate and inefficient measure for this research. Even though this measure of WMC is commonly recognised as a valid and reliable complex span task to measure comprehension (Daneman & Carpenter, 1980; Springer, 1996), reading ability and prior knowledge have been found to influence comprehension, which is often seen as advantageous, and therefore biased (Harley, 2008; Alptekin & Ercetin, 2009).

As aforementioned, Daneman and Carpenter (1980) suggested that overall WMC is the same for both good and poor readers. Whereas, Garrison, Long and Dowaliby (1997) demonstrated that an individual who is classed as a good reader is more efficient at processing information. This could be because prior knowledge has been considered strategic in its ability to influence comprehension (Harley, 2008); participants possessing prior knowledge can easily and efficiently understand and interpret the information given in comparison to those without the same levels of prior knowledge. Moreover, participants who occupy prior knowledge of the information provided may have more available resources – otherwise known as 'activations' (Just & Carpenter, 1992) – to be able to focus mainly on the storage aspect of working memory, rather than the comprehension of the information given. Therefore, a concern is highlighted with the current task used as it can be considered as being task specific and bias; good readers and poor readers may function differently on a task that does not require reading comprehension and participants with prior knowledge can process information more efficiently (Harley, 2008).

Unfortunately, because the relationship between reading span and comprehension was not analysed within the current study, the potential inferences that may have affected the accuracy of the results cannot be measured. However, one wonders whether altering the testing procedure would affect the conclusions made from measuring WMC. It could be beneficial to suggest a combination of span tasks to address whether the reading span task or alternative complex span tasks are task-specific, and/or biased in the case of certain of individuals. Conducting more than one span task is often advised as the 'quartile efficiency (extent the subject is classified in the correct quartile – upper/lower) is significantly better when two span tasks are considered than when just one span task is' (Conway et al. 2005:783). Although the quartile efficiency was not used in this present study, an alternative method – the median split - was used to classify the two WMC groups into high vs. low. Though these methods of grouping differ, the use additional tasks can still be considered an option to further substantiate the findings.

There are a number of potentially appropriate measures of WMC that could be considered for the present study. For example, the use of the operation span task, or counting span task, which are very similar in structure, may be more appropriate than the task in hand. This is because each one does not solely rely on reading comprehension, allowing for a better understanding of individual differences that may influence the findings. Although these are alternative valid measures of WMC, it is worth noting that all complex tasks are interrelated, which is verified by coefficient alphas, and so the likelihood of them correlating with the present findings – even when aspects of the procedure are changed – are relatively high (Conway et al. 2005).

Another potential concern may suggest that the non-significant effects between EC and WMC may not be down to the measurement of WMC, but perhaps the theory itself may be incorrect. This may appear surprising, as numerous researchers, including Vredeveldt (2011), suggested working memory resources provide an integrated framework to explore and explain eye closure effects. Vredeveldt (2011) suggested that EC effects could be explained using a combination of general interference (irrespective of modality) and modality-specific interference (visual vs. auditory), which, in a similar light to the working memory model, can be mirrored by the central executive, the visuospatial sketchpad and the phonological loop. Based on previous literature, it was deemed appropriate to assume that eye closure and WMC would influence one another, but this may not be the case; the presumption that EC and WMC interact with one another may be incorrect, particularly when considering the two variables as two separate cognitive processes with unconnected resources.

Overall, it can be concluded that working memory resources do not underpin EC effects and that EC effects, which previously have been associated to heightened memory ability, do not interact with an individual's ability to maintain attention to efficiently process and store information (Just & Carpenter, 1992). Consequently, it can be assumed that there are other explanations for EC effects that do not involve these effects being critically dependent on WMC. For example, an alternative explanation for the effects improving recall could surround the use of mental imagery (Vredeveldt, 2011). Supporting this justification, Wais, Rubens, Boccanfuso and Gazzaley (2010) found that there were increased 'activations' among the hippocampus and the visual association cortex when participants recalled information with their eyes closed; this is where areas of the brain associated with visualisation and mental imagery are activated when remembering information previously given, and participants that close their eyes when recalling information have been found to utilise this area of the brain (Wais et al. 2012). Therefore, eye closure effects may be dependant on mental imagery and visualisation as Vredeveldt, (2012) suggested, rather than WMC as previously hypothesised.

If this alternative explanation is correct, it may justify why there were significant main effects found between EC and remember responses. To support this, neural correlates have been found, suggesting that remembering is associated with the areas of the brain that are involved in encoding (Danker & Anderson, 2010). These activations are also found in regions of the brain that elicit visual memories such as the hippocampus, which previously had been associated with the use of mental imagery and EC (Wheeler & Buckner, 2004; Danker, & Anderson, 2010). Thus, the significant main effects found between EC and remember responses open up alternative areas of research that could be explored to expand on the findings from this study.

Furthermore, high WMC was also associated with an increased number of remember responses. These results are comparable to previous research that shows enhanced memory for those with high WMC (Daneman & Carpenter, 1980; Hester & Garavan, 2005; Kane et al. 2006). In addition to the findings, the research is extended by demonstrating that these memories are accompanied by remember responses. This is similar to Just and Carpenters theory (1992), whereby participants with a high WMC are described as having more readily available activations to efficiently process and store to-be-remembered information. All of these results contribute to the existing research that surrounds WMC and the effects individual abilities and capacities have on memory performance.

The main effects also found a decreased number of know responses associated with high WMC, which can be explored in conjunction with the main effects found for remember responses. Participants with a high WMC recalled more remember responses than know responses. Thus, it can be suggested that as one variable increases, the other variable decreases in response. This may indicate that remember and know responses can be related to one another in a way that is analogous to a negative correlation, whereby there is an inverse relationship (Dunn, 2001). These contrasting main effects may highlight a potential artifact; whereby the main effects found may be the result of a flawed experiment based upon potential systematic biases (Strohmetz & Rosnow, 2004), but further research would need to confirm these assumptions.

After much discussion, it can be proposed that EC effects are not critically dependent on WMC based upon the results provided from this study, and, accordingly, there are alternative explanations that need to be explored to further understand the theoretical underpinnings of the effects. However, though there were inconsistencies with previous predictions, the results appear to be partially consistent with results of previous research. When comparing results, high WMC has been found to improve memory performance because it allows for a larger intake of information and EC, although ineffective in some areas of the study, is an appropriate method in enhancing the recall of this information. And so, whilst the research proved to be significantly effective for WMC and EC as separate variables when both variables are analysed together, they do not reflect the initial hypothesis: if eye closure enhances memory by freeing working memory resources, then an interaction between eye closure and working memory capacity is expected, with those low in WMC to benefit most from eye closure. Instead, they produced insignificant outcomes. This underexplored area of research provides a basis for future research to be conducted in an attempt to dispute or support these findings.

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