Interference of Dynamic Visual Noise on Encoding Visual Information in Working Memory

Interferência do Ruído Visual Dinâmico na Codificação da Informação Visual na Memória de Trabalho

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Abstract

We aimed to compare the effects of the Dynamic Visual Noise (DVN) on visual memory when presented at different times in an item recognition task either during information encoding, retention interval or throughout the trial. Noise had general effect on participants' performance with stronger impairment on stimuli encoding. The data suggest that visual memory is accessed through perception and, therefore, it suffers external interference, as the one caused by the DVN. We consider that the effect occurred while the information was being kept in consciousness by a specific short-term storage subsystem. These results contribute to the understanding of the architecture used by the visual working memory and show that the DVN is an appropriate technique to study the visual memory.
Keywords: Dynamic visual noise, working memory, visual memory.

Resumo

O objetivo deste estudo foi comparar os efeitos do Ruído Visual Dinâmico (RVD) na memória visual quando apresentado em uma tarefa de reconhecimento de item durante a codificação da informação, no intervalo de retenção ou durante toda a prova. O ruído ocasionou maior interferência na memória quando apresentado durante a codificação do estímulo. Os dados sugerem que a memória visual é acessada via percepção, por isto, sofre interferência externa como a causada pelo RVD. Sugere-se que o efeito ocorreu enquanto a informação era mantida na consciência por um subsistema de armazenamento de curto prazo. Estes resultados contribuem para a compreensão da arquitetura da memória de trabalho e mostram que o RVD é uma técnica apropriada para estudar a memória visual.
Palavras-chave: Ruído visual dinâmico, memória de trabalho, memória visual.

Dynamic Visual Noise (DVN) has been often used in the dual-task paradigm as a tool to study visual working memory. In this paradigm, the participant performs a primary task, which demands the storage of certain information, while observing a screen with small squares that continuously and randomly change from black to white, creating an effect similar to the visual noise seen on the screen of a detuned TV. This configuration was based on the observation that, in order to interfere with the main visual task performance, the irrelevant figure must be sufficiently dynamic to avoid attentional focus in time, in place or semantically (Quinn & McConnell, 1996b).

Logie (2003) considered DVN as a technique that could demonstrate the functional differences in imagination and visual memory processes, instead of being a methodological tool interfering in visual memory. Imagination, herein, is understood as the visual representation generated in response to the presentation of non-visual stimulus, and visual memory refers to an image generated from a visual percept (McConnell & Quinn, 2004a; Quinn, 2012). Logie's hypothesis is that the visual noise interferes with the creation of the mental image, without impairing the information storage in short-term memory. The interference of DVN on the formation of mental images was confirmed in studies that used the Brooks task (Toms, Morris, & Foley, 1994), in a movement imagery task for climbers (Smyth & Waller, 1998), in a task of imagining words based on semantic elements (Dean, Dewhurst, Morris, & Whittaker, 2005; Parker & Dagnall, 2009) and in another task of visually imagining a spatial route (McConnell & Quinn, 2004b; Quinn & McConnell, 1996a).

In agreement with Logie's hypothesis (2003), some studies did not find DVN effects on memory tasks (Andrade, Kemps, Werniers, May, & Szmalec, 2002; Avons & Sestieri, 2005). Avons and Sestieri (2005) did not find any interference from DVN on visual memory tasks with

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matrix patterns. They interpreted these results as evidence that DVN interferes with the generating of the image, but does not gain access to the visual memory system. Andrade et al. (2002) investigated the noise effect on visual working memory in five experiments in which they manipulated the stimuli (matrix patterns or Chinese characters), the retention interval (36 or 4 seconds) and the time at which the noise was presented (encoding or maintenance). Their results showed that DVN did not affect performance in the visual memory task in any of the conditions.

However, recent evidence has challenged findings that show the absence of interference of DVN on memory (Burin, Irrazabal, & Quinn, 2007; Cruickshank, 2008; Darling, Della Sala, & Logie, 2007, 2009; Dean, Dewhurst, & Whittaker, 2008; Dent, 2010; McConnell & Quinn, 2004a; Quinn & McConnell, 2006). McConnell and Quinn (2004a) studied noise interference on visual memory in a task in which participants had to judge if the test stimulus (a circle) was of the same size of the one shown for memorization. The DVN was either presented or not during the interval between the two circles. Task performance was impaired mainly in the negative tasks, i.e., those in which the test stimulus was different from the memorized one. The data were interpreted as evidence that the noise affects the visual representation, and has a stronger effect in situations when it is necessary to maintain a detailed image in consciousness, which implies a more complex task, such as in the case when a condition of greater uncertainty in the response is included (negative trials). Darling et al. (2007) used DVN to verify a visuo-spatial dissociation in working memory. A visual stimulus (a specific letter presented in a graphic font) was shown in a specific spatial location on the computer screen. The visual task was to recognize a test stimulus and the spatial task was to judge whether the spatial position of the test stimulus was the same as that in the memorization display. Besides the DVN, a spatial interference task (spatial tapping) was included in the retention interval. It was expected there would be a double dissociation, that is, that the noise would affect visual memory more than spatial memory and vice-versa for spatial interference. This hypothesis was confirmed by the impairment caused by the DVN on the response accuracy and on the reaction time to the visual memory task, but this effect was not observed in the spatial task.

Dent (2010) found similar results to those of Darling et al. (2007, 2009) in a study in which two different tasks were performed. In the visual memory task, participants memorized a shade of color and in the spatial task they registered four spatial locations that were presented simultaneously. Participants performed both tasks in different blocks of trials. The results showed that DVN impaired the accuracy in the visual memory task, but not in the spatial task. The same effect occurred in conditions when the stimulus presentation time was reduced and the task demand was changed (recall task). The authors interpreted the data as evidence of DVN interference on visual memory tasks, regardless of the nature of the task (recognition or recall).

Burin et al. (2007) provide further evidence of noise effect on visual storage. These authors tested visual memory for visual shapes (polygons) in recognition. Participants were supposed to indicate the memorized target presented among distractor stimuli. After the item was presented, there was a retention interval in which the DVN was presented or not. Results showed that the noise, in its original configuration, did not affect performance. However, the inclusion of another type of noise (referred to as Dynamic Visual Figure), in which geometrical figures crossed the screen forming a movement, affected visual memory. The data evidenced that visual memory is affected by external interferences (caused by perception), but the effect depends on whether the interfering stimulus is dynamic and shares perceptual characteristics with the memorized stimulus.

Dean et al. (2008) analyzed the relationship between the nature of the stimulus to be memorized and the effect of DVN in a study in which participants performed visual memory tasks (matrix and visual texture), under two types of interference during the retention interval (DVN and static visual noise). The dynamic noise affected only the positive trials of memory tasks for textures, that is, when participants were supposed to say whether the visual texture was presented previously. According to these authors, the differences between effects probably occurred due to different encoding routes of the stimuli and to the fact that matrix representation could be supported by long-term memory, which could prevent this type of stimulus from being affected by DVN. Similar to Dean et al. (2008), Kemps and Andrade (2012) did not verify DVN effect on accuracy for matrix patterns. However, the authors identified that DVN reduced the participants' confidence in their responses to the task. By adopting a measurement of how sure the participant is about his response, the presence of DVN caused a larger uncertainty in the response compared to the presence of a static noise or to without interference. The authors concluded that DVN causes small distortions in the representation of information, which are identified in more complete analysis of the storage process, and therefore, it is a valid interference technique to study the short-term visual memory.

Although studies agreed about the deleterious effects of DVN over visual representation, there is still controversy about the specific effect that this kind of noise has on the type of response in the recognition task. While McConnell and Quinn (2004a) confirmed that DVN interfered only in the performance of negative trials (when the test was different from the memorized content), Dean et al. (2008) fond the interference of this noise in positive trials, and Dent (2010) found that the noise equally affected the responses in positive and negative trials. It is likely that these differences could be explained by the nature of the memorized stimulus in each task, which may have demanded a greater or lesser cognitive load to maintain an active representation in the memory (Dent, 2010; Quinn, 2012). Besides the nature of the stimulus, the mode of presentation of items should also be considered. In the cited studies that demonstrated the interference effects of DVN on visual memory (Darling et al., 2007, 2009; Dean et al., 2008; Dent, 2010; McConnell & Quinn, 2004a), only in the study of Darling et al. (2009), simultaneous presentation of the items for storage was compared to sequential presentation, but there was no main effect of presentation mode or interaction with the presence of DVN. This result remains controversial because there is evidence in the literature that memory performance depends on the mode of presentation of items (Rudkin, Pearson, & Logie, 2007). We still need to clarify the relationship between sequential presentation of stimuli and interference effects of DVN.

Quinn (2008, 2012) considers that the DVN effects on visual representation can be interpreted with a two storage subcomponents model. The visual cache is considered an episodic store that maintains information that was semantically encoded. One of its functions is to interact with another component, the visual buffer, which has a short-term memory character, maintaining the image in consciousness. This system is accessed directly through perception if the information is being maintained in consciousness, i.e., during encoding and retrieval (Quinn & McConnell, 2006). In these conditions, the stored content is susceptible to external interference, as that caused by DVN. In this model, the DVN effect is determined by the characteristic of the stimulus to be memorized. Complex figures and visual details are less susceptible to encoding in the episodic component (which carries long-term memory contents) and therefore, would be processed by the visual buffer, and thus would suffer external interferences, as those caused by DVN (Darling et al., 2009; Dean et al., 2008; Dent, 2010). Other memory contents, such as the visual patterns (Avons & Sestieri, 2005), could be quickly interpreted and maintained in the episodic memory.

Quinn (2012) suggested that any type of visual information – internally generated in response to a non-visual input, or as a consequence of a visual presentation – will suffer the same kind of interference, if both types of information demand an internal representation to be actively and consciously maintained in the visual buffer. If the information was in such component, it will suffer interference effects from the DVN. This would occur, for instance, when the stimuli to be memorized are complex, with many visual details or of difficult interpretation.

The underlying hypothesis of Quinn's theory is that this component, the visual buffer, is different from the one registering the interpreted percept, the visual cache. In other words, not all the information in the visual working memory is in consciousness. Therefore, the differences of DVN effects on visual image and visual memory may actually represent different processes occurring in different visual memory components (Quinn, 2012; Quinn & McConnell, 2006).

For this reason, the discussion on DVN effects should take into consideration the type of stimulus to be stored, the time in the memory process in which the interference occurred and the mode of presentation of items. Some studies used dynamic visual noise throughout the memory task, from the beginning of encoding until the test (Quinn & McConnell, 1996b); others, only during encoding (Quinn & McConnell, 2006); and others only during the retention interval (Darling et al., 2007, 2009; Dent, 2010). Of these studies, only one dedicated to study the noise interference with items presented sequentially (Darling et al., 2009). Studies that evaluate the effects of noise on the different times of the memory tasks, using the sequential mode of presentation of items, would allow us to identify more precisely the nature of the DVN interference on visual memory. In this sense, the DVN can be an important resource to understand visuo-spatial working memory, and should be better investigated in order to be properly used. It is necessary to identify, for example, in which phase of the memorization process information is more vulnerable to the interfering effects of DVN. Therefore, in this study we evaluated the effect that DVN has on memory when presented during encoding, maintenance (retention interval), or throughout the whole memorization process information presented sequentially.

Method

Participants

Participants were thirty six students of the University of São Paulo, aged between 18 and 40 years (M = 25, SD = 5), with normal or corrected-to-normal vision. They were not paid for participating in the experiment.

Materials and Stimuli

The visual stimuli were letters (21 consonants, 100 x 150 pixels) in 22 different fonts. The stimuli were presented in the center of a 15'' screen with resolution of 1024 x 768 pixels, in black (.92 cd/m^2) over a white background (70 cd/m^2). The screen was approximately 60 cm away from the participants' eyes. The stimuli presentation and recording of responses were made using E-Prime 1.2 software (Schneider, Eschman, & Zuccolotto, 2002).

The DVN, based on studies of Quinn and colleagues (McConnell & Quinn, 2000; Quinn & McConnell, 1996b), consisted of a 50 x 50 array of black and white dots (10 x 10 pixels) presented in the center of the screen. The dots color changed in a rate of 18% per second. The changes from the original version were necessary to suit the technique to the software available for the experiment.

Procedure

The experimental procedure was approved by an ethics committee of the University of São Paulo (Ribeirão Preto; 090/2009-27/11/2009), following the Brazilian laws (*Conselho Nacional de Saúde* [CNS] 196/96). A dual task paradigm was used. In the primary item recognition task (Sternberg, 1969) the participants memorized a sequence of four stimuli presented one by one. After a retention interval, a test stimulus was presented and the participants' task was to decide whether the stimulus was presented in the sequence presented previously. The secondary task consisted in presenting the DVN at specific times of the recognition task. In addition, the participants also performed an articulatory suppression task.

Each trial began with the digits for articulatory suppression presented for 1000 ms. After a 2000 ms interval, the list of stimuli to be memorized was presented. Each stimulus was presented for 500 ms, with a 2000 ms inter-stimulus interval. After a 3500 ms retention interval, the word "test" was presented in the center of the screen for 500 ms, followed by a test-stimulus that remained on the screen until the participant judged whether it was present in the list to be memorized. If it was present in the list, the participant should give a positive response pressing the key 1 on the numerical keyboard. If not, a negative response should be given by pressing the key 2. After responding, the participant should press the spacebar to begin the next trial.

The DVN was presented at three possible times of the recognition task: during encoding, during the retention interval, and throughout the trial. The participants were randomly assigned to these three possible groups. When the DVN was presented during the whole trial it began after the presentation of articulatory suppression digits. The noise remained on the screen for 2000 ms and was then replaced by the first stimulus to be memorized, which was presented for 500 ms. The DVN was then presented in the 2000 ms inter-stimulus interval and also during the 3500 ms retention interval. In the condition where the noise was presented during encoding, its presentation was similar to that of the former condition, but it was interrupted 2000 ms after the presentation of the last stimulus to be memorized. In the condition when the noise was presented just during the retention interval, the DVN began 2000 ms after the last stimulus to be memorized had been presented (Figure 1). In each condition, two block of trials were performed, one with the noise and one without. The order of blocks was counterbalanced among participants. Each block consisted of 2 practice trials and 24 valid trials: 12 negative (test-stimulus was not present in the list of stimuli to be memorized) and 12 positive (test-stimulus was one in the list of stimuli to be memorized). In this case, the serial position of the test-stimulus was equally represented in the 12 trials.

As a form to prevent the rehearsal of the stimuli in verbal terms, the participants performed an articulatory suppression task, repeating a sequence of numbers ("1, 2, 3, 4" or "2, 3, 4, 5"). The suppression was initiated before the presentation of the stimuli to be memorized and lasted until the presentation of the test-stimulus.

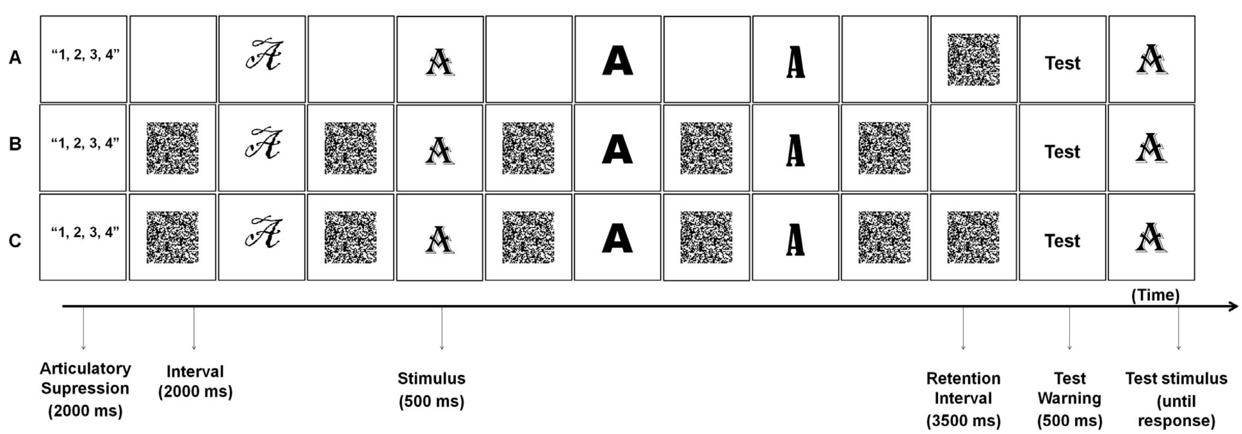

Figure 1 Scheme of the three experimental conditions. A: Dynamic visual noise (DVN) during retention interval; B: DVN during encoding; C: DVN during whole trial.

Results

The correct responses of the item recognition task were submitted to analysis of variance (ANOVA), considering the time of DVN presentation as a between-groups factor (encoding, retention, or whole trial), and the presence of DVN (present and absent) and the type of response (positive and negative responses) as within-participants factors.

Overall, the performance of the retention group was worse (M = 80%, SEM = 7%) than that of the encoding group (M = 87%, SEM = 4%) and the whole trial group (M = 86%, SEM = 5%) [F (2, 33) = 4.18, p = .02, η^2_p = .22].

The presence of DVN had a general effect on the participants' performance (M = 81%, SEM = 6%) causing a 6% impairment in the performance compared to the control condition, without the DVN (M = 87%, SEM = 5%) [F (1, 33) = 13.75, p = .001, η^2_p = .32].

When comparing positive and negative responses, the participants' performance in general was 8% worse in the positive responses (M = 75%, SEM = 6%) compared with negative responses (M = 93%, SEM = 3%) [F (1, 33) = 43.44, p = .001, η^2_p = .56].

An individual analysis of each group was performed considering the factors: presence or absence of DVN and the positive and negative trials. This analysis revealed that DVN had a significant effect on performance when presented during the encoding of the stimuli to be memorized (M = 83%, SEM = 5%), thus producing 8% impairment on memory performance compared to the control condition (M = 91%, SEM = 3%) [F (1, 11) = 11.60, p = .005, η^2_p = .43]. When comparing positive and negative responses, the participants' performance was 9% worse in the positive responses (M = 83%, SEM = 4%) compared with negative responses (M = 92%, SEM = 4%) [F (1, 11) = 9.12, p = .01, η^2_p = .38] (Figure 2).

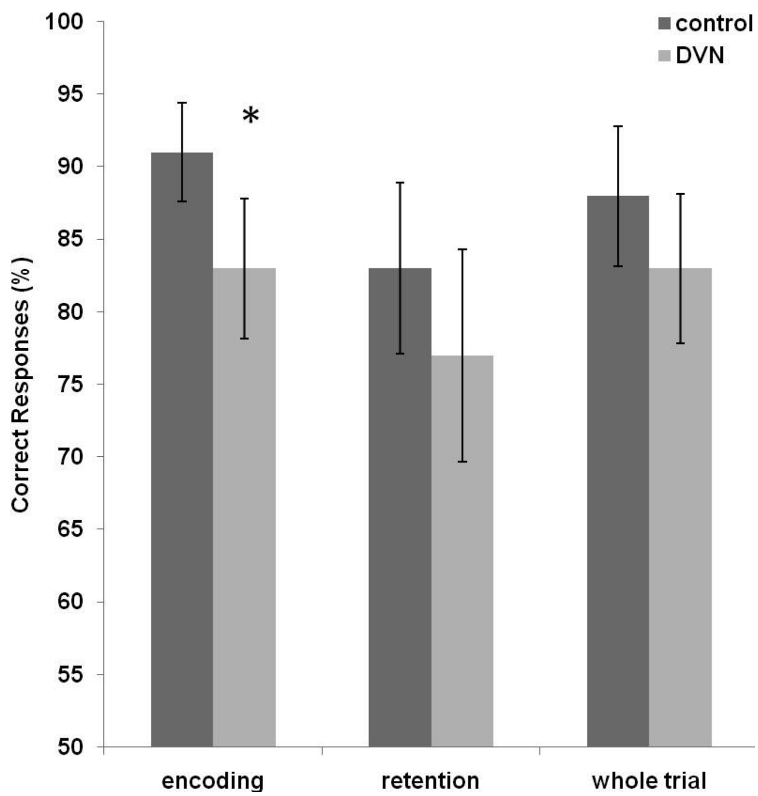

Figure 2 Percentage of participants' correct responses in the three groups (encoding, retention interval, whole trial), in conditions with dynamic visual noise (DVN) and without noise (Control)
*p < .05. Error bars represent standard errors of means.

In the retention interval group, there were no differences between the control (without DVN) and experimental test (with DVN; p = .10). In that condition, there was an effect on the positive and negative responses [F (1, 11) = 16.90, p = .001, η^2_p = .60]. The memory for the positive responses was worse (M = 68%, SEM = 3%) than for the negative responses (M = 92%, SEM = 2%).

In the whole trial group there was no effect of DVN presence (p = .18), but there was an effect of the type of response (positive x negative responses) [F (1, 11) = 19.97, p < .001, η^2_p = .65]. Memory performance for the positive responses was worse (M = 78%, SEM = 3%) than that for the negative responses (M = 95%, SEM = 1%).

It was expected to occur an effect of DVN when presented during the whole trial, similar to the encoding condition. It is possible that the measure adopted for data analysis (rate of correct responses) was not sensitive enough to identify any effect of noise inserted throughout the trial. Andrade and colleagues (2002) did not verify DVN effects on memory for matrices presented sequentially, and so, the authors conducted the analysis of specific effects of DVN in the serial position of memory--test. In the present study, looking for differences that could explain this unexpected result it was performed an analysis, considering the type of trials (DVN during encoding, retention interval and whole trial), the two conditions (absence and presence of DVN), and the serial position in two levels, according to the position of test stimuli in the sequence (first and second positions and third and fourth positions).

The interaction between the presence of DVN and the serial position of test stimulus was confirmed [F (1, 33) = 6.43, p = .01, η^2_p = .20]. The worst performance was verified in the block of trials which DVN was present and the test belong to the last serial positions of the sequence memorized (M = 68%, SEM = 8%).

An individual analysis of each group was performed considering the factors: presence or absence of noise and serial position. This analysis showed an interaction only on encoding group (p = .04), where the recognition of the last stimuli was affected by the DVN (M = 72%, SEM = 4%). On the control condition the recognition of the stimuli was similar for all the serial positions (Figure 3).

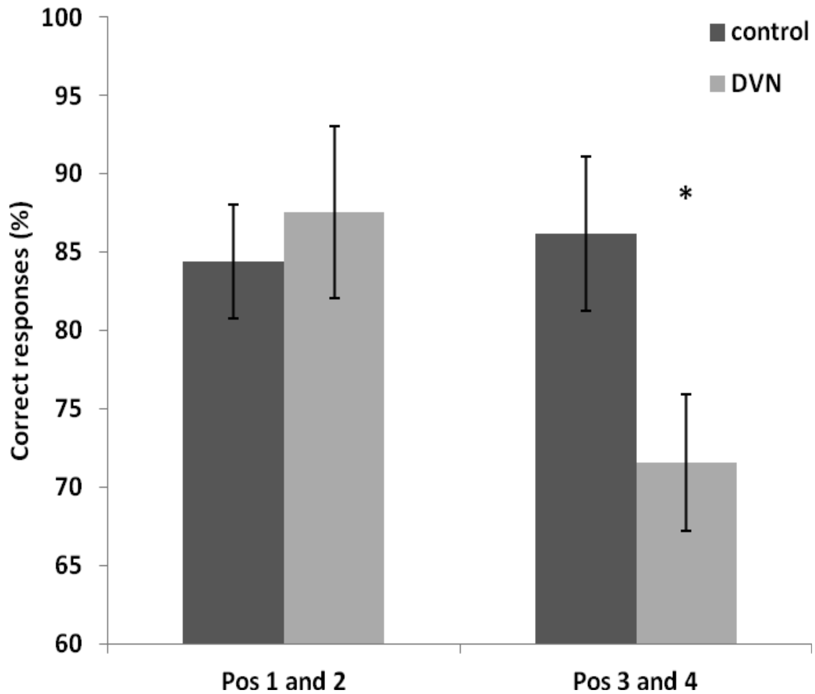

Figure 3 Percentage of participants' correct responses in the condition when the dynamic visual noise (DVN) was present during encoding, according to the serial position of test stimulus
*p < .05. Error bars represent standard errors of means.

Discussion

The objective of this study was to compare the effects of DVN when was presented during information encoding, retention interval, or throughout the recognition task. The data revealed that the noise affects memory, especially when it was presented during the encoding of the stimuli to be memorized. These data are compatible with the statements of Quinn (Quinn, 2012; Quinn & McConnell, 2006) about the interference of DVN on memory when it occurs in the encoding phase. According to the theoretical model proposed by Quinn (2008, 2012), the visual memory is divided in two components of storage, one is the visual buffer, responsible for the short-term retention, and the other one, the visual cache, is described as a episodic memory system, retaining the information encoded semantically. In this model, the visual buffer is the memory component that is capable of storing information and making them available to consciousness, being affected directly by the content of perception. In this way, our results indicate that interference effect occurs because during encoding, the information is available in consciousness, susceptible to external interferences, such as those caused by DVN.

The interference effect of noise on memory observed in this study confirms the hypothesis that visual working memory is accessed through perception, rather than only through the activation of a knowledge previously acquired (Quinn, 2012), as proposed by Logie (1995). These data are corroborated by the results obtained by Dean et al. (2008), who compared the DVN effect on memory for matrices and colored textures. In this study, the DVN affected only the memory for textures, that is, the DVN effect in the visual memory occurs at the level of visual details. This type of information is not easily interpreted or converted into a semantic code, which would eliminate the hypothesis of initial access to long-term memory.

Similar to the first experiment performed in Burin et al. (2007), DVN did not affect memory when presented during information maintenance. During this time there would be an interfering effect only if the content to be memorized and the characteristics of the noise were more complex in perceptual terms, thus forcing the active maintenance of the content in consciousness during maintenance. This supposition would have a direct effect on understanding working memory architecture, as it would be admitted that one same resource was responsible for controlling information processing in working memory. Therefore, the hypothesis of information processing phases could be disregarded (which considers the operation restricted to the initial milliseconds of information processing as short--term or working memory), giving place to the hypothesis that working memory operates based on the interaction of storage subcomponents that process information simultaneously, under the coordination of a supervising system (Baddeley, 2010).

According to Quinn's visual memory model (2008, 2012), it is possible that during the retention interval the information could be already interpreted, i.e., it can be related with the content of long-term memory. Once linked to prior knowledge, the information becomes immune from external interferences caused by perception. Therefore, it is expected that the presence of noise will not affect memory. In his theoretical model, Quinn (2012) suggests that the visual cache subcomponent has the role of interconnecting new content with previous knowledge.

In our study, the stimuli did not have to be maintained in consciousness throughout maintenance. The content may have been maintained by the visual cache, which related the new information with prior knowledge. On the other hand, studies that showed the interference of DVN in maintenance (Darling et al., 2009; McConnell & Quinn, 2004a) used highly complex information, which made interpretation by the cache impossible. In the study by McConnell and Quinn (2004a), for instance, the task was to judge the size of circles, while in the study by Darling et al. (2007, 2009) there was high similarity between the visual patterns presented.

In the present study, the interaction between the presence of noise and the serial position could not be found in a similar previous study (Darling et al., 2009) because of the salience of other stimulus properties that overlapped the serial information. In the study by Darling et al. (2009), the sequential presentation of visual stimuli in different spatial locations may have promoted a hierarchical representation of information, which prioritized the visuo-spatial aspects of the information, making the serial position of the stimuli irrelevant (Parmentier, 2011; Santana & Galera, 2013). On the other hand, in the present study there was no spatial information that could imply a hierarchical representation, thus allowing for the register of visual content according to the serial position of items, thus this group was vulnerable to the interfering effects of noise. Therefore, it is suggested that the analysis of serial position is a good measure to identify the effects of noise on memory, since some standard measurements are not sensitive enough to identify the distortions that noise causes in the storage of information in memory (Kemps & Andrade, 2012).

Considered altogether, the present study results are consistent with the view that DVN is an interference instrument of the visual component of working memory, as suggested by Quinn and McConnell (1996b), proving it is a robust technique to examine the characteristics of that system. We notice that DVN has direct access to the visual system, causing interference only during information encoding. These conclusions can have a direct effect on other studies in this field, which can be supported on safe parameters to use the DVN technique to obtain more precise data about the nature of visual representation in working memory. Further studies could improve the technique, evaluating, for example, the possible variation in the interfering noise effect due to the different manipulations of its characteristics, such as size, and the frequency in point and color changes.

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