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The effect of an induced physiological stress response on reading: an eye tracking study

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Abstract

The perceptual span (PS) is a term used to describe the total visual area from which a person acquires useful information while reading. This area includes the foveal but also part of the parafoveal region. While the foveal input is of high acuity and serves to identify details of the fixated words, the parafoveal one has primarily a preprocessing function. The PS has been shown to be flexible and its size to depend both on the stimulus characteristics (such as text and task properties) and on individual differences. One of the factors that is thought to influence these changes is the systematic shift of attention towards the location of stimuli to be processed before the actual eye movement happens. Attention narrowing is a widely studied phenomenon that shows how stressful events can exert a centralizing effect on attentional resources. Specifically, attention is shifted towards a set of main, central aspects to the task while more peripheral aspects are neglected. Based on this assumption, we conducted a study aiming to investigate whether this effect would also emerge in the case of the PS. Specifically, our hypothesis was that after a stress induction, participants' attention would be shifted towards the foveal region and that less resources would be available for the parafoveal processing, resulting thus in a smaller PS. We obtained an estimate of the PS's changes through the contingent-gaze moving window paradigm, using a small- and a big-window conditions. The stress induction was performed by using a hyperventilation technique. We expected to find an interaction between the arousal state (stress induction vs control) and the window size (4 vs 14 rightwards characters).

We did not obtain the predicted results as from the analysis of the data did not emerge an interaction between arousal level and window condition. However, we found a main effect of the arousal in two of the measures used as dependent variables. After the stress induction indeed, participants showed a lower average fixation duration and a higher

number count of fixation with respect to the control condition. Interestingly, the two effects interpreted together neither reflected an improvement nor a worsening in reading performance in terms of reading speed. A plausible interpretation of these results is provided in the discussion.

1. Introduction

Reading is a peculiar human ability which in time has become essential in everyday life. Starting from a very young age children are introduced to letters and words and in a relatively short amount of time they are able to develop impressive reading skills. However, there are a variety of factors which, during development or later in life, might impair this ability resulting in mild to severe reading difficulties. For this reason, a lot of research has been and is still focusing on the various mechanisms which work in conjunction to allow the reading process to happen. And with the purpose to further expand the knowledge on this matter, in this work I propose a study aiming to elucidate whether and how stress could lead to some deficits in the reading processes.

"Until I feared I would lose it, I never loved to read. One does not love breathing."

(cit. Harper Lee)

1.1. Perceptual span

Reading is a complex process which involves the extraction of visual information, the recognition of the printed letters and the comprehension of what is written. This process relies on the oculomotor system, and specifically on a series of ballistic eye movements called saccades which are separated by fixations. Saccades are short rapid movements that allow the eyes to move along the text that typically last for about 20-50 ms. Fixations are brief stops between the saccades in which the eyes are relatively stationary and it is possible to acquire visual information (Rayner, 1998, 2009). Although being quite variable between readers, the average duration of a fixation is about 200-250 ms (Rayner, 1978b, 1998, 2006, 2009).

The input that is acquired on the retina during fixation can be divided in three main parts: the fovea which is the area surrounding the fixation point, the parafovea, which is the area around the fovea and the peripheral area which is all the information beyond the parafoveal region.

The fovea is responsible for the sharp central vision that permits to clearly see the details of an image and it is therefore fundamental in the reading process: while reading one must move their eyes to place the fovea over the text that has to be processed (Rayner et al., 2014). This region comprises the area of 1° of angle on both the sides of the fixation point which corresponds to about 6-8 letters.

Even though foveal information is the primary source of information acquisition in reading, the spatial area from which meaningful input is collected also includes a part of the parafoveal region (Schotter et al., 2012). The parafovea extends out to about 5° of angle from the fixation point, corresponding to about 14–15 letters and is thought to be involved in the preprocessing of upcoming text.

The total spatial visual area from which useful information is processed during reading is called perceptual span (PS) and it includes both foveal and parafoveal words. Usually, in adult readers of English, the PS covers an area extending from 4 letters leftwards to 15 letters rightwards with respect to the fixation point (McConkie & Rayner, 1975).

The most commonly used method to measure the PS is called the gaze-contingent moving window paradigm (McConkie & Rayner, 1975). In this task, the participants are presented with phrases in which only a virtual window contains visible letters, while the rest of the sentence is masked by chains of letters "Xs". The size of the window varies between conditions and the window itself moves in synchrony with the reader's eye as it moves along the sentence. The detection of the eye's position is possible through the use of an eye-tracking machine. After the experiment, eye movement measures of different window size conditions are compared to those obtained while reading normally (ie. when no window is applied). The basic idea of this paradigm is that the smallest window size allowing normal reading provides an estimate of the PS.

Contrarily to the fovea and the parafovea, the PS has been shown to be quite flexible. Indeed, the size of the PS seems to vary with respect to task difficulty and text properties (such as the presence of a high- vs low-frequency word and the font or the spacing between characters) but also to individual factors (such as reading speed and spelling ability). As this variations mostly happens beyond the foveal region, the flexibility of the PS can be attributed to the different amount of parafoveal information processed across conditions.

1.1.1. Task and text properties

With respect to text properties, it has been shown that factors such as font difficulty and spacing between letters have an influence on the size of the PS. In reading fonts that are difficult to encode usually people tend to present longer fixations, shorter saccades and a higher number of regressions with respect to easier fonts, suggesting a smaller PS (Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006d; Slattery & Rayner, 2009). In a study in which spacing between letters was manipulated, the authors found a significant increase in reading rate when the spacing was reduced by 10% (Rayner, & Bélanger, 2010). Additionally, the PS seems to be affected also by specific properties of the writing system such as the writing direction and visual complexity of an orthography. For instance, from the comparison of Chinese and English reader's performance emerges that the Chinese's saccadic length is much shorter than the English's one. This is coherent with the fact that linguistic information in Chinese words is much more densely packed than in English words. An analogous result emerged in a study comparing Hebrew and English readers (Pollatsek, Bolozky, Well, & Rayner, 1981). Beside the size changes, the PS has been shown to vary also with respect to the direction of its asymmetry, contingently to the specific language-characteristics (Zhou et al., 2021). This topic will be further discussed in a later section.

Task difficulty is another aspect widely documented as a contributing factor of the PS's size. For instance, a study has found that the fixation of low-frequency words is associated with the acquisition of a lower amount of parafoveal information (and therefore a smaller PS) with respect to the condition in which a high-frequency word is fixated (Henderson & Ferreira, 1990; Rayner, 1998). Likewise, words that are more predictable given the previous context in the phrase, are fixated for less time than unpredictable words indicating a lower foveal processing and therefore a larger PS. (Balota, Pollatsek, & Rayner, 1985; Drieghe, Rayner, & Pollatsek, 2005b; Ehrlich & Rayner, 1981).

Oral reading -which is considered to be a more difficult task than silent reading- leads to longer fixation duration, reduction of saccade amplitude, more regressions and more fixations with respect to silent reading, suggesting a smaller PS (Inhoff & Radach, 2014; Laubrock & Kliegl 2015).

Taken together, these results provide strong evidence of the PS's variations as being dependent on the difficulty of encoding. Specifically, a text or a task that are hard to encode -as opposed to easier ones- require a higher amount of resources to process foveal information and consequently less parafoveal pre-processing can occur. Given that parafoveal encoding is what mostly contributes to the PS variations, a lower amount of parafoveal information processed implies also a smaller PS.

1.1.2. Individual factors

Individual factors are increasingly taken into account in research of various domains, as they are thought to account for part of the variance observed in people's performances. Individual reading abilities such as general reading skills emerged to be associated with the PS, such that in general its size is larger in participants with better reading skills than in those with lower reading skills. Rayner et al. (2010) demonstrated that fast readers have a larger PS with respect to slow readers. Indeed, after performing the moving window task, fast readers predictably read faster than slow readers in no-window conditions, but as a masking was introduced (if large enough to cover the perceptual span) the difference between the two groups decreased. Furthermore, the smaller the window of visible letters was, the smaller the difference between the two groups of participants. This suggests that fast-readers´ ability to read faster than slow-readers might be -at least partially- related to their larger PS with respect to slow-readers (Rayner, Slattery & Bélanger, 2010). It is important to take into account that a better performance in terms of reading speed does not necessarily imply an efficient reading (Prefetti, 2007). Fast readers could be indeed adopting a strategy favoring the speed of reading to the comprehension threshold. Supporting this hypothesis, the results of a study have shown that faster readers did not produce better summaries of a text than slower readers (Hyönä, Lorch, and Kaakinen's, 2002).

In the field of developmental psychology, recent research demonstrated that children -who's reading abilities are still under development- present a much smaller PS with respect to the adults' one (Yan et al., 2021). Two experiments demonstrated that older readers have a smaller and a more symmetric PS than younger readers (Rayner, Castelanho and Yang, 2009a). The presence of these two characteristics in older adults might be the consequence of their slower processing of foveal information and their less efficient processing of parafoveal information (Ball et al., 1988; Sekuler, Bennett & Mamelak 2000). In some experiments indeed, slow reading -as in the case of beginning or dyslexic readers (Rayner, Murphy, Henderson,& Pollatsek, 1989)- and difficulty in encoding the fixated words emerged to be key factors associated with smaller PS (Henderson & Ferreira, 1990; Rayner, 1986; White, Rayner, & Liversedge, 2005) The authors propose that this might lead older adults to adopt more risky, contextually guided strategies while reading. Specifically, in order to compensate for their slowed reading performance, they would skip more words, resulting in them making longer saccades (Laubrock, Kliegel &Engber, 2006; Rayner et al., 2006) but would also present more regressions (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007; Kliegl et al., 2004; Rayner et al., 2006). Furthermore, given the lowered effectiveness of rightward processing, older readers would need more information available to the left of the fixation point.

Research on the effect of individual differences on the PS size is not limited to the distinction between poor and skilled readers. In a study, the authors proposed that also within skilled readers the PS might differ as a consequence of individual factors (Veldre & Andrews, 2014). Specifically, they were interested in understanding whether and how differences in lexical quality (defined as the precision, the coherence and the redundancy of a lexical representation) among skilled readers modulate the extraction of parafoveal processing. As an index of the lexical quality, the authors used orthographic precision, which refers to the specificity and the completeness of the representation of a word's letters identity and order. Orthographic precision was assessed by measuring both reading comprehension and spelling ability (Andrews & Lo, 2012). The results demonstrated that participants with higher lexical quality presented a larger PS, supporting the idea that also within people that -on the base of their reading comprehension and spelling ability- are considered to be skilled readers, individual differences modulate the proportion of foveal and parafoveal processing.

1.1.3. Asymmetry of the perceptual span

As previously stated, usually in adult readers of English the PS extends from 4 letters leftwards to 15 letters rightwards with respect to the fixation point. The PS is therefore normally not centered but shifted towards the right (when native language is written from left to right), and while the left side includes only foveal information, the right one extends also to the parafovea. As McConkie and Rayner (1976) demonstrated, this asymmetry is reflected in the slower reading performance of the participants in the moving window task when presented with a window shifted towards the left as opposed to when the window is shifted towards the right. Unsurprisingly, for readers of languages written from right to left, such as Arabic (Jordan et al., 2014) and Hebrew (Pollatsek et al., 1981) the direction of the asymmetry is reversed. This can be explained by the fact that parafoveal processing allows the reader to preprocess upcoming words found in the reading direction side and therefore to facilitate the whole reading process. Further support to this hypothesis is given by experiments on bilinguals readers of English and languages read from right-to-left, which demonstrate a change in the asymmetry direction of the PS within the same participant as a function of the language presented (Pollatsek et al., 1981; Paterson et al., 2014; Jordan et al., 2014).

1.1.4. Perceptual span and attention

A key factor that has been proposed as central in influencing the changes in size and position of the PS is attention (Miellet, O'Donnell & Sereno, 2009). The amount of parafoveal information utilized in the PS is indeed thought to depend on attentional mechanisms, which are closely related both, to text and task demands and to individual differences (Leung, Sugiura, Abe, & Yoshikawa, 2014). For instance, the fixation on a difficult word (such as a low-frequency word) with respect to an easier one, would impose a greater processing load on the fovea resulting in a decrease in attention on the parafoveal region, and therefore a smaller PS. In this perspective, attention may also be responsible for the different PS's asymmetry direction in left-to-right and right-to-left languages. In both the cases indeed, the asymmetry of the span would reflect the shift in attention to upcoming words (Kliegl et al., 2011). With respect to individual factors, Leung et al. (2014) propose that slower or less skilled readers apply more attentional resources to fixated words in the fovea compared to faster or skilled readers, resulting in a reduced attention for parafoveal processing and therefore a smaller PS.

Rather than being a purely perceptual process as its name suggests, the PS seems hence to be highly influenced by top-down cognitive factors and to reflect functional demands of reading in addition to letter recognition (Frey & Bosse, 2018). Further evidence supporting this idea is given by an experiment aiming to directly investigate attentional mechanisms underlying the PS by compensating for visual acuity loss in parafoveal vision (Miellet, O'Donnel & Sereno, 2009). In order to study this hypothesis, the authors used a variation of the moving window paradigm called 'parafoveal magnification', in which the letters increased in size following an eccentric trend, allowing to compensate for parafoveal vision acuity loss. The results demonstrated that in the parafoveal magnification condition there was not an increase in the amount of text processed, suggesting that rather than depending on visual acuity, the amount of information that can be obtained in each fixation in reading is determined by attentional mechanisms.

1.2. Stress, arousal and hyperventilation

When our body perceives a threatening situation (stressor) it automatically responds with a series of physiological and psychological reactions. A stressor can be considered as a stimulus that disrupts the body homeostasis and therefore a stress response is the set of changes that aim to re-establish the normal balance. These changes occur at the psychological (emotional and cognitive), behavioral (fight-or-flight) and biological (autonomic and neuroendocrine alteration) levels (Bali & Jaggi, 2015). The two body systems mainly involved are the sympathetic nervous system and the Hypothalamic-Pituitary-Adrenal (HPA) axis. The activation of the sympathetic nervous system leads to the mobilization of the body's resources towards what is perceived as a threat and involves an increase in heart rate, blood pressure, pupil size and breathing rate. This sequence of changes has an adaptive connotation since it prepares the body either to appropriately face the stressor or to promptly avoid it (fight-or-flight response).

The Hypothalamic Pituitary Adrenal (HPA) axis is a neuroendocrine system which controls reactions to stress by regulating the release of the Corticotrophin Releasing Hormone (CRH). CRH acts at the level of the anterior pituitary gland by controlling the secretion of the Adrenocorticotropic hormone (ACTH) which in turn facilitates the release of corticoids (Dushyant, 2018). Corticoids, and specifically glucocorticoids are fundamental factors in the stress response since they release the energy necessary to cope with the effects of stressors. Besides the CRH controlled by the HPA axis, other hormones such as the Growth Hormone (GH) and thyroid hormones play a significant role in stress.

A stressor can be either physical, which has a direct effect on the body by inducing metabolic and physiological changes, or psychological, in which case there is an activation of the brain centers without having any direct effect on the body (Bali & Jaggi, 2015). Psychological stressors can be cognitive, such as in the case of work pressure or hard vs no choices, and emotional as in the case of fear and anxiety or other threat-producing feelings. Physical stressors can be environmental, including for instance cold/hot temperatures, hypoxia and noise, and physiological, such as dehydration, malnutrition or illness.

While research has largely focused on psychological stressors, which require the interpretation of a situation to initiate a stress response, not many studies have been done on environmental and physiological stressors. Physical stressors are part of everyday life and as such, the understanding of their effects on cognition is not secondary to psychological stressors. Mild hypoxia (oxygen deprivation) for instance, is a physical stressor commonly faced by mountain climbers, skydivers and aircrew members characterized by the disruption of the respiratory homeostasis. As opposed to the psychological ones, this stressor does not require the involvement of higher-order cognitive processes and since it does not usually reach awareness, there is no acquaintance of coping strategies (Pighin, Bonini, Hadjichristidis, Schena, &, Savadori, 2020).

A mild form of hypoxia can also occur as a consequence of hyperventilation. The term hyperventilation refers to the state in which a person abnormally breathes very fast. When breathing, there is usually a balance between the exchange of oxygen and carbon dioxide. During hyperventilation the rate of removal of carbon dioxide from the blood is increased resulting in a decreased CO_2 pressure in the blood. This condition is called hypocapnia and it is associated with a series of secondary physiological changes and subjective symptoms. First, it induces respiratory alkalosis which is a condition characterized by a disturbance in the blood PH's balance that increases the neurons' excitability and causes symptoms such as muscle spasms and tingling sensations in the hands. Second, it affects cardiac activity (Gardner, 1996), resulting in cardiac symptoms such as irregular rapid heartbeat and hot flushes. Third, it produces cerebral vasoconstriction, which gives rise to cerebral hypoxia (Bisgard & Neubauer, 1995). Cerebral hypoxia refers to the situation in which there is a lack of oxygen in the brain that -if severe or prolonged- could lead to neuronal tissue damage and consequently to cognitive impairment. Hypoxia can be considered as a potent stressful stimulus and as such it is involved in hormonal release of HGH and ACTH (Sutton, 1977).

The idea that more generally hyperventilation could act as a stressful stimulus is supported by a study investigating hormonal responses to breathing exercises (Djarova et al., 1987). After hyperventilation indeed, besides showing a predictable reduction of arterial CO_2, the participants presented an increase in HGH and in cortisol. This hormonal response is analogous to the one found in stress response and can be interpreted as an expression of the respiratory stress reaction induced by hyperventilation. No studies have examined yet the potential hormonal response to hypocapnia alone. However, given that it is the main factor leading to the typical symptoms following hyperventilation, and that as in the case of hypoxia it disrupts the respiratory homeostasis, it is not to be excluded that hypocapnia itself could act as a physical stressor. As the combined effect of different stressors seems to increase the stress response (Lloyd et al., 2016; Girard & Racinais, 2014), there is reason to think that the hypoxic and hypercapnic states typically associated with hyperventilation, might conjunctively increase the following stress response .

Although the terms stress and arousal are often used as synonyms, they have different meanings. While stress -as previously mentioned- can be defined as a threat to the body homeostasis, arousal refers to the general state of readiness of an individual to process sensory information and to organize a response, that can occur even without a specific stimulus (Posner & Rothbart, 1986). However the two concepts are inextricably linked, as usually a stressful situation is correlated with an increased arousal. Given that hyperventilation is generally associated with activating effects analogous to those of an increased arousal, in this study I will sometimes use the two terms interchangeably, meaning the general activation and awakeness following hyperventilation.

1.3. Stress and cognition

The effect of stress on cognitive functioning has been widely studied in a range of different disciplines, going from animal studies to human perceptual psychology (Mendl, 1999). The close interaction between stress and cognition reflects its adaptive power throughout evolution and is supported by the overlap in their respective neurobiological systems (Sandi, 2013). Indeed, both the sympathetic nervous system and the HPA axis, besides being activated in response to stressors, also play a central role in information processing. In contrast to the common belief, stress does not always have a negative impact on cognitive functioning. In 1908, Yerkes and Dodson proposed the Inverted-U function Theory stating that the best performance in cognitive tasks is reached when there is an optimal level of arousal, above or below which, performance decreases (Yerkes & Dodson, 1908). The Yerkes-Dodson Law has been widely criticized due to methodological problems in the original study and incongruent results in following research. Indeed, while some studies did replicate Yerkes and Donsons' findings in cats (Dodson, 1915), rats (Broadhurts, 1957) and people, many others failed to find comparable results (Christianson, 1992; Strokes & Kite, 1994). Nowadays rather than for the Law itself, the two researchers are given credit for coming up with the idea of a unitary theory for the relationship between arousal and performance. However, as Broadbent (1963) argued, since there are different sources of stress and not all the stressors lead to the same effects, there might not be a single mechanism mediating stress reaction. His research indeed showed that while noise and heat stressors affected the accuracy but not the speed of the participants's performance, the opposite results emerged in the case of sleep deprivation. Even so, in later works his view seems to have converged to the theories supporting a linear trend, where an increasing arousal level would be related to a progressively lower performance (Broadbent & Broadbent, 1988). This idea has found empirical support in the results of various studies (Giesbrecht et al., 1993; Lovallo, 1997) but as Sullivan and Bhagat (1992) highlight in their literature review, evidence from different studies on the relationship between stress and cognitive performance fit with a number different models, including the inverted U-like curve, the non-inverted U curve, different linear patterns and even straight lines indicating absence of relationship. Many researchers attempted to disentangle the mechanisms involved in the stress-performance relationship by proposing a variety of theories aiming to give a meaning to the empirical findings. New factors such as emotions (Lazarus, 1991; Stokes and Kite, 2001; Stemmler, Heldmann, Pauls, & Scherer 2001), motivational drives (Welford, 1973; Lovallo, 1997; Matthews, 2001), cognitive resources (Kahneman, 1973; Szalma & Hancock, 2002) and workload (Gopher & Donchin, 1986; Hancock & Desmond 2001) have been introduced in different models with the purpose of finding a more complete and generalizable explanations of the processes underpinning performances under stress. However, up to now no unitary interpretation has been found and rather than searching for a general, universal explanation, studies are mostly focusing on how the different manifestations of stress and arousal affect performance in specific cognitive tasks.

Currently, researchers investigating the relationship between stress and cognitive functions are taking into account a broad range of additional factors which are likely involved. The main components of this complex interaction are the duration of the stress exposition (acute or chronic), the type and the intensity of a stressor, the task's characteristics and individual differences.

Even though acute stress - taken alone- can be considered as an adaptive response to an experienced threat, if the exposure to acute stressors is prolonged or repeated, it can lead to a series of chronical negative consequences on a physiological, psychological and physical level. Furthermore, individuals with a chronic stress background seem to be affected differently by acute stressors from those who do not (Radenbach, 2014)

As already mentioned, different acute stressors exert different effects on cognitive performance (Broadbent, 1963; 1971). A recent study conducted on rats demonstrated that also chronic stress varies in terms of behavioral and physiological outcomes when the source of stress is psychological vs. when it is physical (Mousavi et al., 2019). The results indeed showed that prolonged exposure to psychological stress in adolescent age resulted in a larger set of behavioral and physiological changes with respect to exposure to physical stress.

Cognitive performance under stressful situations has been also shown to vary with respect to the difficulty of a task. A literature review examining a series of studies conducted on military personnel, aimed to elucidate how the exposure to different environmental types of stressors (such as heat, cold and altitude) influences cognition (Martin, 2019). Generally, participants' performance seems to be related to both, the level of stress exposure and to the task complexity. While in lower severity or shorter duration heat and cold stress conditions only complex tasks performance (such as executive function tasks) was impaired, an increase of the heat stress severity or duration resulted in an impairment also of the simpler tasks (such as choice reaction time tasks). Oei et al. (2006) conducted a study which provided further evidence of the task complexity as being a moderator in the stress-performance relationship. The results indeed showed that psychosocial stress impaired working memory performance but only when tasks were highly demanding. Similar outcome was found also in a study investigating the differential effects of stress in the two digit span subtests: after the stress induction the performance was impaired in the more demanding backwards task but not in the forward one (Schoofs, Wolf & Smeets, 2009).

Lastly, individual differences have been shown to play a crucial role in the complex stress and cognitive interaction. Factors such as gender (Baran et al., 2009), personality traits (Sandi & Richter-Levin,2009) and age (Fenoglio, Brunson & Baram, 2006) contribute to the variability in the performance outcomes and to individuals' capabilities when exposed to a particular stress condition (Sandi, 2013). For instance, individuals with low-anxiety traits seem to be less prone to the negative effects on cognition of acute stressors than high-trait anxious individuals (Wofford, Goodwin, & Daly 1999, Staal, 2003).

Considering that all these variables are likely involved in the relationship between stress and cognitive functions, the reason for research being still far from reaching a convergence between models appears clearer.

1.3.1. Stress and attention

As explained in the previous paragraph, the effect of stressors on cognitive performance across tasks is multifaceted and not always easily interpretable. A particularly interesting cognitive domain in this context is attention. Attentional mechanisms indeed are strictly related to other cognitive processes and as such they have been shown to affect the performance in various cognitive tasks. Generally, under stress, attention appears to narrow, resulting in a centralization of the focus on the main task and consequently a reduced focus on peripheral information (Easterbrook, 1959). The main task can either be the stimulus (or the stimuli) subjectively perceived as the most important or the one unconsciously perceived as the most salient. Given that depending on the specific task or situation, central aspects might be more or less important, this tunneling effect on attention can either lead to a better or to a worse performance (Staal, 2003). Indeed, if the peripheral cues are irrelevant to the task, a narrowing of attention to the main components of the stimuli is going to be beneficial to the performance while the opposite is true if peripheral cues are important to the task completion.

The attention tunneling hypothesis has been mostly applied to psychological types of stressors, but empirical evidence supports congruent effects also in the case physiological stress is experienced (Broadbent, 1978; Houston, 1969).

For instance, research on thermal stressors documented that participants exposed to cold stimuli tended to judge objects as larger than matched control (Callaway & Dembo, 1958). The authors explained this effect by addressing the idea of the tunneling hypothesis: since size judgments usually require the incorporation of peripheral contextual cues, the estimation of a larger object's size in stressful conditions can be attributed to the deviation of the attention towards the central object, and the neglect of peripheral cues. Analogous effects were found also in the case of noise stressors. Various studies indeed demonstrated that when a loud noise was played, performance in a Stroop task (Stroop, 1935) improved, suggesting that stress led the focus to centralize on the main task while limiting the attention directed to peripheral cues resulting in a reduced interference effect from the task-irrelevant stimuli (Houston 1969; Chajut & Algom, 2003; Ballard, 2001). Further support to this hypothesis is given by the results of another study, which documented that participants exposed to noise showed a lowered performance when asked to recall peripheral words that were not central to the task (O'Malley & Poplawsky, 1971) .

However, not all the experiments have reported a significant effect of noise stressors on attention. From an exhaustive literature review (Wright et al., 2014) emerges that noise stress seems to affect performance only when the tasks are complex and high-demanding. The reason for it could be attributed to the so-called attention-depletion hypothesis, which states that when stress is low individuals have more available attentional resources compared to high-stress conditions. This predicts a negative relationship between the level of stress and cognitive performance but only when the task is highly attention-demanding. When the task is low-demanding indeed, the reduced level of available attentional resources consequent to stress does not affect task performance.

This is in line with the previously stated idea of stress effects on cognition as not being univoque in their expression but rather to depend on a variety of secondary factors. An additional example supporting this statement comes from experiments investigating if and how anxiety trait levels might modulate the relationship between stress and attention.

1.3.2. Hyperventilation and cognitive functions

Very little research has been conducted on the effects of hyperventilation on cognitive functions and the results obtained are controversial. Van Diest et al., (2000) conducted a research aiming to study whether hypocapnia following hyperventilation affects attentional mechanisms.

In order to investigate if any possible effect was specifically related to hypocapnia, the researchers used an apparatus to control the CO_2 level administered to the participants during hyperventilation which allowed differentiating between a normocapnic and a hypocapnic condition. The participants performed a numerical Stroop task comprehending two subtasks characterized by different attentional consuming levels: an easy number-naming task and a more difficult size-counting task. In general, participants performed poorer in hypocapnic than normocapnic conditions, presenting a higher error rate but no difference in RT's in both the tasks. However, a post-hoc analysis separating the results of participants who presented spontaneous apneas following hypocapnia with those who did not, revealed that this effect was significant only in the first subgroup. Furthermore, with respect to the normocapnic condition, after hypocapnia the apneic subgroup showed longer RT but only in the attentional-demanding task. The authors suggest that being a consequence of apnea, central hypoxia -rather than hypocapnia- might be the main cause leading to attentional deficits. Friend, Balanos and Lucas (2019) however, in a recent study demonstrated that hypocapnia and hypoxia following hyperventilation exert independent effects on cognitive functions. By controlling the oxygen and CO_2 pressure levels indeed, the researchers were able to recreate a condition in which the state of hypocapnia was isolated from the hypoxia (normoxia) and compare it to the normal hypoxia-induced hyperventilation condition. The results demonstrated that both during normoxic and hypoxic hypocapnia exposure, the participants' performance was impaired in a single reaction and in a five reaction task but not in a spatial working memory task. An experiment investigating the ability to discriminate speech found a decrease in performance during hyperventilation (Whitehead et al., 1977). The reduction of alveolar CO_2 such as in the case of hyperventilation has been shown to impair also the ability to rehearse and recall information (Marangoni & Hurford, 1990).

Based on these results, hyperventilation generally seems to have adverse effects on cognitive function. However, given that the performance was not impaired in all the cognitive tasks and that only a very little number of studies has been conducted on the subject, the mechanisms underlying the hyperventilation-induced stress and its effects on cognition are still far from being understood.

1.4. The current study

As previously described, the perceptual span changes are thought to depend on attentional constraints: as the attentional resources of a person are limited, if more attention is required to process foveal information, there is going to be a decrease in the amount of resources available for parafoveal processing, resulting in a smaller PS. Several studies have demonstrated that stress has a narrowing effect on attention, which consists in a restriction of attention to a small set of information, and the potential neglect of other information. There is therefore reason to think that stress might also affect the PS. Although the effects of stressors on cognitive functions have been widely investigated, no studies have yet specifically focused on the effects of stress on the perceptual span.

For this reason we decided to conduct an experiment aiming to study this phenomenon. The estimate of the PS in the different conditions was obtained from the moving window task's results and the stress induction occurred through a hyperventilation exercise. We decided to use this technique because being a physical type of stressor, it allows focusing purely on the physiological effects of stress and to reduce the possible emergence of emotional responses which often come into play when stress is elicited in a psycho-social context. Given that stress has been often shown to have a narrowing effect on attention, our prediction was that after the stress induction, participants' attentional resources would be shifted towards the foveal region resulting thus in a smaller PS. Therefore, we expected that with respect to the control condition, after hyperventilation participants would present a lower difference in reading speed between the small-window and the big-window conditions. In other words, we predicted a slower reading performance in high-arousal state than in low-arousal state but only in big-window conditions. Since in small-windows conditions the perceptual span is already restricted by nature of the stimulus, we did not expect differences between the two arousal conditions.

However, given that the effect of stress varies with respect to a number of different factors such as the type and the intensity of the stressor, and that the few studies on hyperventilation have shown controversial results, we did not exclude the possibility that also other factors of the reading process, independent from the PS would be affected by the stressor. For instance, as stress has been shown to impair reading comprehension (Gheewalla, McClelland & Furnham, 2020), we hypothesized that independently from the window conditions, the stress-induction might lead to a general decrease in reading performance. Difficulty in comprehension indeed are usually associated with longer fixations and a higher number of regressions resulting in an overall slowing in reading speed.

2. Methods

2.1. Participants

Fourteen female (mean age 22.1 ± 6.1 years) and eight male (mean age 24.5 ± 7.1 years) participants took part in the experiment. All the participants completed at least the high-school education, had normal or corrected-to normal eyesight, and were Spanish native speakers. Some of the subjects were students of the psychology course in the University of La Laguna and their participation was rewarded with extra university credits, while others were given 10 euro as a contribution for taking part of the study. All the participants signed a written consent before carrying out the experiment. For safety purposes, subjects with history of epilepsy, panic attacks or asthma were excluded from the study.

2.2. Study design

For the study we used a 2 (Arousal: high vs low) x 2 (Window: large vs small) design. The experiment involved two blocks for each arousal condition, for a total of four blocks. All the participants were assessed repeatedly in the high and the low arousal conditions. Half of the participants started the experiment by performing the hyperventilation while the other half began with the control condition. The dependent variables we measured were the reading rate, the average fixation duration, the average saccadic length and the count of fixation.

2.3. Materials

2.3.1. Stress induction

In order to generate a physiological stress response in the participants we used a breathing technique which has been shown as effective in terms of inducing hyperventilation (Diest et al, 2000). The subjects were presented with the following instructions:

a) breathe at a faster rate than usual during the next 30 breaths trying to inhale with the nose and exhale both with the nose and the mouth at the same time;

b) when you reach the last respiration, exhale and hold your breath for as much as you can;

c) inhale deeply and hold your breath for 10 more seconds.

The whole cycle was repeated twice in a row.

In the control condition, the subjects were asked to breathe slower than their normal breathing rate and to try for the exhalations to be longer than the inhalations. The change of ratio between breathing in and breathing out, and specifically the increase of exhalation length is a technique used in different breathing approaches in order to reduce stress (Bergland, 2019). We suggested to the participants to close their eyes and try to relax while performing the exercise. This phase lasted for about 4 minutes, timed by the experimenter. The duration has been chosen in order to approximately match the time taken to perform the hyperventilation task.

2.3.2. Perceptual Span Task

For the Perceptual Span Task we used a total of 192 sentences provided by the university of La Laguna. The phrases were all in Spanish. Some examples are “El pescador sale cada mañana a pescar en su barca de madera” (*The fisherman goes out* *every morning to fish in his wooden boat*)·and "El universo está lleno de planetas que aún no han sido descubiertos" (*The universe is full of planets that have not yet been discovered*). ·

The size of the sentences was controlled in terms of mean and maximum number of characters (spaces included) per phrase and average number of words: $M_{characters}$= 68.63, $sd_{characters}$= 7.43, $Max_{characters}$= 83 ; M_{words}=12.54, sd_{words}= 1.80. Half of the phrases were presented for the stress condition and the other half for the control condition in a random way between the participants. The sentences were used in the contingent-gaze moving window paradigm (McConkie & Rayner, 1975): each phrase was shown as partially masked by letters 'X' except for a virtual window of visible letters. The window size varied across two conditions: while the leftward window (with respect to the fixation point) was kept constant at 4 characters, the rightward had a size of 4 in the "small window" condition, and 15 in the "big window" condition (Figure 1). The window moved synchronously in time to the fixation point of the subjects, which was possible to detect through the eye tracker camera. Some short comprehension questions referring to the preceding sentence were shown after the 25% of the phrases. Participants had to reply 'yes' or 'no' by pressing respectively the 'm' or 'x' button on the keyboard.

stimulus phrase

```
el pescador sale cada mañana a pescar en su barca de madera
```

small window *(4 characters leftwards and 4 rightwards)*

```
xx xxxxxxxx xxxe cada mxxxxx x xxxxxx xx xx xxxxx xx xxxxxx
                   *

xx xxxxxxxx xxxx xxxx mañana x xxxxxx xx xx xxxxx xx xxxxxx
                         *
```

big window *(4 characters leftwards and 15 rightwards)*

```
xx xxxxxxxx xxxe cada mañana a pesxxx xx xx xxxxx xx xxxxxx
                   *

xx xxxxxxxx xxxx xxxx mañana a pescar en xx xxxxx xx xxxxxx
                         *
```

Figure 1. An example of a sentence as presented in the small and the big window conditions of the moving window task. The asterisk indicates the fixation point at a specific moment in time.

2.3.3. SAM (the self assessment Manikin)

The SAM is a self-report non-verbal measure which assesses arousal and emotional response (Bradley & Land, 1994). Participants are asked to rate on a 9-point scale, their valence (from 1- ‘very sad’ to 9- ‘very happy’) and their arousal (from 1- ‘very calm’ to 9- ‘very active) with 5 being neutral in both the conditions (Figure 2). The scale was used with the purpose to examine the participants’ arousal and valence levels right after each breathing exercise. We chose this scale because it is quick to complete, which in our experiment was a fundamental requirement. Indeed, as it was administered before the moving-window task, we wanted to minimize as possible the time between the arousal induction and the task initiation.

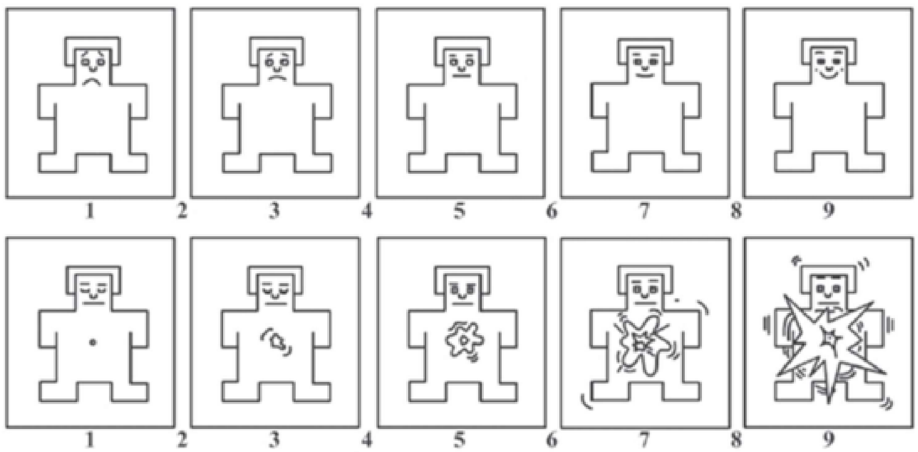

Figure 2. The Self Assessment Manikin (Bradley & Land, 1994). The top row represents valence while the bottom row represents arousal.

2.4. Apparatus

Eye movements were recorded at a rate of 1000 Hz via an EyeLink CL SR Research Ltd. eye tracker with a 10 arcmin resolution and a 1 ms sampling rate. The stimuli were presented on an LCD screen monitor of Eizo (1024×768 px) with a refresh rate of 120 Hz linked to an eye tracking system EyeLink CL Version 4.21 SR Research Ltd, Mississauga, Ontario, Canada. A chin and rest were used to minimize head movements. A regular keyboard was placed at a comfortably reachable distance to the participant. Vision was binocular but eye movements were recorded mostly from the right eye.

2.5. Procedure

2.5.1. Preparation phase

The participants were firstly instructed with the procedure of the experiment and asked to read and sign the informed consent. They were asked about their age and gender and it was made sure they did not present medical conditions for which a fast breathing rate could be unsafe. They were seated in an adjustable chair in front of a monitor and asked to place their head on a chin and head rest situated at 60 cm from the screen in order to minimize head movements. The eye-tracking camera was positioned in a way not to obstruct the participants' view to the monitor, pointing towards the eyes of the subjects. A keyboard was placed at an easily reaching distance from the participant. Before starting a practice session, the experimenter performed the calibration of the subject's eye consisting of 9 points in a squared grid shape sequentially appearing in a random order on the screen. The calibration was followed by a validation sequence with the same 9 dot square grid. Once the calibration and validation procedures were successfully completed, the participants started the practice session in order to familiarize with the gaze-contingent moving window technique. To start they had to fixate a point placed in the left side of the screen at the level of the midline and press "space". A sentence masked by letters "X" appeared on the screen and the participants were told to silently read it and to press "space" as they finished, in order to pass to the next one. This phase consisted of five sentences which were not used during the actual PS task.

2.5.2. Breathing manipulation

Before starting the PS task, half of the participants performed the hyperventilation exercise. After completing this phase they were given a paper sheet with the two scales of the SAM and asked to indicate their levels of valence and arousal in that moment. Afterwards they started the PS task. At the end of the first block, the task stopped and the breathing exercise was repeated before continuing with the second half of the high arousal-condition sentences. This was done in order to reinforce the potential effect of the hyperventilation. The second part of the experiment was structured in the same way but instead of the hyperventilation, the subjects carried out the long-exhalation breathing technique. The other half of the participants performed the two breathing exercises in the reverse order.

2.5.3. PS task

Right after the breathing exercise, we performed the calibration and the validation procedure and started the PS task. When the participants completed the first block, the breathing exercise and the calibration were repeated before starting the second block. Then the same procedure was performed for the other breathing technique. Each block in total was formed of 48 sentences and thus, for each arousal condition a total of 96 sentences was presented.

3. Results

Our main purpose was to understand whether the physiological stress response induced by the hyperventilation had an effect on the perceptual span of the participants. In order to test for changes in the PS, we compared reading performance differences between small and big window conditions in high and low arousal states. Reading performance was assessed with respect to four main dependent variables commonly used in moving window experiments: words per minute (wpm), average fixation duration, average saccade amplitude and number of fixations. Furthermore, we calculated the pupil size at the beginning and at the end of each block and used it as an indirect measure of the physiological arousal.

To analyze the effects of stress and window size over reading we conducted a 2 (Arousal: Stress vs Control) X 2 (Window: large vs small) ANOVA for each of the previously mentioned dependent variables.

3.1. Reading Rate (wpm)

The reading rate was calculated by measuring the time in minutes taken by each participant to read a sentence and dividing it by the number of words present in the phrase. From the analysis emerged a main effect of the window size, $F(1,3287) = 516.7$, $p<0.0001$, with subjects' reading rate being much higher in big-window than in small-window conditions. This result replicates the ones widely found in literature about the moving window paradigm. Surprisingly, no significant main effect of the stress induction nor of a possible interaction between arousal and window size has been found for the reading rate measure.

3.2. Average Fixation Duration

The fixation duration refers to the time in which the eyes rest on a certain object and therefore it can be considered as an approximation of the time for visual information to be encoded. Given that the harder the task, the more a subject is expected to fixate on a word, we predicted a higher average fixation duration in small-window conditions than in large-window ones. The results, as expected, showed a main effect of the window size, $F(1,3278) = 24.95$, $p<0.0001$, with the fixation duration being on average higher for the small-window than for the big-window condition. We also found a main effect of the arousal, $F(1,3251) = 10.45$, $p<0.002$, with the average fixation duration being longer for the control rather than for the stress condition (Figure 3). This suggests that in stressful conditions, people fixate for a shorter time and therefore tend to read faster than when no stress is induced.

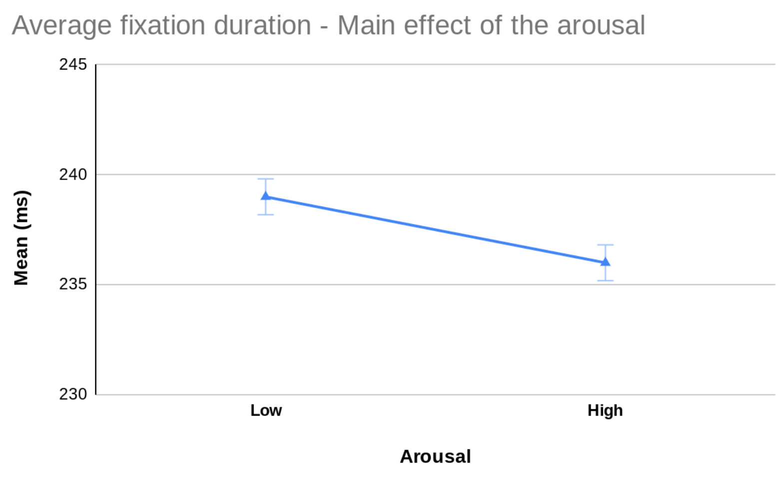

Figure 3. Main effect of Arousal state on the average fixation duration

3.3. Average Saccade Amplitude

The average saccade amplitude refers to the average size of the rapid movement the eyes compute between fixations in order to place the fovea to successive words. The larger the saccade is, the faster one is reading a string of words. The results have shown a main effect of the window size, F(1, 3450)=819.92, p<0.0001, with larger saccades in the big window rather than the small window condition. No effect of the stress induction has been found.

3.4. Fixation Count

Fixation count is the number of times one fixates while reading a sentence. Predictably, the results showed a main effect of the window size, F (1, 3397) = 580.79, p<0.0001 with small window condition being characterized by a higher amount of fixations than big window condition. We also found a main effect of the stress induction, F(1, 3394) = 16.02, p<0.0001, which surprisingly goes in the opposite direction of the result found in the average fixation duration (Figure 4). Indeed, in the stress condition there is a significantly higher number of fixations with respect to the control condition.

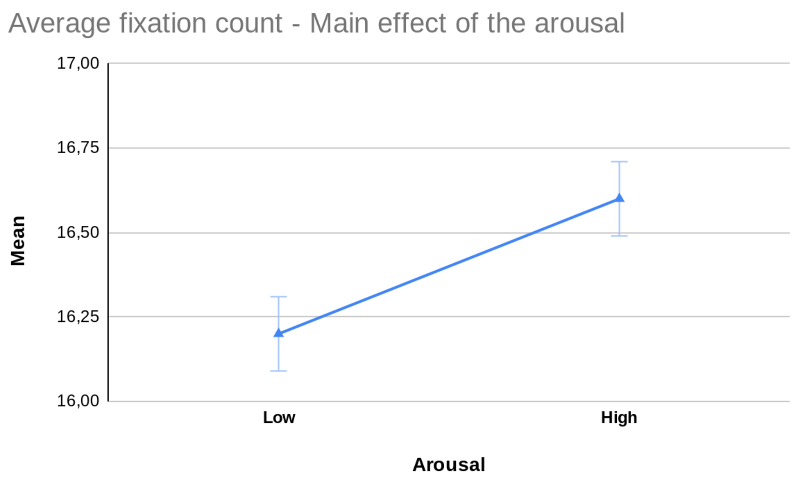

Figure 4. Main effect of Arousal state on the average fixation count

This could be the reason why in the reading rate no difference between stress and control condition has been found: even though while being in a high arousal state people tend to fixate for a shorter amount of time they need to execute a higher amount of fixations with respect to the low arousal state resulting in the same amount of time needed to read the full sentence (measured in words per minute).

3.5. Mean Pupil Size

We found a main effect of the pupil size both of the window size, $F(1, 3591) = 8.85$, $p < 0.001$, and of the stress induction, $F(1, 3591) = 91.68$, $p<0.0001$. Specifically, people tend to have a larger pupil size in the larger window and while being in a high arousal state than in the small window condition and while being in a low arousal state (Figure 5). It is interesting to notice that this is the only measure in which the effect of the arousal is much stronger than the effect of the window.

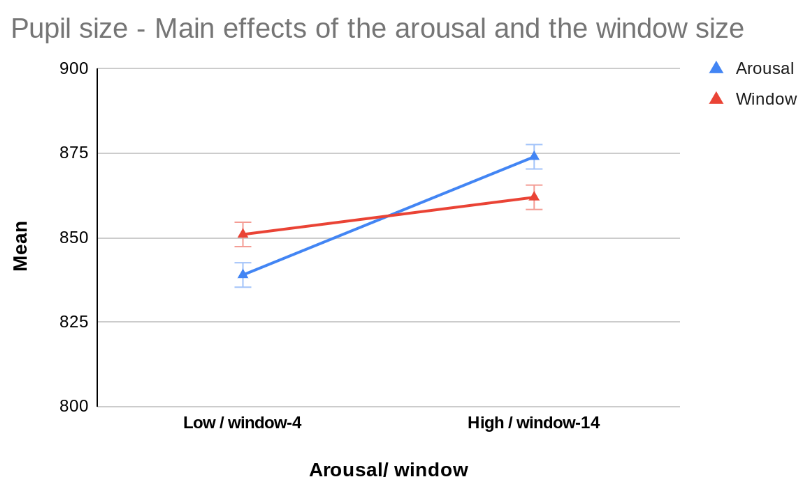

Figure 5. Main effects of Arousal state and Window condition on the pupil size.

3.6. SAM scores

A two-tailed paired t-test was conducted in order to analyze if there was a significant difference between the control and the stress condition for both valence and arousal. No significant difference has been found for the valence, $t(21)= 0.79$, ns ($M_{valence\_stress-control}= 0.20$). For the arousal instead, the difference was significant, $t(21)= 3.64$, $p<0.01$, and specifically participants' scores after hyperventilation were higher than the scores after control ($M_{arousal\_stress-control}= 1.29$).

The results found in the SAM support the idea that the effects of the hyperventilation are related to an increased physiological activation rather than to a change in the participants' emotional state.

4. Discussion

Our main prediction was to find an interaction between the window size and the arousal level such that with respect to control conditions, after the stress induction participants would present a lower difference in reading speed between big and small window sentences. This hypothesis was based on the idea that as other cognitive processes, the PS would be subjected to attentional narrowing as a consequence of the exposure to a stressor. Namely, stress is thought to converge the focus on the central factors of a stimulus while reducing the attentional resources available in the periphery. In the case of the PS a stressor would act by decreasing the attention oriented towards the parafoveal information resulting therefore in a reduction in the PS.

The analysis of our data however, did not show such interaction. We were able to replicate the results of previous research using the contingent-gaze moving window paradigm, as we found a main effect of the window size for all the dependent variables we measured. Independently from the arousal level indeed, participants' reading performance was lower in small than in big window conditions. Specifically, in small window conditions reading rates and average saccadic amplitudes were lower while average number and duration of the fixations were higher than in big window conditions. We can therefore state that the moving window paradigm was correctly applied and that the reason for our results not to reflect what we predicted is not attributable to an incorrect performance of the task.

The fact that after hyperventilation the pupil results on average more dilated than in the control conditions, provide strong evidence that the body arousal has actually increased. High arousal indeed is usually associated with the activation of the sympathetic nervous system, which also controls pupil dilation (Szabadi, 2018). The positive relationship between high arousal and pupil size has been widely documented in literature. For instance, in a study investigating the effect of emotional induced arousal on pupil size, it has been found that when shown emotionally charged pictures, subject's pupils increased their size to a larger extent with respect to when they were shown emotionally neutral pictures (Bradley, Miccoli, Escrig & Lang, 2008). These pupillary changes covaried with skin conductance measures furtherly supporting the idea of an involvement of the sympathetic nervous system.

The result about the different pupillary size in the two window conditions is controversial. Several studies have documented that pupils tend to dilate when tasks are cognitively demanding (Beatty, 1982; Gavas et al., 2018). Intuitively this leads to think that in the small window conditions, where less parafoveal information is available and therefore more attentional effort is required, pupils would have a larger size than in the big window condition. However, in this study we found the opposite effect, with a larger pupil dilatation in the big rather than the small window condition. One possible explanation could be the fact that while being easier to encode because of the higher amount of informative contextual content, sentences with larger windows would also require a higher amount of effort to be perceptually processed. In a previous study indeed, it has been found that the farther away from the central fixation point a stimulus appears, the harder is its evaluation and consequently the stronger is the pupil's dilation (Klatt, Noël, & Brocher, 2021). Further support to the fact that stress induction did actually increase participants' arousal is given by the self-report measures obtained from the SAM. After the hyperventilation indeed participants reported significantly higher levels of activation with respect to the control condition. The levels of valence experienced by the participants did not significantly differ in two arousal conditions. This confirms the fact that hyperventilation acted on a physiological level but did not appreciably affect people's emotional state.

Even though we did not find the effect we predicted on the PS size, the results show that hyperventilation has more generally affected the reading performance. Indeed, a main effect of stress has been found both in the average fixation duration and in the fixation count. Specifically, as opposed to low arousal state, while being in high arousal participants computed a higher number of fixations and the average duration of the fixations was lower. Interestingly, these two results interpreted together neither reflected an improvement nor a worsening in reading performance, and this explains the reason why no difference is found in reading rates between the two conditions. On one hand, an average shorter duration of fixations reflect a faster reading, as it translates in people spending less time on the words they are fixating. One the other hand, a higher number of fixations- considering that the saccadic amplitude remains constant between the two conditions- can be interpreted as a higher number of regressions to previous words, which intuitively leads to an increased average time spent on each sentence (and word consequently). The interpretation of these results could be that stress increased reading speed in terms of automatic decoding of the text, but at the same time participants's levels of comprehension were reduced, leading them to compute more regressions.

Given that the properties of the stimuli remain identical in the two arousal conditions, the difference found in fixations number is likely to be related to internal changes. Specifically, as regressions typically occur when the perceived stimulus has not been fully comprehended, it is possible that stress exerted an impairing effect on semantic processing. In line with this hypothesis, previous research has found a decrease in reading comprehension performance as a result of the exposition to a noise stressor (Gheewalla, McClelland & Furnham, 2020).

The fact that despite a potential semantic impairment the participants presented shorter average fixation durations, could be interpreted in light of the idea of two systems guiding our thoughts, as proposed by Kahneman (2011). According to this theory, our brain has two operating systems which act complementary to each other. System 1 acts in a fast, instinctive and unconscious way while System 2 is rational, conscious and slower in its processing. Both systems are always active when we are awake and they interact with each other in a way that System 1 continuously generates 'suggestions' which can be adopted, rejected or modified by System 2. Given that System 2 is very energy consuming, most of the time the 'suggestions' proposed by System 1 are adopted. As suggested by Yu (2016), in this perspective stress could be viewed as a factor facilitating the acceptance of the automatic responses. Specifically, by reducing the resources available, stress would also limit the rational system's efficiency and consequently individuals would be taken to adopt a more intuitive and automatic pattern of behaviors. Our results can be interpreted under the light of this hypothesis. The ability to read is acquired in time and initially it requires energy and effort. With learning however, it becomes progressively faster and less demanding up to the point of becoming automatized. In same cases however, when a difficulty is presented in a text, system 2 might come up to intervene on the automatic system flow and lead more attentional resources towards the adversity. In our experiment, after the stress induction participants have been shown to present a higher number of fixations, suggesting that they did face some difficulty, probably at the level of comprehension. However, the general reading rate did not decrease since participants's fixation duration was on average shorter than in control condition. This could be thought of as stress having a weakening effect on the rational system, which would lead to a more mechanized reading behavior. In summary, we proposed that two different mechanisms might have been affected by the stress exposure. On one hand, it might have led to an impairment in the comprehension processing, resulting in a higher number of fixations. On the other hand, the reduced efficiency of the rational systems and therefore the lower inhibition exerted on impulsive responses could have driven the participants to adopt an automated-type of reading strategy, characterized by shorter fixations despite the lack of comprehension. In order to test this hypothesis, further research investigating the issue should include measures accounting for text comprehension and for general response-inhibition thresholds.

4.1. Limitations of our study and future directions

The effects of stress on cognition are multifaceted and depend on a variety of factors. One of those is task complexity, and in general it has been found that performance is majorly impaired when tasks are highly demanding. Our experiment consisted in a reading task which, despite the masking, is considered to be relatively easy. This could be a possible reason for which we did not find the predicted effects. Up to now however, none of the alternative available tests estimating the PS would fulfill this requirement. I therefore suggest future investigations addressing this issue to rather focus on different types of stressors able to elicit a higher level of arousal.

A second limitation of our study is the lack of a measure for text comprehension. Besides the fact that our main hypothesis was centered on the effects of the PS, we did predict that the stress-induction would generally affect reading performance. Given that previous studies have demonstrated that stress led to a lowered performance in text comprehension, accounting for this factor would have been appropriate.

Lastly, the sample size of our experiment was not big enough to test for differences related to the gender of the participants. I would suggest future research to take into account individual differences which could be influencing participants' responses to stress. Besides gender, features like the anxiety trait and genetic factors are thought to be part of the complex net of interaction modulating the stress-performance relationship and thus, accounting for these individual differences could be a fundamental requisite when addressing this issue.

4.2. Conclusions

In conclusion, our study demonstrated that stress induced by a hyperventilation exercise does not affect people's perceptual span nor the reading speed but rather changes their reading pattern. While the PS's size did not significantly differ in high- and low-arousal conditions indeed, interesting effects have been found with respect to the fixations' number and duration. Specifically, the results suggest that when exposed to stress individuals tend to read faster but to compute more regressions, indicating a possible impairment in reading comprehension.

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