Reading with induced worry: The role of physiological self-regulation and working memory updating in text comprehension

Sonia Zaccoletti[1] (iD), Daniela Raccanello[2] (iD), Roberto Burro[2] (iD) and Lucia Mason[1]* (iD)

[1]Department of Developmental Psychology and Socialization, University of Padua, Italy

[2]Department of Human Sciences, University of Verona, Italy

Background. An interplay of emotional and cognitive aspects underlies academic performance. We focused on the contribution of such interplay to text comprehension.

Aims. We investigated the effect of worry on comprehension and the role of two potential moderators of this effect: physiological self-regulation as resting heart rate variability (HRV) and working memory updating.

Sample. Eighty-two seventh graders were involved in a quasi-experimental design.

Methods. Students read an informational text in one of two reading conditions: to read for themselves to know more ($n = 46$; low-worry condition) or to gain the highest score in a ranking ($n = 36$; high-worry condition). Students' resting HRV was recorded while watching a video of a natural scenario. The executive function of working memory updating was also assessed. After reading, students completed a comprehension task.

Results. Findings revealed the moderating role of HRV in the relationship between induced worry and text comprehension. In the high-worry condition, students with higher resting HRV performed better than students who read under the same instructions but had lower HRV. In contrast, in the low-worry condition, students with higher resting HRV showed a lower performance as compared to students with lower HRV. Finally, working memory updating was positively related to text comprehension.

Conclusions. Our findings indicate that the cognitive component of anxiety, that is, worry, plays a role in performing a fundamental learning activity like text comprehension. The importance of physiological self-regulation emerges clearly. In a condition of high worry, higher ability to regulate emotions and thoughts acts as a protective factor.

Reading and comprehending texts are essential for learning successfully at school. According to the well-known Kintsch's Construction-Integration Model (1988), reading comprehension is the result of two phases. In the construction phase, readers form a mental representation of the text creating an associative network of concepts. In the

*Correspondence should be addressed to Lucia Mason, Department of Developmental Psychology and Socialization, University of Padova, via Venezia 8, 35131 Padova, Italy (email: lucia.mason@unipd.it).

integration phase, textual information and prior knowledge are integrated in a definitive mental representation of the text, that is, the situation model. Irrelevant information is deactivated as inappropriate for comprehension.

Research on reading comprehension has widely focused on individual factors that may facilitate or impede the construction of meaning from texts. The role of cognitive (e.g. McNamara & Kintsch, 1996) and motivational components (e.g. Guthrie, McRae, & Klauda, 2007) has been largely explored, but much less attention has been paid to how emotions influence text comprehension. In fact, only recently there has been an increased interest in how emotions may affect the processes of comprehending texts (Bohn-Gettler & Kaakinen, 2021). Moreover, very few studies have involved readers younger than university students and most of the findings are based on correlational data (Zaccoletti, Altoè, & Mason, 2020b). Furthermore, we lack research that examines learning-related self-regulation processes in educational contexts by using objective physiological measures.

To advance current knowledge, we experimentally manipulated worry in lower secondary school students to investigate its effect on text comprehension. We were also interested in factors that can potentially moderate the relationship between worry and reading comprehension. Seeking to integrate relevant issues from different research areas, we focused on the role of the physiological component of self-regulation as well as on working memory updating when reading in high- or low-worry conditions. We considered Pekrun's control-value theory (CVT) of achievement emotions as the main theoretical framework (Pekrun, 2006, 2018; Pekrun & Perry, 2014) and focused on the cognitive component of anxiety, that is, worry.

Reading texts with induced worry

Pekrun's CVT of achievement emotions has given great impetus to research on the impact of emotions in learning contexts (Pekrun, 2006, 2018; Pekrun & Perry, 2014). According to the CVT, anxiety is a negative activating achievement emotion – an emotion felt in relation to learning activities or outcomes – which is detrimental for learning in a variety of domains (Pekrun, 2006, 2018; Pekrun & Perry, 2014). While the negative relationship between anxiety and achievement has been well documented for disciplines such as mathematics, also through meta-analytical approaches (Zhang, Zhao, & Kong, 2019), findings concerning native language and specifically reading are sparse and sometimes inconsistent. For example, some studies indicated that anxiety felt at school has a negative impact on achievement in native language, but only for lesson and test settings, while the effect is positive when anxiety is referred to the context of homework (Raccanello, Brondino, Moè, Stupnisky, & Lichtenfeld, 2019). A negative impact was also found for reading, but without distinguishing across settings where anxiety is experienced (Zaccoletti, Altoè, & Mason, 2020a). In light of the mixed findings, it is worthwhile referring to the long tradition of studies dating back to Yerkes and Dodson's law (1908; Teigen, 1994). Such law regards physiological arousal, whose increase is one of the primary indicators of anxiety (Roos, Goetz, Voracek, et al., 2021). According to their inverted-U theory, increased performance is associated with medium levels of arousal, while both at low and high levels its effects are detrimental. It is worth noting that many studies on anxiety and achievement are observational, limiting the generalizability of the findings in terms of causal inferences (Siedlecka & Denson, 2019). This issue can be dealt resorting to emotion induction procedures.

One way to deepen our knowledge on the relationship between anxiety and performance is to consider both the impact of anxiety and the evaluative nature of the task it is referred to. Specifically, in this study, we focused on the impact of worry as a cognitive component of test anxiety that is a type of anxiety specific to assessment-related situations (Zeidner, 2007). Worry usually implies interfering thoughts during a task as they are related to a possible failure (Putwain & Symes, 2011). Worry is associated with impairments in working memory and anxious individuals are usually deficient in the executive processes deputed to control learning (Zeidner, 2014). It also seems that the association between anxiety and academic performance is closer when the measure of the emotion is operationalized in terms of cognitive components such as worry rather than other types of components (Seipp, 1991). This has been found in mathematics with eighth graders as the cognitive component of anxiety had a relatively higher impact on performance compared to the affective component. According to theoretical approaches like the Resource Allocation Model (Ellis & Ashbrook, 1988), being worried can reduce the amount of cognitive resources deputed to process information, for example, during reading.

According to the CVT (Pekrun, 2006, 2018; Pekrun & Perry, 2014), the effect of emotional states on academic performance can be moderated (or mediated) by factors that mitigate or exacerbate it. In the current study, we focused on two factors that can play a moderating role in the relationship between worry and reading comprehension. The main factor was the physiological component of self-regulation and the secondary factor was working memory updating. In the next sections, we introduce and theoretically justify the use of the two moderators.

Resting heart rate variability as physiological self-regulation

Students' general functioning is strongly determined by their ability to control emotions, thoughts, and behaviour, selecting optimal responses to successfully perform in academic tasks like text comprehension (Gross, 1998; Thayer & Lane, 2000). Scholars have identified resting HRV as a biological somatic marker reflecting self-regulation (Kreibig & Gendolla, 2014). Specifically, resting HRV is the basal variation in the intervals between heart beats (Li et al., 2009), which reflects the influence of the vagal nerve on the heart (Porges, 2007).

Cardiac activity is essential in responding to threatening and stressful situations, and in self-regulating to environmental requirements. The autonomic nervous system (ANS), which regulates cardiac activity (Kreibig & Gendolla, 2014), involves two branches: the excitatory sympathetic nervous system (SNS) and the inhibitory parasympathetic nervous system (PNS). The two branches act antagonistically in influencing cardiac activity. The SNS is active during physical or psychological stress as a 'quick response mobilizing system' (Ernst, 2014, p. 3). Therefore, SNS increases heart rate and stroke volume, which leads to higher physiological arousal to aid in regulating the response to stressful situations (Appelhans & Luecken, 2006). In contrast, PNS is active during periods of rest and stability to maintain lower levels of physiological arousal. PNS provides heart rate reduction and energy recovery and storage. It is a 'more slowly activated dampening system' (Ernst, 2014, p. 3). The parasympathetic control on the heart is mediated by the vagus nerve, the main nerve of the PNS (Brodal, 2010), and its activity is also referred to as cardiac vagal tone ('the brake'), which is indexed by HRV.

We examined the physiological component of self-regulation as reflected in resting HRV. Throughout the article we use the term 'self-regulation' to refer to participants'

resting cardiac activity. Self-regulation and resting HRV are, therefore, used interchangeably. The more individuals can physiologically self-regulate and adapt to environmental requirements, the more they are in a balanced state of calm. For example, HRV increases when a student pays attention to a task and is able to concentrate without responding to other requests from the environment. In fact, increases and decreases in HRV reflect changes in autonomic self-regulation for applying or withdrawing, respectively, the vagal brake on sympathetic activation (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Of note is that self-regulation is a crucial concept in educational psychology research. Despite differences in the various models of self-regulated learning, scholars substantially agree that this construct refers to students' active control of their cognitions, affects and behaviours to direct them towards the achievement of the established goals (e.g. Panadero, 2017; Zimmermann & Schunk, 2011). In the current work, however, we did not take into account self-regulation in its multiple components as we focused on the physiological capacity to change or suppress thoughts, emotions, impulses, or overt behaviours (Scrimin, Patron, et al., 2018; Thayer et al., 2009).

Associated with emotional and cognitive self-regulation (Bertsch, Hagemann, Naumann, Schächinger, & Schultz, 2012), resting HRV is a dispositional characteristic relatively stable in time (Thayer et al., 2009; Thayer & Lane, 2000). High levels of resting HRV indicate greater flexibility in adjusting arousal to meet situational demands. In contrast, low levels indicate autonomic inflexibility that implies vulnerability in adapting to stressful situations (Appelhans & Luecken, 2006). Resting HRV has been reported to be positively associated with moderate-to-vigorous physical activity in children and adolescents, which improves cardiovascular health, as documented in a systematic review (Oliveira, Barker, Wilkinson, Abbott, & Williams, 2017).

Resting HRV is also positively associated with performance in basic cognitive tasks (Thayer et al., 2009). For example, Scrimin, Patron, Florit, Palomba, and Mason (2017) indicated that higher HRV was related to higher inhibitory control in preschoolers. Research has also indicated that among first graders, those with higher resting HRV who were experiencing a positive classroom climate, were also more able to focus attention in a typical attention task, while lower resting HRV was associated with poorer focused attention (Scrimin, Osler, Moscardino, & Mason, 2018). Another study revealed that in a negative classroom climate, first graders with higher resting HRV were also more able to allocate attentional resources in the presence of distracting emotional, school-related materials (Scrimin, Moscardino, & Mason, 2019).

Furthermore, resting HRV is positively associated with cognitive tasks that require executive control in selecting, maintaining, updating, and remembering information (Hansen, Johnsen, & Thayer, 2003; Thayer et al., 2009). Successful text comprehension is a complex academic task that implies the regulation of all these cognitive processes. In this regard, when considering resting HRV, the very few available studies have indicated that the physiological index is positively related to oral text comprehension in preschoolers along with inhibitory control (Scrimin et al., 2017). Resting HRV is also positively related to Internet sources evaluation in terms of more accurate reliability judgments of a set of online informational sources in lower secondary school students (Mason, Scrimin, Tornatora, Suitner, & Moè, 2018).

All these research findings regarding HRV are consistently interpretable within the unifying neurovisceral model by Thayer and Lane (2000). It integrates different systems – autonomic, attentional, and affective – into a flexible neural network (i.e. prefrontal cortex, insular cortex, and anterior cingulate cortex) that operates in the service of self-regulation and adaptability to demands from the environment, and goal-directed

behaviour. Such neural network is related to HRV and cognitive performance (Thayer et al., 2009; Thayer & Lane, 2000).

Daley, Willett, and Fischer (2014) reported that parasympathetic activity during reading predicted text comprehension in upper secondary school students. Becker et al. (2012) also showed that higher HRV during a challenging task was associated with greater reading achievement in primary school-aged children. However, they did not find a significant relationship between resting HRV and reading achievement. Given the very few and mixed results about resting HRV for text comprehension, further investigations are needed on this important individual characteristic. Specifically, we were interested in the possible moderating role of resting HRV in the relationship between worry and text comprehension. Students may approach a reading task with high worry and this affective state is per se detrimental on cognitive performance (Zeidner, 2007, 2014). However, if they are dispositionally characterized by higher resting HRV, they are likely more able to regulate their emotions and thoughts; thus, their performance may not be negatively affected as in case of lower HRV.

Working memory updating in text comprehension

According to the CVT (Pekrun, 2006, 2018; Pekrun & Perry, 2014), executive functions can also moderate or mediate the impact of achievement emotions on performance. Executive functions is an umbrella term for higher order cognitive processes involved in the dynamics of human cognition. According to Miyake et al. (2000), updating of working memory is one of the three main executive functions along with shifting and inhibition. Updating is the ability to continuously refresh information in working memory. It is clearly separable from the other two executive functions, although it moderately correlates with them because of some underlying commonality (Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006). In research on text comprehension, there is a broad agreement on the contribution of working memory updating. To exemplify, this updating is essential in continuously selecting the relevant information while reading, monitoring, and reviewing information in working memory (Borella, Carretti, & Pelegrina, 2010; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001; Zaccoletti et al., 2020b). Of note is that when readers have difficulty to control activated information, they maintain irrelevant information in their working memory with negative consequences for text comprehension (Carretti, Cornoldi, De Beni, & Romanò, 2005).

The positive contribution of working memory updating has been discussed in a systematic review in relation to the aforementioned Kintsch's model (1988; Butterfuss & Kendeou, 2018). However, contradictory results on the role of this executive function have also been reported (Artuso & Palladino, 2016; Mujselaar & De Jong, 2015; Nouwens, Groen, & Verhoeven, 2016). Inconsistent findings may be explained in reference to updating during a reading comprehension task and updating during the execution of tasks specifically devised to measure this executive function. In the former case, updating is a much more complex process than in the latter case (Mujselaar & De Jong, 2015).

We focused on this executive function as research has documented that working memory and related executive processing are affected by anxiety (Zeidner, 2014). However, a central theory on executive functioning, that is, the attentional control theory (ACT; Eysenck & Derakshan, 2011), posits that the associations between anxiety and executive functions are not all the same. Specifically, the associations emerge for two of the three executive functions included in Miyake et al.'s (2000) model. Anxiety can be related to impairment for inhibition and shifting, but not for working memory updating.

For the latter, worse performance can be detected only in case of threatening and stressful situations. Moreover, most of the studies did not distinguish the different components of anxiety, and this does not allow to understand the specific effects of the cognitive component and those of the affective component (Eysenck & Derakshan, 2011; Gustavson & Miyake, 2016).

Based on these research issues, the secondary interest of the current investigation was in the possible moderating role of working memory updating in the relation between worry and text comprehension. Students with high ability to constantly refresh information in their working memory can be advantaged in general, but even more in a high-worry condition that drains cognitive resources from the task at hand. Thus, readers who are well equipped with executive functioning of working memory can be facilitated in performing a cognitively demanding reading task in a high-worry condition (Ellis & Ashbrook, 1988). Before investigating this issue, it is also worthwhile checking whether induced worry impacts on updating as, according to the ACT, this effect would only emerge in situations that are really stressful or threatening, luckily different from the events that usually characterize school activities (Eysenck & Derakshan, 2011).

The Study

The study was solicited by four gaps in the current literature. First, scarce attention has been paid to the effect of induced worry on academic performance. We manipulated worry by instructing students to read a text in one of two reading conditions, that is, to read (a) for themselves to know more about a science topic, and (b) to answer questions and to gain the highest score in a ranking of students' performance. Second, while the assumptions concerning the relevance of domain-specific processes for explaining the relationships between achievement emotions and their correlates have been largely confirmed, studies focused on reading are lacking. Yet, reading, either on paper or the screen of a digital device, is the main learning activity since the last years of elementary school. It is, therefore, relevant to investigate the relationship between achievement emotions and academic performance in a fundamental domain of the school curriculum. Third, to the best of our knowledge, this is the first study that examined the role of worry in text comprehension by taking into account the role of possible moderators. Focusing on worry enables to extend the current literature diminishing the risk of masking the effects of the different components of anxiety on related components which have been rarely distinguished in previous studies. Thus, we combined relevant issues pertaining to three separate lines of research, that is, worry, physiological self-regulation, and working memory updating. Fourth, we focused on seventh graders in lower secondary school as research documents increased anxiety after the transition from primary to lower secondary school (Bouffard, Boileau, & Vezeau, 2001; Pekrun & Perry, 2014). Therefore, it is theoretically and practically relevant at this educational level to understand which factors can mitigate the impact of worry on a fundamental activity for school success like text comprehension.

The study was guided by the following research questions (RQ) and hypotheses.

RQ1. Does induced worry affect text comprehension? Based on the aforementioned relevant literature (Raccanello et al., 2019; Zaccoletti et al., 2020a; Zhang et al., 2019), we expected greater text comprehension in students in the low-worry reading condition compared to those in the high-worry reading condition (Hypothesis 1).

RQ2. Does physiological self-regulation as reflected in resting HRV impact on text comprehension and moderate the effect of worry on text comprehension? Based on the

relevant literature, we hypothesized that physiological self-regulation would be related to text comprehension, also when considering its interaction with induced worry (Hypothesis 2). Specifically, we expected HRV to be a moderator, so that students with higher HRV in the high-worry reading condition would comprehend better than those with lower HRV. This is because high HRV can act as a protective factor against the negative influence of worry on comprehension performance. In other words, students with higher HRV are better able to regulate emotions and thoughts, and this is presumably more salient in demanding situations (Thayer et al., 2009; Thayer & Lane, 2000).

RQ3. Does working memory updating impact on text comprehension and moderate the effect of worry? Based on the aforementioned literature, we hypothesized that updating would significantly impact on text comprehension, also through the interaction with induced worry (Hypothesis 3). In particular, we expected the executive functioning of working memory to be a moderator, so that students with higher ability to continuously refresh their working memory would comprehend better than those with lower updating ability in a high-worry condition that can negatively affect their cognitive performance. In fact, the executive function can also act as a protective role in reading performance, as documented by research on text comprehension (Butterfuss & Kendeou, 2018) and research on emotions and academic performance (Ellis & Ashbrook, 1988).

Method

Participants and design

We initially involved 94 Italian seventh graders upon written parental consent after the approval of the study by the Ethics Committee. They attended six classes of seventh grade in lower secondary schools. Data from 12 students were not considered as six had cognitive/learning disabilities or language difficulties; two were not present in all the sessions; and for four there was a poor recording of physiological responses. The final sample consisted of 82 students (M_{age} = 12.24, SD = 0.25; females = 43), who provided their verbal assent to participate. Of these, 80 were native-born Italian with Italian as their first language and two came from families where Italian was the second language (from Argentina and Ghana).

We assigned the students to one of two reading conditions: to read for themselves to know more on a science topic in the low-worry condition (n = 46) and to read to gain the highest score in a ranking of students' performance in the high-worry condition (n = 36). We assumed worry related to the reading task to be higher in the second condition. The assumption was tested in preliminary analyses.

Procedure

Data collection took place in three sessions during school hours in three separate days. Session 1 (about 50–60 min) involved the collective administration in the classroom of the tasks to measure the control variables of prior knowledge and reading comprehension ability. Session 2 (about 30 min) took place in a quiet room of the school in which two students watched a relaxing video while we measured their HRV. They then completed the working memory updating task individually. Session 3 (about 60 min) took place in the classroom and involved the text reading and comprehension tasks. We asked students to read the text according to the assigned reading condition. Because of constraints in the school setting, students were not randomly assigned to one of the two conditions.

However, we randomly assigned three classes to the low-worry condition and the other three to the high-worry condition.

Reading material

Participants read an informational text about the science concept of natural selection (615 words; Gulpease index for readability = 50, appropriate for seventh graders; Lucisano, 1992). Students were allowed to go back and read the text as many times as they wanted. We chose this topic with science teachers to ensure that the students had not yet studied it.

We asked students to read according to two reading conditions. For the expected low-worry condition, we asked the student "to read the text and then answer the questions to see how much you understood about the text you just read". For the expected high-worry condition, we asked "to read the text and answer as best you can to gain the highest score in a ranking of students' performance".

Manipulation check

After reading the text and before answering the post-reading task, we asked participants to indicate on a 7-point scale (1 = *not at all*, 7 = *completely*) how worried they were in performing the task (adaptation from Achievement Emotions Adjective List; Raccanello, Brondino, Crescentini, Castelli, & Calvo, 2021). As in typical ecological momentary assessment, we used only one item for an easy assessment and to minimize the intrusiveness of the measure. In addition, previous findings have supported the adequacy of single items to assess subjective experiences (Roos, Goetz, Krannich, et al., 2021). Such item was focused on the cognitive component of anxiety (i.e. *worried*, in Italian *preoccupato/a*). At the end of the study, the participants were debriefed on its purposes as a way to compensate the effect of the manipulation and to guarantee their well-being.

Measures

Resting heart rate variability

We measured resting HRV while students were at rest watching a 5-min video of a natural scenario taken from National Geographic, as in other studies (e.g. Mason et al., 2018). We used a natural scenario as research has documented that both direct and indirect exposures to nature are beneficial for well-being as they sustain positive affective states in terms of calm, relaxation, and refreshment (Norwood et al., 2019). According to the stress reduction theory, exposure to natural environments promotes recovery from psychophysiological stress as indicated by lower blood pressure and stress hormones (Ulrich et al., 1991). Participants' cardiac responses while watching the video were measured using photoplethysmography, a non-invasive technique that detects blood volume changes through sensors attached to a fingertip of the participant's non-dominant hand. Photoplethysmography was recorded in a standardized fashion using a multi-modality physiological monitoring device that encodes biological signals in real-time (ProComp Infiniti, Thought Technology; Montreal, Canada). We used blood volume changes to determine the inter-beat intervals and derive HRV. Successively, the data of time distances between each beat were exported in the Kubios-HRV 2.2 (Kuopio, Finland) software to correct artifacts with a piecewise cubic spline interpolation method that generates

missing or corrupted values into the series of inter-beat intervals. After artifact cleaning, we calculated HRV through the root Mean Square of the Successive Differences (rMSSD) of heart periods, which is an index of the variations in the inter-beat intervals between heart beats and is sensitive to short-term fast heart period fluctuations. This index reflects parasympathetic activity through the 'brake' on the heart (Porges & Byrne, 1992).

Working memory updating

We used an updating task that involved six lists of 10 words, each representing objects or animals (Palladino et al., 2001). Students were asked to listen to and repeat the three smallest objects or animals from each list in the correct order of presentation (target words). The maximum score for each list was 3. We presented each word in a fixed order reading at the rate of 1 word per second. If students could not recall a word but the other two were repeated in the correct order, we assigned 2 points. If students could not recall a word but they repeated the other two in the wrong order, we assigned 1 point. When students either remembered words from the list which were not the target words or when no words were repeated, we assigned 0 points. We computed a total score for the items repeated in the correct order (maximum score = 18; McDonald's ω = .70).

Text comprehension

Participants answered eight multiple-choice questions that included four factual and four transfer questions specifically devised for the current study or taken and adapted from Mason and Gava (2007) (maximum score = 8; McDonald's ω = .70). Answers to the factual questions required information introduced in the text, while answers to the transfer questions required the application of the newly learned factual knowledge. An example of factual questions is as follows: "Where did Charles Darwin carry out his most important studies? (a) In Africa; (b) In Ecuador; (c) In the Galapagos islands; (d) In Northern America". An example of inferential questions is as follows: "The first cheetahs used to run at a maximum speed of only 20 kilometers/h. Nowadays cheetahs run at 60 kilometers/h when they are hunting prey. How can the evolution of their running speed be explained? (a) The need to run faster increased their running speed over time in the struggle for survival; (b) The struggle for survival favored the cheetahs that tried to run faster so they reproduced over time and survived; (c) Natural selection favored survival of the most adaptable, those that were faster, the winners in the struggle for survival; and (d) The will to run faster increased their running speed over time in the struggle for survival".

Control variables

We measured three control variables. As previous studies showed that females outperformed males in text comprehension, we considered potential gender differences (Logan & Johnston, 2009). We used two written open-ended questions to assess prior knowledge of the science topic of the text (0 = incorrect response, 1 = correct but incomplete response, 2 = correct and incomplete response; maximum score = 4; inter-rater reliability = 98%). We measured reading comprehension ability using the standardized MT-3 test (Cornoldi & Carretti, 2016) for seventh graders. Students read an expository text and then answered 12 multiple-choice questions (maximum score = 12; McDonald's ω = .88).

Statistical approach

We used the R software (R Core Team, 2021). We performed generalized linear mixed models (GLMM) and LMM utilizing *glmer/lmer* functions ("lme4" package; Bates, Maechler, Bolker, & Walker, 2015), after verifying that the residuals of the variables were normally distributed by examining the diagnostic plots. We utilized the Satterthwaite's method for degrees of freedom (Kuznetsova, Brockhoff, & Christensen, 2017). To answer our three research questions, we implemented a model selection procedure. This procedure aims to test whether the most complex models are significantly better at accounting for the observed data than the simpler models. We reported in Table 3 the factors and interactions included in the eight models that we tested. The full model included class as random effect; worry condition (low worry, high worry), HRV, and working memory updating as fixed effects; all the two-way and three-way interactions between the fixed effects; and text comprehension as the dependent variable. We calculated seven fit indexes and then considered as the target score a composite performance score that we obtained by normalizing the seven indexes and taking the mean value for each model. This score ranges from 0% to 100%; higher values indicate a better model performance (Burnham & Anderson, 2002; Lüdecke, Ben-Shachar, Patil, Waggoner, & Makowski, 2021). We used standardized variables for HRV and working memory updating.

Results

Preliminary analyses

We reported descriptive statistics in Table 1 and bivariate correlations in Table 2.

Preliminarily, we conducted a GLMM (random effect: class; fixed effect: condition) to ensure that the two worry conditions were equal in terms of gender, and then four LMMs (random effect: class; fixed effect: condition) to check whether the two worry conditions were equal in terms of prior knowledge, reading comprehension ability, HRV, and working memory updating. No significant effects or interactions emerged. Then, we ran a LMM (random effect: class; fixed effects: gender, prior knowledge, and reading comprehension ability) to check for possible effects on text comprehension and we found no significant effects or interactions. Therefore, we excluded gender, prior knowledge, and reading comprehension ability from the following analysis.

As for the manipulation check, we ran a LMM (random effect: class; fixed effect: condition) with worry as dependent variable. The students in the low-worry condition ($M = 3.24, SD = 1.61, 95\%$ CI [2.76, 3.72]) were less worried than those in the high-worry condition ($M = 4.19$, $SD = 2.05$, 95% CI [3.50, 4.89]), $F(1, 35.262) = 5.868$, $p = .021$, conditional $R^2 = .16$, supporting the effectiveness of the manipulation in affecting worry.

The role of worry, resting heart rate variability, and working memory updating in text comprehension

The best model explained the 45% of variance ($p < .001$; see Table 3 for the comparisons among the tested models). It included the effects of class, worry condition, resting HRV, working memory updating, and the condition x resting HRV interaction. Both the effects of worry condition (Hypothesis 1), $F(1, 23.897) = 20.339$, $p < .001$, and working memory updating (Hypothesis 3), $F(1, 76.949) = 13.226$, $p < .001$, were significant, as well as the worry condition x resting HRV interaction (Hypothesis 2), $F(1,$

Table 1. Descriptive statistics of the variables for the total sample (N = 82) and by condition (low worry, n = 46; high worry, n = 36)

Variable	Total sample				Low-worry condition				High-worry condition			
	M (SD)	95% CI	Skewness	Kurtosis	M (SD)	95% CI	Skewness	Kurtosis	M (SD)	95% CI	Skewness	Kurtosis
Prior knowledge	1.29 (0.94)	[1.08, 1.49]	0.20	-0.51	1.22 (0.87)	[0.96, 1.47]	-0.02	-1.04	1.39 (1.02)	[1.04, 1.73]	0.29	-0.49
Reading comprehension ability	9.21 (2.19)	[8.72, 9.68]	-0.68	-0.41	9.11 (2.30)	[8.42, 9.79]	-0.62	-0.61	9.33 (2.07)	[8.63, 10.03]	-0.70	-0.33
Updating	11.31 (2.88)	[10.68, 11.94]	0.20	-0.30	11.13 (2.89)	[10.27, 11.99]	0.25	-0.29	11.54 (2.89)	[10.56, 12.52]	0.13	-0.42
HRV	55.08 (19.43)	[50.81, 59.35]	0.64	-0.07	57.69 (19.87)	[51.79, 63.60]	0.53	-0.41	51.73 (18.58)	[45.44, 58.02]	0.76	0.38
Text comprehension	3.79 (1.65)	[3.43, 4.15]	0.23	-0.93	3.22 (1.46)	[2.78, 3.65]	0.26	-1.03	4.53 (1.59)	[3.98, 5.06]	0.07	-1.31

Table 2. Bivariate correlations between the variables for the total sample (N = 82) and by condition (Low Worry, n = 46; High Worry, n = 36)

	1	2	3	4
1. Prior knowledge	—			
2. Reading comprehension ability	.12/.14/.09	—		
3. Updating	.28*/.36*/.19	.37***/.34*/.40*	—	
4. HRV	−.03/.04/−.07	−.20/−.43***/.18	−.07/−.15/.06	—
5. Text comprehension	.02/.08/−.13	.28*/.01/.16	.37***/.35*/.39*	−.03/−.42**/.60***

Note. Correlations are reported for the total sample before the first slash, for the low-worry condition between the first and second slash, and for the high-worry condition after the second slash.
*p < .05, **p < .01, ***p < .001.

76.609) = 27.265, $p < .001$ (see Table 4 for the standardized betas). Text comprehension was greater for the high-worry condition compared to the low-worry condition (Table 1). Moreover, it increased with higher working memory updating (Table 2).

To examine the interaction between worry and resting HRV, we performed a simple slope analysis (Bauer & Curran, 2005; Figure 1). The slope emerged as significant in both conditions (low worry, $\beta = -0.027$, $t = -2.855$, $p = .006$; high worry, $\beta = 0.049$, $t = 4.305$, $p < .001$). Moreover, the two slopes significantly differed, $t = -5.105$, $p < .001$, with higher values for the high-worry condition. In the low-worry condition, the participants with higher HRV showed a poorer text comprehension than those with lower HRV; in the high-worry condition, the students with higher HRV showed a greater text comprehension than those with lower HRV (Table 2).

Our findings, therefore, did not support Hypothesis 1, showing the significant main effect of induced worry. Text comprehension was higher for the students in the high-worry condition compared to those in the low-worry condition. The findings partially supported Hypothesis 2 as resting HRV was a moderator in the relationship between worry and text comprehension. Finally, the findings also partially supported Hypothesis 3, revealing the significant main effect of working memory updating on text comprehension.

Discussion

To advance current knowledge on factors underlying text comprehension, we investigated the role of resting HRV as the main moderator of the effect of worry on text comprehension. We also examined the role of working memory updating as a secondary moderator.

Effect of worry on text comprehension (Research question 1)

Our data indicated that students with induced higher worry showed greater text comprehension compared to less worried students, not supporting Hypothesis 1. This is in line with findings about achievement in native language focusing on homework-related anxiety (Raccanello et al., 2019), but differs from data on the negative impact of lesson-related and test-related anxiety about achievement in native language (Raccanello et al., 2019), or anxiety for reading (Zaccoletti et al., 2020a). Differences from previous research can be due to the specific characteristics of the task context in for which we assessed worry. We can speculate that the instructions given to the students for eliciting higher worry might have fostered challenge appraisals, which are usually adaptive. A worthwhile issue for future research is to investigate whether induction procedures similar to the one we used affect this kind of appraisal.

Moderating role of resting HRV (Research question 2)

The effect of worry on text comprehension was moderated by resting HRV, as physiological self-regulation significantly contributed to text comprehension only when in interaction with the reading condition. These findings partially confirmed Hypothesis 2. When worry was elicited, those with higher HRV – an indicator of higher physiological self-regulation – showed greater reading comprehension than those with lower HRV.

**Table 3.** Indexes of model performance for the tested models

Models	AIC weights	BIC weights	Conditional R^2	Marginal R^2	ICC	RMSE	Sigma	Performance Score
Model 6. condition+HRV+updating+(condition*HRV)	.676	.883	.464	.452	.022	1.176	1.222	85.95%
Model 3. condition+HRV+updating+(condition*HRV)+(condition*HRV)	.202	.079	.465	.450	.026	1.171	1.226	65.61%
Model 2. condition+HRV+updating+(condition*HRV)+(condition*updating)+(HRV*updating)	.087	.003	.461	.447	.025	1.171	1.234	59.15%
Model 4. condition+HRV+updating+(condition*HRV)+(HRV*updating)	.007	.084	.461	.450	.021	1.176	1.229	58.06%
Model 1. condition+HRV+updating+(condition:HRV)+(condition*updating)+(HRV*updating)+(condition*HRV*updating)	<.001	<.001	.458	.444	.026	1.171	1.242	57.68%
Model 7. condition+HRV+updating+(condition*updating)	<.001	<.001	.311	.281	.042	1.353	1.411	15.03%
Model 5. condition+HRV+updating+(condition*updating)+(HRV*updating)	<.001	<.001	.312	.283	.040	1.346	1.413	14.27%
Model 8. condition+HRV+updating+(HRV*updating)	<.001	<.001	.306	.281	.034	1.355	1.411	8.90%

Note. The symbol + indicates adding a parameter; the symbol * indicates the interaction between parameters. Condition = induced worry (low, high); HRV = resting HRV; updating = working memory updating. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; R^2 = coefficient of determination; ICC = Intra-class Correlation Coefficient; RMSE = Root Mean Squared Error. For each model, the performance score is a composite score obtained by normalizing the previous seven indexes and calculating their mean value. Model 1 was the full model testing the effects of the three factors, the three 2-way interactions and the 3-way interaction. Model 2 included the effects of the three factors and the three 2-way interactions. Models 3, 4, and 5 included the effects of the three factors and the effects of the 2-way interactions. Models 6, 7, and 8 included the effects of the three factors and one of the 2-way interactions between worry condition and resting HRV, between worry condition and updating, and between resting HRV and updating, respectively. The eight models are ordered according to their performance score.

Table 4. Summary of the best model predicting text comprehension

Variables	β (SE)	t	p
(Intercept)	0.00 (0.00)	3.48***	<.001
Condition	−0.88 (.26)	−3.39**	.001
HRV	−0.32 (.11)	−2.92**	.005
Updating	0.30 (.08)	3.64***	<.001
Condition x HRV	1.33 (.25)	5.22***	<.001

*p < .05; **p < .01; ***p < .001.
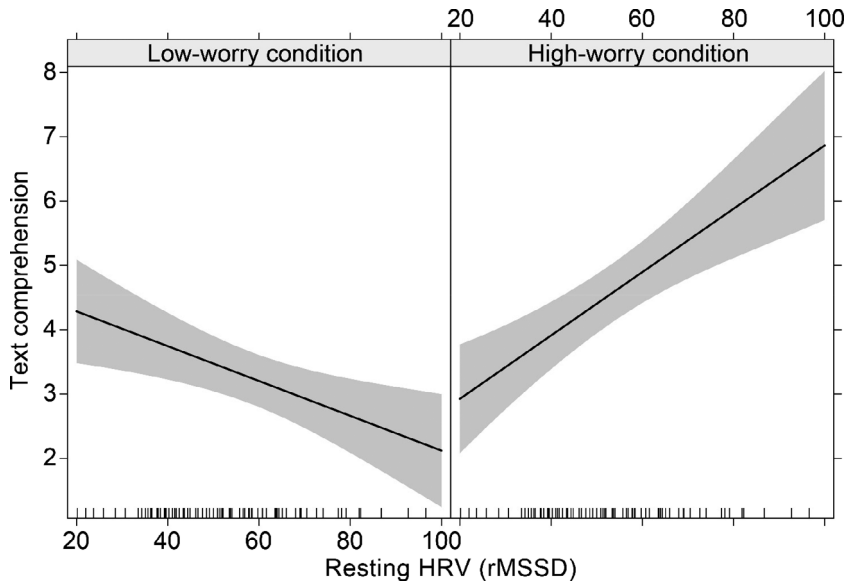
Figure 1. Two-way interaction between worry condition and resting HRV.

The literature on achievement emotions has demonstrated that high levels of a negative activating emotion such as anxiety – of which worry is a cognitive component – are detrimental for performance in learning tasks (Pekrun, 2006, 2018; Pekrun & Perry, 2014; Raccanello et al., 2019; Zaccoletti et al., 2020a; Zhang et al., 2019). Therefore, for students who are dispositionally more able to regulate their emotions and cognitions, showing higher HRV, there are more chances to be able to cope with their worry, with the consequential decrease of its detrimental effects on task performance. In contrast, students with lower HRV have reduced possibility to diminish the arousal associated with worry, which remains high and as a result negatively impacts performance. However, it was surprising that when students read with low levels of anxiety, their text comprehension was lower than that of students with higher HRV. We can speculate that this is linked to the effectiveness of students' self-regulation processes in diminishing anxiety. In other words, when task-related anxiety is medium or medium–low, dispositional HRV abilities can make it so low to lead to students' disengagement in the task with even detrimental effect on task performance, in line with the inverted-U theory (Teigen, 1994; Yerkes & Dodson, 1908). In contrast, for students who are dispositionally less able to regulate their worry, its medium or medium–low levels can have no

detrimental effect on their performance. Future studies using a similar manipulation procedure with other tasks, emotions, and domains are needed to confirm these effects. On the whole, the study highlights that resting self-regulation is an important ability when students perform a reading comprehension task for its role in modulating the intensity of their achievement emotions that affect performance (Scrimin et al., 2017).

Role of working memory updating (Hypothesis 3)

Concerning working memory updating, our data partially confirmed Hypothesis 3 as this executive function was related to text comprehension. The finding confirms the important role of continuously selecting the relevant information in a text, monitoring and updating information in working memory to successfully create a situation model of the text content (Butterfuss & Kendeou, 2018; Kintsch, 1988). Moreover, our data revealed that working memory updating did not moderate the relationship between worry and text comprehension. This finding is in line with expectations based on the ACT, according to which updating is affected by anxiety only when the situation is particularly stressful (Eysenck & Derakshan, 2011). As our preliminary results confirmed that the students in the two worry conditions did not differ for their working memory updating, likely, the examined situation was not so stressful. Moreover, based on the CVT (Pekrun, 2006, 2018; Pekrun & Perry, 2014), we can speculate that higher working memory updating may have dampened the negative effect of worry on task performance. Nevertheless, it is also possible that if updating relates to irrelevant or worry-related information, the protective effect of high updating diminishes. Future studies are needed to investigate this issue trying to monitor which kind of information the students are focusing on during the task, for example, distinguishing content worry, that is, concerning the topics of the text, from self-evaluation worry, that is, focusing on self-relevant things (Chang, 2021).

Educational implications

Understanding how worry interacts with physiological processes that are related to text comprehension has important implications for reading performance and, more generally, for school achievement. Our findings suggest that the more self-regulated students are in terms of their physiological disposition, the more they succeed when worried. Teachers can take into account perceived individual differences in self-regulation to dose the appropriate support to help students to manage their emotions and thoughts, given their relevant role in interaction with students' worry and comprehension performance. Even if resting HRV is a relatively stable index for its significant genetic component, "it should be noted that it is still possible to change one's level of HRV" (Thayer et al., 2009, p. 147). Interestingly, physical activity, for example, is not only important to maintain or improve physical and mental health (Biddle, Ciaccioni, Thomas, & Vergeer, 2018; Ortega, Ruiz, Castillo, & Sjöström, 2008), and to support subsequent learning behaviour (Heemskerk, Lubans, Strand, & Malmberg, 2020), but also to increase dispositional self-regulation with benefits for cognitive performance (Hillman, Erickson, & Kramer, & A. F., 2008; Scrimin, Patron, Peruzza, & Moscardino, 2020).

Moreover, as seventh graders' regulation strategies are not fully developed, it is also important from a prevention perspective to teach strategies in the classroom for the self-regulation of affective states and thoughts in the service of better cognitive performance (Goetz & Bieg, 2016; Somerville & Whitebread, 2018). The focus of these strategies can be on teaching students how to deal with worries and high arousal in relation to academic

tasks (Raccanello & Hall, 2021; Rozek, Ramirez, Fine, & Beilock, 2019). For example, students can learn that some strategies, such as reappraisal, are more effective than others, such as suppression (Harley, Pekrun, Taxer, & Gross, 2019). In line with this, they can be trained through a variety of techniques to shift from the use of a less adaptive strategy to the use of a more adaptive one in relation to specific school tasks.

Our finding regarding the contribution of working memory updating to text comprehension also suggests the importance of interventions designed to improve this crucial executive function (Robin & Parkinson, 2015). A typical updating training is based on computerized games. In the intervention study by Ang, Lee, Cheam, Poon, and Koh (2015), for example, at level 1 children had to remember the last exemplar in a sequence or from a category (e.g. monsters), while at level 2 they had to remember the last two exemplars of a sequence or the last exemplar from each of two categories, and so on until level 4. As participants did not know the length of the sequence, they had to update the old with the new. Although the effectiveness of interventions in increasing individuals' updating ability have been documented (Ang et al., 2015), there is still little evidence that the enhancement of updating leads to an improvement in text comprehension. Further studies are needed to shed more light on this issue.

Limitations

This study is not without limitations. First, the working memory updating task that we used might have been too easy considering the updating abilities required during text comprehension (Mujselaar & De Jong, 2015). However, in the school context, time constrictions are very frequent, and it is not always possible to assess these abilities in an optimal way. Second, we only measured resting HRV as a physiological disposition. Further studies may investigate the role of HRV both at baseline and during the reading process to shed light on the dynamic change of physiological responses while students are reading. Third, we measured HRV at school and the measurement condition may not have been optimal. Participants faced something new with respect to their school routine and may have experienced some excitement, although we created a setting for making them comfortable and relaxed. This may have caused higher HRV than in most baseline conditions (Becker et al., 2012).

Conclusions

Despite these limitations, the study has scientific significance as it sheds light on the effect of induced worry on text comprehension by documenting that the physiological component of self-regulation as resting HRV moderates this effect. Specifically, higher resting HRV may act as a resource when students perform learning tasks associated with high levels of worry. Our findings, therefore, indicate how the role of a rarely examined component of self-regulation in learning processes can intervene in the link between worry and text comprehension. The contribution of working memory updating to comprehension performance is also important as the study confirms the direct effect of the executive function on the examined fundamental learning activity.

Acknowledgements

Conflicts of interest

All authors declare no conflict of interest.

Author contribution

Sonia Zaccoletti: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing – original draft. **Daniela Raccanello:** Conceptualization; Methodology; Writing – original draft and revision. **Roberto Burro:** Formal analysis; Methodology. **Lucia Mason:** Conceptualization; Methodology; Supervision; Writing – original draft and revision.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Ang, S. Y., Lee, K., Cheam, F., Poon, K., & Koh, J. (2015). Updating and working memory training: Immediate improvement, long-term maintenance, and generalisability to non-trained tasks. *Journal of Applied Research in Memory and Cognition*, *4*, 121–128. https://doi.org/10.1016/j.jarmac.2015.03.001

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, *10*, 229–240. https://doi.org/10.1037/1089-2680.10.3.229

Artuso, C., & Palladino, P. (2016). Letter updating is related to reading fluency but not comprehension. *Learning and Individual Differences*, *52*, 53–59. https://doi.org/10.1016/j.lindif.2016.10.008

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bauer, D. L., & Curran, P. J. (2005). Probing interactions in fixed and multilevel regression: Inferential and graphical techniques. *Multivariate Behavioral Research*, *40*, 373–400. https://doi.org/10.1207/s15327906mbr4003_5

Becker, D. R., Carrere, S., Siler, C., Jones, S., Bowie, B., & Cooke, C. (2012). Autonomic regulation on the Stroop predicts reading achievement in school age children. *Mind, Brain, and Education*, *6*(1), 10–18. https://doi.org/10.1111/j.1751-228X.2011.01130.x

Bertsch, K., Hagemann, D., Naumann, E., Schächinger, H., & Schultz, A. (2012). Stability of heart rate variability indices reflecting parasympathetic activity. *Psychophysiology*, *49*, 672–682. https://doi.org/10.1111/j.1469-8986.2011.01341.x

Biddle, S. J., Ciaccioni, S., Thomas, G., & Vergeer, I. (2018). Physical activity and mental health in children and adolescents: An updated review of reviews and an analysis of causality. *Psychology of Sport and Exercise*, *42*, 146–155. https://doi.org/10.1016/j.psychsport.2018.08.011

Bohn-Gettler, C. M., & Kaakinen, J. K. (2021). Introduction to the special issue on emotions in reading, learning, and communication. *Discourse Processes*. Advance Online Publication, https://doi.org/10.1080/0163853X.2021.1899369

Borella, E., Carretti, B., & Pelegrina, S. (2010). The specific role of inhibition in reading comprehension in good and poor comprehenders. *Journal of Learning Disabilities*, *43*, 541–552. https://doi.org/10.1177/0022219410371676

Bouffard, T., Boileau, L., & Vezeau, C. (2001). Students' transition from elementary to high school and changes of the relationship between motivation and academic performance. *European Journal of Psychology of Education*, *16*, 589. https://doi.org/10.1007/BF03173199

Brodal, P. (Ed.). (2010). Visceral efferent neurons: The sympathetic and parasympathetic divisions. In *The central nervous system* (pp. 413–431). Oxford, UK: Oxford University Press. https://doi.org/10.1093/med/9780190228958.003.0028

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach* (2nd ed.). New York, NY: Springer. https://doi.org/10.1007/b97636

Butterfuss, R., & Kendeou, P. (2018). The role of executive functions in reading comprehension. *Educational Psychology Review*, *30*, 801–826. https://doi.org/10.1007/s10648-017-9422-6

Carretti, B., Cornoldi, C., De Beni, R., & Romanò, M. (2005). Updating in working memory: A comparison of good and poor comprehenders. *Journal of Experimental Child Psychology*, *91*, 45–66. https://doi.org/10.1016/j.jecp.2005.01.005

Chang, Y. F. (2021). 2-dimensional cognitive test anxieties and their relationships with achievement goals, cognitive resources, motivational engagement, and academic performance. *Learning and Individual Differences*, *92*, 102084. https://doi.org/10.1016/j.lindif.2021.102084.

Cornoldi, C., & Carretti, B. (2016). *Prove di lettura MT-3 per la clinica [MT-3 reading comprehension tests]*. Florence, Italy: Organizzazioni Speciali.

Daley, S., Willett, J. B., & Fischer, K. W. (2014). Emotional response during reading: Physiological responses predict real-time reading comprehension. *Journal of Educational Psychology*, *106*(1), 132–143. https://doi.org/10.1037/a0033408

Ellis, H. C., & Ashbrook, P. W. (1988). Resource allocation model of the effects of depressed mood states on memory. In K. Fiedler & J. Forgas (Eds.), *Affect, cognition, and social behavior: New evidence and integrative attempts* (pp. 25–43). Toronto, Canada: Hogrefe.

Ernst, G. (2014). *Heart rate variability*. London, UK: Springer.

Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences*, *50*, 955–960. https://doi.org/10.1016/j.paid.2010.08.019

Goetz, T., & Bieg, M. (2016). Academic emotions and their regulation via emotional intelligence. In A. Lipnevich, F. Preckel & R. Roberts (Eds.), *Psychosocial skills and school systems in the 21st century* (pp. 279–298). Basel, Switzerland: Springer.

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology*, *2*, 271–299. https://doi.org/10.1037/1089-2680.2.3.271

Gustavson, D. E., & Miyake, A. (2016). Trait worry is associated with difficulties in working memory updating. *Cognition and Emotion*, *30*, 1289–1303. https://doi.org/10.1080/02699931.2015.1060194

Guthrie, J. T., McRae, A., & Klauda, S. L. (2007). Contributions of concept-oriented reading instruction to knowledge about interventions for motivations in reading. *Educational Psychologist*, *42*, 237–250. https://doi.org/10.1080/00461520701621087

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48*(3), 263–274. https://doi.org/10.1016/s0167-8760(03)00073-4

Harley, J. M., Pekrun, R., Taxer, J. L., & Gross, J. J. (2019). Emotion regulation in achievement situations: An integrated model. *Educational Psychologist*, *54*, 106–126. https://doi.org/10.1080/00461520.2019.1587297

Heemskerk, C. H. H. M., Lubans, D., Strand, S., & Malmberg, L.-E. (2020). The effect of physical education lesson intensity and cognitive demand on subsequent learning behavior. *Journal of Science and Medicine in Sport*, *23*, 586–590. https://doi.org/10.1016/j.jsams.2019.12.012

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience*, *9*, 58–65. https://doi.org/10.1038/nrn2298

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*, 163–182. https://doi.org/10.1037/0033-295X.95.2.163

Kreibig, S., & Gendolla, G. H. E. (2014). Autonomic nervous system measurement of emotion in education and achievement settings. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 625–642). New York, NY: Routledge.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, *82*, 1–26. https://doi.org/10.18637/jss.v082.i13

Li, Z., Snieder, H., Su, S., Ding, X., Thayer, J. F., Treiber, F. A., & Wang, X. (2009). A longitudinal study in youth of heart rate variability at rest and in response to stress. *International Journal of Psychophysiology*, *73*, 212–217. https://doi.org/10.1016/j.ijpsycho.2009.03.002

Logan, S., & Johnston, R. (2009). Gender differences in reading ability and attitudes: Examining where these differences lie. *Journal of Research in Reading*, *32*, 199–214. https://doi.org/10.1111/j.1467-9817.2008.01389.x

Lucisano, P. (1992). *Misurare le parole [Measuring words]*. Rome, Italy: Kepos.

Lüdecke, D., Ben-Shachar, M. S., Patil, I., Waggoner, P., & Makowski, D. (2021). Performance: An R package for assessment, comparison and testing of statistical models. *Journal of Open Source Software*, *6*, 3139. https://doi.org/10.21105/joss.03139

Mason, L., & Gava, M. (2007). Effects of epistemological beliefs and learning text structure on conceptual change. In S. Vosniadou, A. Baltas & X. Vamvakoussi (Eds.), *Reframing the conceptual change approach in learning and instruction* (pp. 165–196). Oxford, UK: Elsevier.

Mason, L., Scrimin, S., Tornatora, M. C., Suitner, C., & Moè, A. (2018). Internet source evaluation: The role of implicit associations and psychophysiological self-regulation. *Computers & Education*, *119*, 59–75. https://doi.org/10.1016/j.compedu.2017.12.009

McNamara, D. S., & Kintsch, W. (1996). Learning from texts: Effect of prior knowledge and text coherence. *Discourse Processes*, *22*, 247–288. https://doi.org/10.1080/01638539609544975

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Muijselaar, M. M. L., & De Jong, P. F. (2015). The effects of updating ability and knowledge of reading strategies on reading comprehension. *Learning and Individual Differences*, *43*, 111–117. https://doi.org/10.1016/j.lindif.2015.08.011

Norwood, M. F., Lakhani, A., Fullagar, S., Maujean, A., Downes, M., Byrne, J., . . . Kendall, E. (2019). A narrative and systematic review of the behavioural, cognitive and emotional effects of passive nature exposure on young people: Evidence for prescribing change. *Landscape and Urban Planning*, *189*, 71–79. https://doi.org/10.1016/j.landurbplan.2019.04.007

Nouwens, S., Groen, M. A., & Verhoeven, L. (2016). How storage and executive functions contribute to children's reading comprehension. *Learning and Individual Differences*, *47*, 96–102. https://doi.org/10.1016/j.lindif.2015.12.008

Oliveira, R. S., Barker, A. R., Wilkinson, K. M., Abbott, R. A., & Williams, C. A. (2017). Is cardiac autonomic function associated with cardiorespiratory fitness and physical activity in children and adolescents? A systematic review of cross-sectional studies. *International Journal of Cardiology*, *236*, 113–122. https://doi.org/10.1016/j.ijcard.2017.02.022

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, *32*, 1–11. https://doi.org/10.1038/sj.ijo.0803774

Palladino, P., Cornoldi, C., De Beni, R., & Pazzaglia, F. (2001). Working memory and updating processes in reading comprehension. *Memory & Cognition*, *29*, 344–354. https://doi.org/10.3758/BF03194929

Panadero, E. (2017). A review of self-regulated learning: six models and four directions for research. *Frontiers in Psychology*, *8*, 1–28. https://doi.org/10.3389/fpsyg.2017.00422

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, *18*, 315–341. https://doi.org/10.1007/s10648-006-9029-9

Pekrun, R. (2018). Control-value theory: A social-cognitive approach to achievement emotions. In G. A. D. Liem & D. M. McInerney (Eds.), *Big theories revisited 2: A volume of research on sociocultural influences on motivation and learning* (pp. 162–190). Charlotte, NC: Information Age Publishing.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120–141). New York, NY: Routledge.

Porges, S. W. (2007). A phylogenetic journey through the vague and ambiguous Xth cranial nerve: A commentary on contemporary heart rate variability research. *Biological Psychology*, *74*, 301–307. https://doi.org/10.1016/j.biopsycho.2006.08.007

Porges, S. W., & Byrne, E. A. (1992). Research methods for measurement of heart rate and respiration. *Biological Psychology*, *34*, 93–130. https://doi.org/10.1016/0301-0511(92)90012-J

Putwain, D. W., & Symes, W. (2011). Teachers' use of fear appeals in the mathematics classroom: Worrying or motivating students? *British Journal of Educational Psychology*, *81*, 456–474. https://doi.org/10.1348/2044-8279.002005

R Core Team (2021). *R: A language and environment for statistical computing. R Foundation for statistical computing*. R Core Team. Retrieved from: https://www.r-project.org/

Raccanello, D., Brondino, M., Crescentini, A., Castelli, L., & Calvo, S. (2021). A brief measure for school-related achievement emotions: The Achievement Emotions Adjective List (AEAL) for secondary students. *European Journal of Developmental Psychology*. Advance Online Publication. https://doi.org/10.1080/17405629.2021.1898940

Raccanello, D., Brondino, M., Moè, A., Stupnisky, R., & Lichtenfeld, S. (2019). Enjoyment, boredom, anxiety in elementary schools in two domains: Relations with achievement. *The Journal of Experimental Education*, *87*, 449–469. https://doi.org/10.1080/00220973.2018.1448747

Raccanello, D., & Hall, R. (2021). An intervention promoting understanding of achievement emotions with middle school students. *European Journal of Psychology of Education*, *36*, 759–780. https://doi.org/10.1007/s10212-020-00498-x

Robin, J., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research*, *85*, 512–552. https://doi.org/10.3102/0034654314561338

Roos, A. L., Goetz, T., Krannich, M., Jarrell, A., Donker, M., & Mainhard, T. (2021). Test anxiety components: an intra-individual approach testing their control antecedents and effects on performance. *Anxiety, Stress, & Coping*, *34*, 279–298. https://doi.org/10.1080/10615806.2020.1850700

Roos, A. L., Goetz, T., Voracek, M., Krannich, M., Bieg, M., Jarrell, A., & Pekrun, R. (2021). Test anxiety and physiological arousal: a systematic review and meta-analysis. *Educational Psychology Review*, *33*, 579–618. https://doi.org/10.1007/s10648-020-09543-z

Rozek, C. S., Ramirez, G., Fine, R. D., & Beilock, S. L. (2019). Reducing socioeconomic disparities in the STEM pipeline through student emotion regulation. *Proceeding of the National Academy of Science*, *116*, 1553–1558. https://doi.org/10.1073/pnas.1808589116

Scrimin, S., Moscardino, U., & Mason, L. (2019). First-graders' allocation of attentional resources in an emotional Stroop task: The role of heart period variability and classroom climate. *British Journal of Educational Psychology*, *89*(1), 146–164. https://doi.org/10.1111/bjep.12228

Scrimin, S., Osler, G., Moscardino, U., & Mason, L. (2018). Classroom climate, cardiac vagal tone, and inhibitory control: links to focused attention in first graders. *Mind, Brain, and Education*, *12*, 61–70. https://doi.org/10.1111/mbe.12169

Scrimin, S., Patron, E., Florit, E., Palomba, D., & Mason, L. (2017). The role of cardiac vagal tone and inhibitory control in pre-schoolers' listening comprehension. *Developmental Psychobiology*, *59*, 970–975. https://doi.org/10.1002/dev.21576

Scrimin, S., Patron, E., Peruzza, M., & Moscardino, U. (2020). Cardiac vagal tone and executive functions: Moderation by physical fitness and family support. *Journal of Applied Developmental Psychology*, *67*, 101120. https://doi.org/10.1016/j.appdev.2020.101120

Scrimin, S., Patron, E., Ruli, E., Pagui, C. E. K., Altoè, G., & Mason, L. (2018). Dynamic psychophysiological correlates of a learning from text episode in relation to reading goals. *Learning and Instruction*, *54*, 1–10. https://doi.org/10.1016/j.learninstruc.2018.01.007

Seipp, B. (1991). Anxiety and academic performance: A meta-analysis of findings. *Anxiety Research*, *4*(1), 27–41. https://doi.org/10.1080/08917779108248762

Siedlecka, E., & Denson, T. F. (2019). Experimental methods for inducing basic emotions: A qualitative review. *Emotion Review*, *11*(1), 87–97. https://doi.org/10.1177/1754073917749016

Somerville, M. P., & Whitebread, D. (2018). Emotion regulation and well-being in primary classrooms situated in low-socioeconomic communities. *British Journal of Educational Psychology*, *89*, 565–584. https://doi.org/10.1111/bjep.12222

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology*, *59*, 745–759. https://doi.org/10.1080/17470210500162854

Teigen, K. H. (1994). Yerkes-Dodson: A law for all seasons. *Theory & Psychology*, *4*, 525–547. https://doi.org/10.1177/0959354394044004

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. J. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*, 141–153. https://doi.org/10.1007/s12160-009-9101-z

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*, 201–216. https://doi.org/10.1016/S0165-0327(00)00338-4

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*, 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482. https://doi.org/10.1002/cne.920180503

Zaccoletti, S., Altoè, G., & Mason, L. (2020a). Enjoyment, anxiety and boredom, and their control-value antecedents as predictors of reading comprehension. *Learning and Individual Differences*, *79*, 101869. https://doi.org/10.1016/j.lindif.2020.101869

Zaccoletti, S., Altoè, G., & Mason, L. (2020b). The interplay of reading-related emotions and updating in reading comprehension performance. *British Journal of Educational Psychology*, *90*, 663–682. https://doi.org/10.1111/bjep.12324

Zeidner, M. (2007). Test anxiety in educational contexts. In P. A. Schutz & R. Pekrun (Eds.), *Emotion in education* (pp. 165–184). Cambridge, MA: Academic Press.

Zeidner, M. (2014). Anxiety in education. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 265–288). New York, NY: Routledge.

Zhang, J., Zhao, N., & Kong, Q. P. (2019). The relationship between math anxiety and math performance: A meta-analytic investigation. *Frontiers in Psychology*, *10*, 1613. https://doi.org/10.3389/fpsyg.2019.01613

Zimmermann, B. J., & Schunk, D. H. (Eds.). (2011). Self-regulated learning and performance: An introduction and overview. In *Handbook of self-regulation of learning and performance* (pp. 1–12). New York, NY: Routledge.