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The placebo effect in reading performance: A cross-over experimental study

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ABSTRACT

Converging evidence suggests that clinically-relevant benefits from placebo treatment – such as words and rituals of the therapeutic act - may change the chemistry and circuitry of the brain underlying perceptual and sensorimotor enhancements. The present study aimed to test whether placebo and nocebo effects can also modulate high-level processing, such as single word reading and pseudoword decoding. In a within-subject experiment, 102 young adults were asked to wear a sham pair of glasses purported to modify reading performance, and were informed that the purpose of the study was to evaluate the effects of these special glasses on pupil size. Positive and negative expectations were induced both explicitly, through verbal instructions provided by the experimenter, and implicitly, through feedback-based learning via manipulation of computerized performance feedback. Subjective effects and Big Five personality, as well as pupil size and heart rate, were also measured. Participants reported the lenses had influenced their performance. Explicit placebo expectations enhanced word and pseudoword reading speed. In contrast, negative expectations did not significantly impair performance, although nocebo might exert an effect in longer tasks. Expectations were not affected by the conditioning phase. Big Five factors did not modulate the effect of expectations. No significant differences were observed between the placebo and nocebo conditions in heart rate and pupil size. These findings highlight the need to consciously harness such effects in clinical practice and to rigorously control for such effects during reading training programs.

1. Introduction

In modern society, where the vast majority of individuals have access to formal education, proficient reading skills are indispensable. Their importance extends beyond individuals with developmental dyslexia to the general population, as reading competence is instrumental for achievement across academic and professional domains (Schofer & Meyer, 2005). Although the extent to which a complex, high-level skill such as reading can be enhanced through targeted behavioral training remains debated (e.g., Galuschka et al., 2014; Bowers, 2020; Puccio et al., 2024; Breznitz et al., 2013), confirmation of this potential would carry substantial implications for real-world outcomes (Pasqualotto et al., 2022).

Despite evidence on placebo and nocebo effects in perceptual tasks, it remains unclear how expectancy influences higher-level processes such as reading. The present study addresses this gap by examining the impact of positive and negative expectations on reading performance and related physiological markers.

Alongside training specifically designed to enhance the core abilities underlying reading skills (e.g., Breznitz et al., 2013; Horowitz-Kraus et al., 2025), other augmenting factors, such as expectations and emotions, could be manipulated to further amplify reading performance (e.g., Franceschini et al., 2022; Franceschini, Puccio, Bertoni, Mascheretti, et al., 2025). Expectation effects arise from the meaning responses elicited by a treatment - that is, the brain-mind reactions triggered by the significance and context attributed to the intervention - rather than from

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its physical or pharmacological properties (Moerman & Jonas, 2002; Wager & Atlas, 2015). Within this framework, placebo effects represent positive outcomes resulting from expectations of benefit, while nocebo effects represent negative outcomes arising from expectations of harm. Both placebo and nocebo effects are considered specific instances of expectancy effects, which are conscious, conceptual beliefs about the future occurrence of an event and a subclass of broader predictive processes (Wager & Atlas, 2015). Positive (placebo) and negative (nocebo) expectations in intervention efficacy can induce measurable changes in attention, perception and working memory as well as physiological responses (e.g., Vera et al., 2022; Parong et al., 2023; see Benedetti et al., 2005; Finniss et al., 2010; Frisaldi et al., 2023 for reviews).

From a Bayesian brain perspective, expectations function as top-down predictive signals that modulate the precision and weighting of incoming sensory information, biasing processing toward anticipated outcomes. Rather than simply altering perceptual content, they shape attentional deployment and cognitive resource allocation in a task-relevant manner (Pagnini et al., 2023). In clinical contexts, this predictive tuning may enhance positive (in case of positive expectation) outcomes by directing patients' attention toward cues consistent with improvement while attenuating the salience of illness-related signals (Barbiani et al., 2024).

While the neurochemistry underlying the placebo effect – associated with the release of dopamine, noradrenaline, endogenous opioids and endocannabinoids - is sometimes regarded as distinct from the neurochemistry of the nocebo effect - linked to the release of adrenocorticotropic hormone and cortisol - the two phenomena are also described as interconnected along a continuum (Exton et al., 2002; Frisaldi et al., 2015). This is exemplified by observing the role of cholecystokinin in modulating the opioid system (Benedetti, 2007; 2011). The multiplicity of models is likely attributable to the fact that there is not just one placebo or nocebo effect, but rather many, arising from different psychophysiological mechanisms (Frisaldi et al., 2015, 2023; Pagnini et al., 2023), and multiple mechanisms - not necessarily exclusive - can operate at the same time.

Because of the diverse psychological mechanisms underlying the expectancy effect, research on potential personality correlates has produced mixed findings. Assessed through multiple tests, such as the Big Five framework (McCrae & John, 1992), multiple personality traits have, at times, been linked to expectancy-related effects. Openness to experience and Agreeableness were found to be higher in placebo responders (Beedie et al., 2008; Kelley et al., 2009), whereas high levels of Conscientiousness were negatively correlated with nocebo effects (Corsi et al., 2016). Extroversion (Beedie et al., 2008; Darragh et al., 2014) and Neuroticism (Beedie et al., 2008; Peciña et al., 2013) showed mixed results. Nevertheless, for all the traits the evidence remains far from conclusive (Kang et al., 2023; Kern et al., 2020), highlighting the need for more fine-grained investigations targeting specific domains of expectation.

The expectancy effect does not necessarily have to involve inert pills or sham procedures. The clinical environment surrounding treatment administration encompasses various types of contextual information that are perceived and interpreted by the recipient: symbols, beliefs, and expectations can elicit powerful psychological occurrences, both positive and negative (Crum & Langer, 2007; Frisaldi et al., 2015). The external context information includes factors such as the intervention itself, the tools, the location, the social cues, and the verbal suggestions that elicit specific internal responses - context memories and emotions - through which the context is assessed for its significance to well-being (Meissner et al., 2011; Wager & Atlas, 2015). Literature indicates that placebo and nocebo effects can be mediated by both conscious expectancy learning and non-conscious associative learning processes. Verbal instructions and prior experience can shape explicit expectancies that influence outcomes, while classical conditioning and other feedback-based learning associations can also produce placebo/nocebo responses even in the absence of conscious expectancy (Stewart-Williams & Podd, 2004; see also Wager & Atlas, 2015). If an individual receives verbal instructions about the effectiveness of a given intervention in improving a cognitive skill - similar to a reward-like effect - their attention will be more focused, allowing for more effective allocation of cognitive resources and enhancing both persistence and effort (Piedimonte et al., 2024; Summerfield & Egner, 2009). Similarly, previous (perceived) positive experiences in task execution can induce conditioned beneficial cognitive and behavioral effects (Wager & Atlas, 2015), thereby perpetuating placebo effects over time. Parong et al. (2023), used both the explicit (participants were explicitly told what behavioral changes they should expect) and implicit learning (participants were made to experience a behavioral change associated with expected outcome) to study the effect of expectation about working memory training on their performance. The authors demonstrated that positive expectation - compared to negative one - leads to substantial improvements in working memory, executive functions, and general cognitive abilities measured with tasks that involve discrimination and integration of visuo-spatial information. These improvements were obtained independently from training contents, simply inducing positive and negative expectations about training effects (Parong et al., 2023). Similarly, Vera et al. (2022) showed that at visuo-perceptual level, a more stable accommodative response and better stereoacuity could be obtained administering inert pills accompanied by positive (compared to negative) expectations. Other studies have confirmed that the induction of expectations through instructions, devices, or physical activities can enhance letter recognition abilities, as measured by the Snellen Chart or similar tasks (e.g., Langer et al., 2010; Piedimonte et al., 2024). Langer et al. (2010) demonstrate that the observed visuo-attentional improvements were not a mere consequence of variation in arousal activation. In addition, Piedimonte et al. (2024) showed, through EEG observation, that the effects of expectation were attributable to top-down attentional components rather than to changes in bottom-up, lower-level visual perceptual abilities. Expectations seem to influence selective attention, which may subsequently amplify or modulate the processing of sensory information (Barbiani et al., 2024; Franceschini, Puccio, Bertoni, Gori, et al., 2025; Pagnini et al., 2023). These findings suggest that positive expectations (placebo) may shift the decision criterion toward faster endorsement of perceived stimuli, whereas negative expectations (nocebo) may induce a more conservative response threshold, thereby prolonging decision time (Green & Bavelier, 2012).

Based on expectancy theory, both positive and negative expectations can lead to observable variations not only in the recognition of single letters, but also in individuals' word reading abilities. In this regard, Lubineau et al. (2023), testing the effectiveness of commercial glasses with flickering lenses, found that users' expectations could influence their reading performance. Furthermore, a recent study investigating the efficacy of these specific glasses demonstrated their potential to induce a placebo effect in the word reading among both children and adults with reading difficulties (Franceschini, Puccio, Bertoni, Mascheretti, et al., 2025). However, the small sample size and the use of a paper-and-pencil test limited the precision in quantifying the comparability of the observed effects on reading performance.

This study aims to investigate whether: (i) positive and negative expectations induced in participants influence their reading speed and accuracy. Based on the literature, an improvement (placebo) and a decrease (nocebo) in reaction times was expected, regardless of the type of word or pseudoword stimuli used (Franceschini, Puccio, Bertoni, Mascheretti, et al., 2025; Langer et al., 2010; Piedimonte et al., 2024; Vera et al., 2022), (ii) these effects can be attributed to feedback-based learning or previously induced explicit expectations (Stewart-Williams & Podd, 2004), (iii) expectation effects on reading performance are associated with specific personality traits (Kern et al., 2020), and (iv) expectations modulate pupil diameter and heart rate as indirect markers of norepinephrine and acetylcholine release, and consequently arousal (Grujic et al., 2024).

2. Methods

2.1. Participants

A power analysis indicated that a sample size of 70 participants is required to detect a small-to-moderate interaction effect (Cohen's d = 0.3) using linear mixed-effects models, with a significance level of $\alpha < 0.05$, and a statistical power of 0.80.

A total of 104 undergraduate students were initially recruited for the study. Two participants were excluded from the final analysis due to incomplete data, yielding a final sample of 102 students (20 males). The age of participants ranged from 19 to 36 years (M = 20.68, SD = 2.02). Students received one bonus point toward a course examination for their participation.

2.2. Ethical approval

The research was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Department of General Psychology at the University of Padova. Participation in the study was obtained following the signing of informed consent (122/b). The experimental session duration was approximately 50 min. A diagnosis of epilepsy or not being a native Italian speaker were considered exclusion criteria.

2.3. Procedure

2.3.1. Administration procedure and expectancy induction

Participants were informed that the study involved the use of glasses equipped with flickering lenses, which were designed to enhance reading performance. They were told that previous literature had shown significant effects of these glasses on reading, and that these effects were attributed to the specific flickering frequencies (measured in Hz) of the lenses. It was further explained that the aim of the study was to determine whether the effects of the lenses were associated with changes in pupil size. Participants were informed that to work properly, the glasses required individual calibration. This procedure was performed by an experimenter introduced as an external expert, who wore a lab coat and spoke with a noticeably strong foreign accent to enhance perceived credibility and authority. Participants were instructed to wear a chest strap for heart rate monitoring. Following this, the glasses calibration procedure was conducted using a staircase method to determine the individual optimal flicker frequency. Once calibration was completed, the participant wore the wireless glasses (always turned-off, the fine calibration was only used to induce expectations) and the computerized reading task began.

Participants were informed that, during the initial phase of the experiment, their ability to read isolated words and pseudowords would be assessed while wearing frequency-modulating glasses that were active, but not adjusted according to individual calibration - this constituted the baseline condition (see Fig. 1). In subsequent phases, participants were informed that the glasses were set at higher frequencies than that determined during the individual calibration procedure, and it was clarified that this procedure will have enhanced word reading performance (placebo) while impairing the processing of pseudowords (nocebo). In another condition, participants were informed that the glasses were set to frequencies slightly lower than the previous calibrated value, and it was clarified that this frequency will have enhanced pseudoword reading (placebo) but interfere with word recognition (nocebo). The baseline condition was always administered first. The two experimental conditions (high- and low-frequency settings relative to baseline) were presented in a counterbalanced, randomized order across participants. Prior to each list presentation, the experimenter reminded the participant of the current lens frequency setting

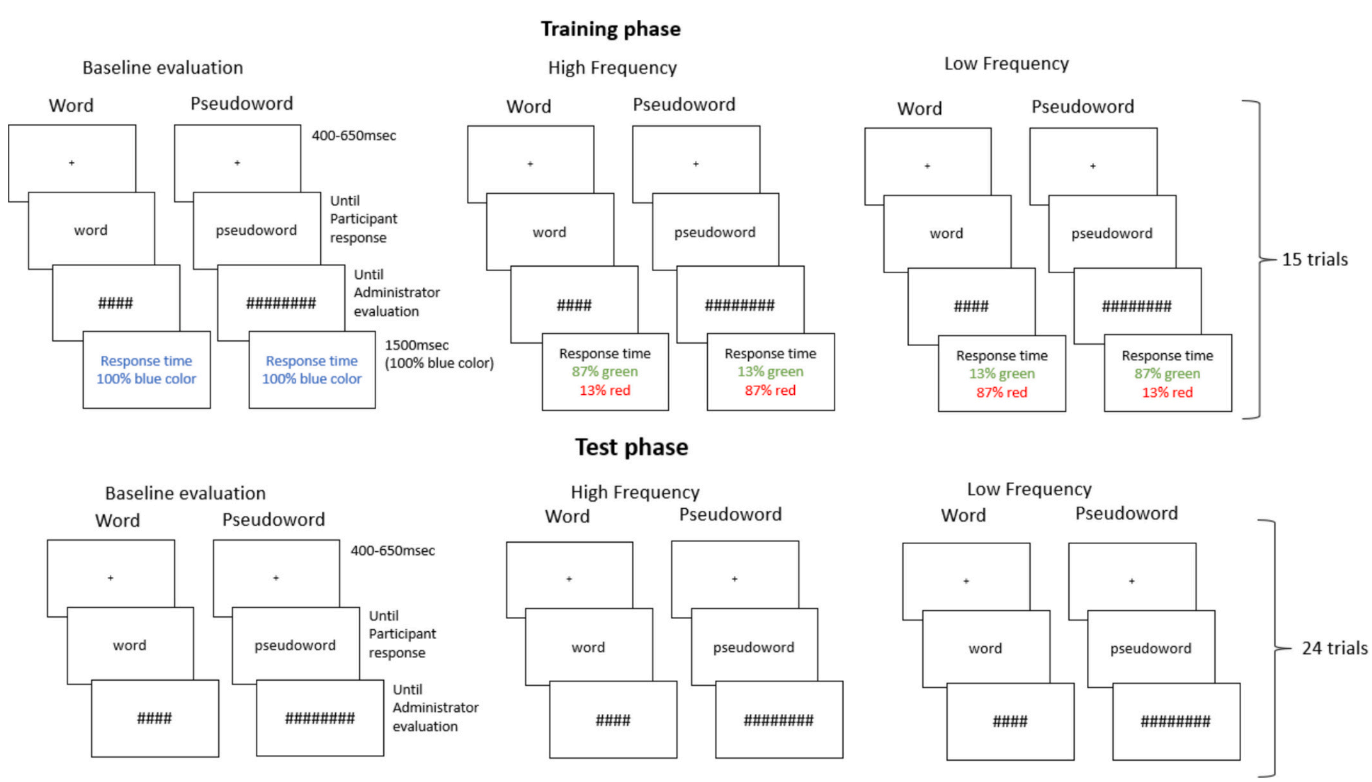

Fig. 1. Reading test procedure. The Baseline condition preceded the sham manipulation of the glasses' calibration frequencies. Both the order of high- and low-frequency condition and the sequence of word and pseudoword reading tasks were randomized between participants. During the 15 trials Training phase, feedback was green in 87% and red in 13% of trials for placebo conditions, with the opposite pattern observed in nocebo conditions, regardless of participants' actual performance. In the 24 trial Test phase no feedback was given. Pupil size and heart rate were measured at the end of the Training phase, before the Test phase. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and the expected reading effects. A second experimenter simulated the frequency shift using a mobile application.

2.3.2. Conditioning procedure: Training phase

In the Training phase, the first 15 items of each list in every condition (i.e. baseline, high- and low-frequency) were followed by on-screen feedback of the participant's RTs.

Participants were informed that, during the baseline condition, RTs would appear in blue, indicating that the system was functioning correctly and that RTs were being accurately recorded. In the high- and low-frequency conditions, RTs were instead color-coded based on performance relative to the baseline, considering word length and lexical frequency. RTs appeared in green if they were shorter than baseline, and in red if they were longer. Participants were not informed that feedback colouring was presented independently of actual RTs. In the placebo conditions, 87% of items were displayed in green and 13% in red, whereas in the nocebo conditions, these proportions were reversed (Lidstone et al., 2010).

2.3.3. Test phase

At the conclusion of the Training phase, physiological assessments – including pupillometry and heart rate monitoring - were conducted.

Following physiological assessments, the reading task restarted, in the Test phase, without the display of RTs (See Fig. 1).

At the end of the experimental session, participants were invited to fill in the Big Five Inventory and were asked whether they had noticed effects of the glasses efficiency on their reading performance. A full debriefing was provided via email to all the participants, explaining the actual purpose of the study.

2.4. Methods and materials

2.4.1. Experimental computerized reading task

Three lists of 39 words and three lists of 39 pseudowords were used (font: Arial bold; point size: 18). The three word lists were balanced for word length (number of letters and syllables), stress on syllables, and usage frequency, based on frequency data for written Italian (https://linguistica.sns.it/CoLFIS/Home.htm). The pseudoword lists were also balanced for length and for the frequency of the original words, which were subsequently modified by changing one or two letters to eliminate semantic content. The three lists were administered in randomized order across participants in the three different experimental conditions. The items were presented one at a time in a fixed order for all participants (see Supplementary materials). Of the 39 items in each list, 15 were used in the training phase, and the remaining 24 in the test phase (See Fig. 1, Procedure section and Supplementary materials). The participant was instructed to pronounce the display-presented item aloud as quickly as possible. Vocal reaction time (RT in ms) and errors were registered. All trials with RTs shorter than 100 ms and longer than 1000 ms were considered to be outliers and removed (0.8% of trials). For each participant, mean RTs were computed based on correctly answered trials, while trials with response latencies exceeding ± 2 standard deviations from the individual mean were excluded from the analyses.

2.4.2. Glasses for calibration and reading evaluation

A pair of Lexilens glasses (https://lexilens.com/) was used. These glasses, unlike the commercially available ones, were wired to a device that allowed the adjustment of the lenses' flickering rate in hertz (Hz) and luminance in candelas per square meter (cd/m^2) via two micrometric knobs (see also Supplementary materials). These glasses, used only in this phase, were turned on.

2.4.3. Glasses for reading evaluation

A second pair of commercially available Lexilens glasses was used for the baseline and experimental phases. The lenses of these glasses were always, in all the phases of the experiment, turned-off.

Participants were informed that the glasses were being "calibrated" in each phase based on the earlier calibration session, using a smartphone app connected to the glasses via Bluetooth (see Supplementary materials).

2.4.4. Personality traits assessment

All participants completed the Big Five Inventory (McCrae & John, 1992; Ubbiali et al., 2013), which assesses five core personality traits: Openness to experience (curiosity and creativity), Conscientiousness (self-discipline and organization), Extraversion (sociability and energy), Agreeableness (cooperation and empathy) and Neuroticism (emotional instability and susceptibility to negative emotions). One participant was excluded from the final analysis due to incomplete questionnaire data.

2.4.5. Single question on self-report temporal frequency efficiency

Participants were asked to indicate (yes/no) if they noticed an effective influence of Hz manipulation.

2.4.6. Pupillometry

Pupil size measurement was recorded using the Tobii PRO X3, with a sampling frequency of 120 Hz. During the experiment, participants underwent a total of six pupil measurements: at the end of each training phase for each of the three conditions, together with the heart rate measurements. Participants were required to fixate on a visual stimulus on a screen positioned 65 cm away for 60 s.

2.4.7. Heart rate measurement

Average heart rate was recorded using the COOSPORIDE H6 heart rate monitor, paired with the corresponding COOSPORIDE app. Evaluation started with each pupillometry evaluation.

3. Outcomes

3.1. Expectation effects in test and training phase

Linear mixed models (LMM) were applied to analyze the data, as this approach is widely recommended in experimental psychology studies that apply within-participants design (Magezi, 2015). Two separate models were fitted for each Experimental Phase (Training and Test), one considering reading speed (log-transformed) and one considering accuracy as dependent variable). Significant results are presented in milliseconds to facilitate interpretation.

In all models, fixed effects included Lexicality effect (words and pseudowords), Experimental Condition (baseline, placebo, and nocebo) and progressive number of trials, together with all their interactions. The random-effects structure included by-subject random intercepts and random slopes for Condition and Lexicality effect. Marginal R^2 represents the proportion of variance explained by the fixed effects alone, whereas conditional R^2 represents the variance explained by both fixed and random effects. Fixed effects were tested using F-tests with Satterthwaite approximation for degrees of freedom.

3.2. Personality traits influencing expectation effects

To investigate the potential role of each Big Five personality trait on the effect of condition (baseline, placebo, nocebo) during the Test phase, we conducted an additional analysis extending the previous model by including each personality trait and its interaction with Condition.

3.3. Heart rate

As in the previous LMM analyses, fixed effects included Lexicality (words and pseudowords) and Experimental Condition (baseline, placebo and nocebo), along with their interactions.

3.4. Pupillometry

The same LMM procedure was applied to pupil-size data. Due to data loss, these analyses were conducted on a sample of 63 participants.

4. Results

4.1. Test phase

4.1.1. Vocal RTs

The model showed marginal $R^2 = 0.096$ and conditional $R^2 = 0.463$ (see also Results section in Supplementary material). Words were associated with significantly shorter log-transformed RTs than pseudowords ($\beta = -0.124$, SE $= 0.007$, 95% CI[-0.137, -0.110], $t_{(101)} = -18.040$, $p < .001$). Relative to baseline, the placebo condition showed significantly shorter log-RTs ($\beta = -0.014$, SE $= 0.006$, 95% CI[-0.026, -0.002], $t_{(101)} = -2.283$, $p = .025$). Relative to nocebo, the placebo condition showed significantly shorter log-RTs ($\beta = -0.019$, SE $= 0.006$, 95% CI [-0.030, -0.008], $t_{(101)} = 3.448$, $p < .001$). The nocebo condition did not differ significantly from baseline ($\beta = 0.005$, SE $= 0.007$, 95% CI [-0.008, 0.019], $t_{(101)} = 0.729$, $p = .468$).

To provide a standardized effect size for the main comparisons of interest, we computed Cohen's d on the raw RTs in ms. Comparison of response time obtained in Placebo (mean = 458, SE = 5.49) and baseline (mean = 464, SE = 5.58) showed a significant difference ($t_{(101)} = 2.070$, $p = .041$, Cohen's d = 0.205 95% CI = 0.008 / 0.401). Similarly, comparison of response time obtained in placebo and nocebo condition (mean = 467, SE = 5.51) showed a significant difference ($t_{(101)} = 3.418$, $p < .001$, Cohen's d = 0.338 95% CI = 0.138 / 0.537; See Fig. 2).

The Condition × Trial interaction was significant, relative to baseline the placebo condition showed a small negative slope difference across trials ($\beta = 0.001$, SE < 0.001, 95% CI [0.000, 0.002], $t_{(12814)} = -2.215$, $p = .027$), whereas the nocebo condition showed a larger positive slope difference ($\beta = 0.002$, SE < 0.001, 95% CI [0.001, 0.003], $t_{(12814)} = 3.692$, $p < .001$) (See Fig. 3).

4.1.2. Accuracy rate

The model shows marginal $R^2 = 0.308$ and conditional $R^2 = 0.473$ (See also Supplementary materials). The main effect of Lexicality was significant, with words associated with higher rate of correct responses than pseudowords ($\beta = 2.701$, SE $= 0.299$, 95% CI [2.115, 3.287], $z = 9.034$, $p \leq 0.001$); as expected the reading accuracy of word (mean = 0.99, SE = 0.001) was higher than pseudoword (accuracy = 0.95, SE = 0.004). No other main effect or interaction was significant.

In order to investigate the possible role of feedback-based learning on the positive and negative expectancy effects observed in the Test phase, we repeated the same analysis in the Training phase.

4.2. Training phase

4.2.1. Vocal RTs

The model showed marginal $R^2 = 0.080$ and conditional $R^2 = 0.407$ (See Supplementary materials). The main effect of Lexicality was significant, with words associated with shorter log-RTs than pseudowords ($\beta = -0.109$, SE $= 0.009$, 95% CI [-0.127, -0.092], $t_{(101)} = -12.517$, $p < .001$). The main effect of Condition was also significant. Relative to the baseline condition, the placebo condition showed significantly shorter log-RTs ($\beta = -0.060$, SE $= 0.008$, 95% CI [-0.076, -0.044], $t_{(101)} = -3.345$, $p < .001$), and the nocebo condition also showed significantly shorter log-RTs compared to baseline ($\beta = -0.032$, SE $= 0.007$, 95% CI [-0.046, -0.018]). There was a significant main effect of Number of trials, indicating a systematic change in RTs across trials ($\beta = 0.004$, SE < 0.001, 95% CI [0.003, 0.005], $t_{(101)} = -4.367$, $p < .001$).

Significant two-way interactions emerged between Lexicality and Condition, the interaction was further examined using Bonferroni-corrected pairwise comparisons on the estimated marginal means. In the pseudoword condition, responses in the placebo condition were significantly faster than in the nocebo condition (delta (Δ) $= -0.028$, SE $= 0.009$, 95% CI [-0.046, -0.010], $t_{(193)} = 3.018$, $p = .043$), and than in the baseline condition ($\Delta = -0.078$, SE $= 0.010$, 95% CI [-0.097, -0.059], $t_{(188)} = 8.218$, $p < .001$). Also between baseline and nocebo was observed a significant difference ($\Delta = -0.050$, SE $= 0.009$, 95% CI [-0.067, -0.033], $t_{(211)} = 5.673$, $p < .001$). In the word condition, a difference was observed between placebo and nocebo condition ($\Delta = -0.027$, SE $= 0.009$, 95% CI [-0.045, -0.009], $t_{(178)} = -2.994$, $p = .047$), and baseline and placebo: $\Delta = 0.041$, SE $= 0.009$, 95% CI [0.023, 0.059], $t_{(173)} = 4.418$, $p < .001$), whereas no significant difference emerged between nocebo and baseline ($p = .999$) (see Fig. 4).

Significant two-way interactions emerged also between Lexicality and Number of trials, indicating that the effect of Lexicality changed

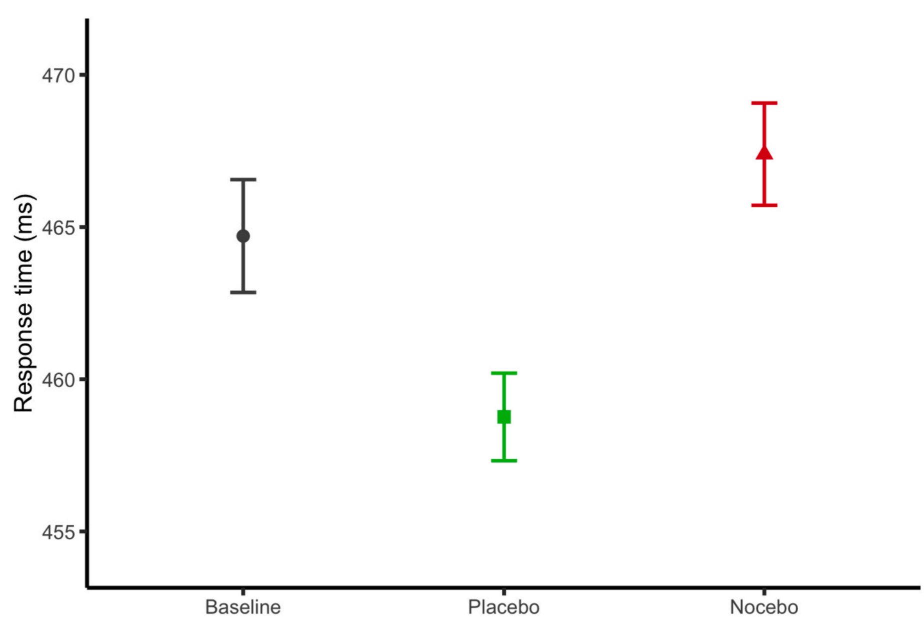

Fig. 2. Main effect of expectation on reading RTs. In the positive expectation condition (placebo), participants read significantly faster than in both the baseline and the negative expectation (nocebo) conditions. Bars represent standard error of the mean.

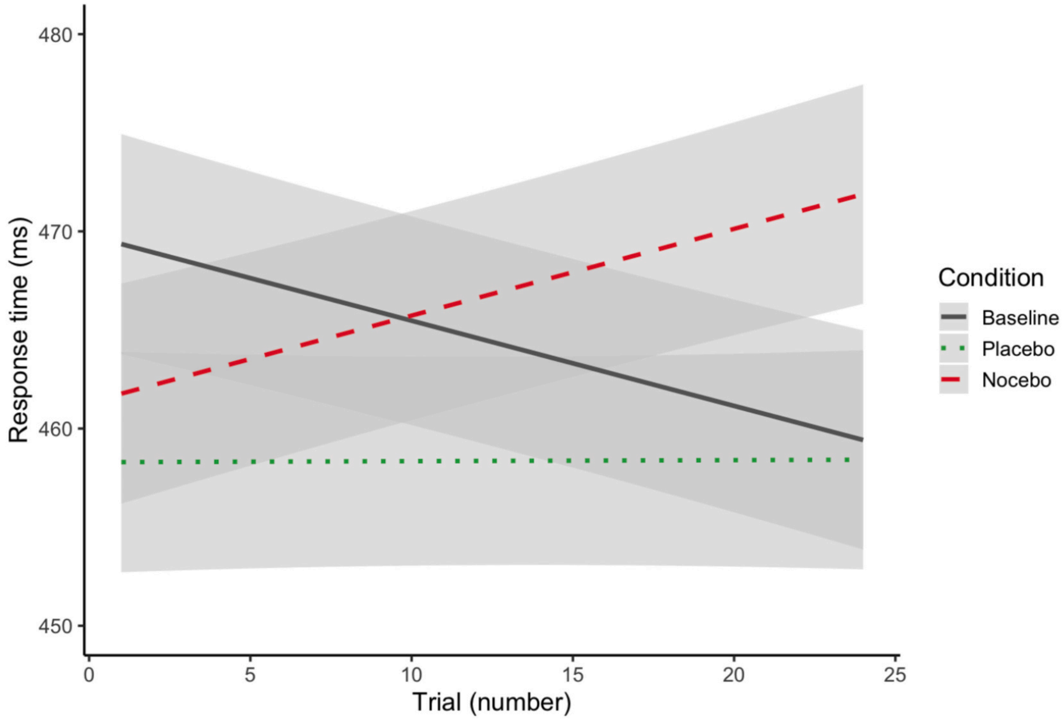

Fig. 3. Interaction between Condition and Number of trials. Grey shadows represent standard errors.

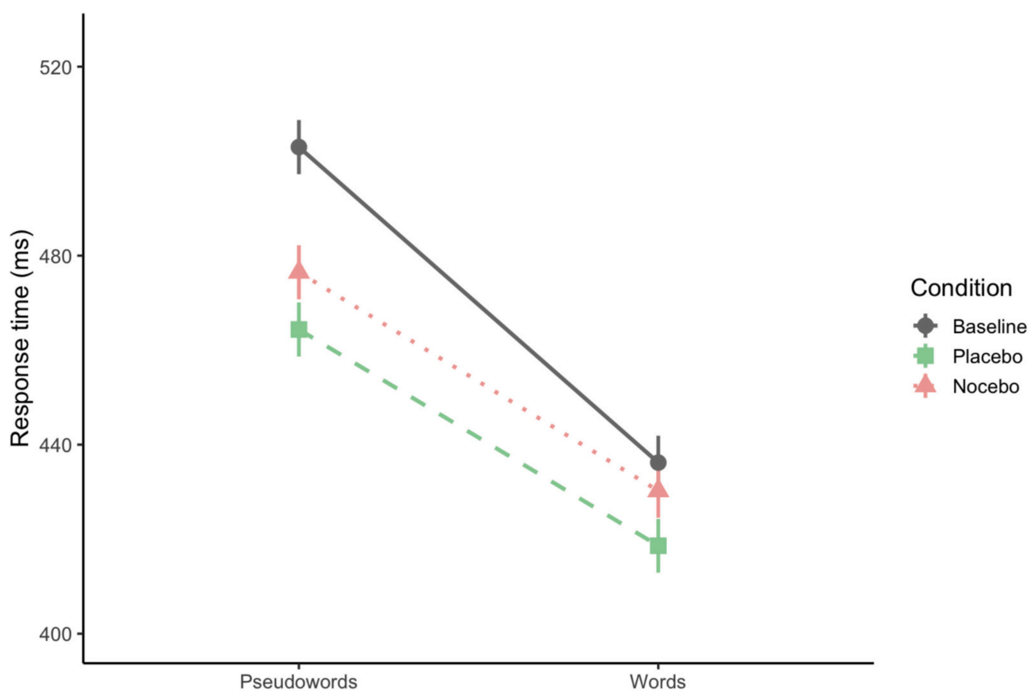

Fig. 4. Lexicality by Condition interaction. Bars represent standard error of the mean.

across trials (β = −0.005, SE = 0.001, 95% CI [−0.007, −0.003], $t_{(7785)} = -5.286$, $p < .001$). Responses to pseudowords became progressively slower relative to words over the course of the experiment, resulting in a widening Lexicality effect across trials.

Finally, the significant Condition and Number of trials interaction (see Fig. 5) indicated that the effect of Condition decreased across trials excluding any possible effect of our feedback-based learning procedure to induce placebo and nocebo during the Training phase. Simple effects analyses showed that Condition remained significant at all levels of Number of trials, although the effect attenuated over time. At −1 SD (near the beginning of the task), both placebo (β = −0.083, SE = 0.009, 95% CI [−0.102, −0.064], $t_{(186)} = -8.749$, $p < .001$) and nocebo (β = −0.047, SE = 0.009, 95% CI [−0.064, −0.030], $t_{(208)} = -5.355$, $p < .001$) yielded shorter log-RTs than baseline. At the mean number of trials (middle of the task), the effects were still significant (placebo: β = −0.060, SE = 0.008, 95% CI [−0.076, −0.044], $t_{(101)} = -7.345$, $p < .001$; nocebo: β = −0.032, SE = 0.007, 95% CI [−0.047, −0.017], $t_{(101)} = -4.367$, $p < .001$). At +1 SD (near the end of the task), the placebo

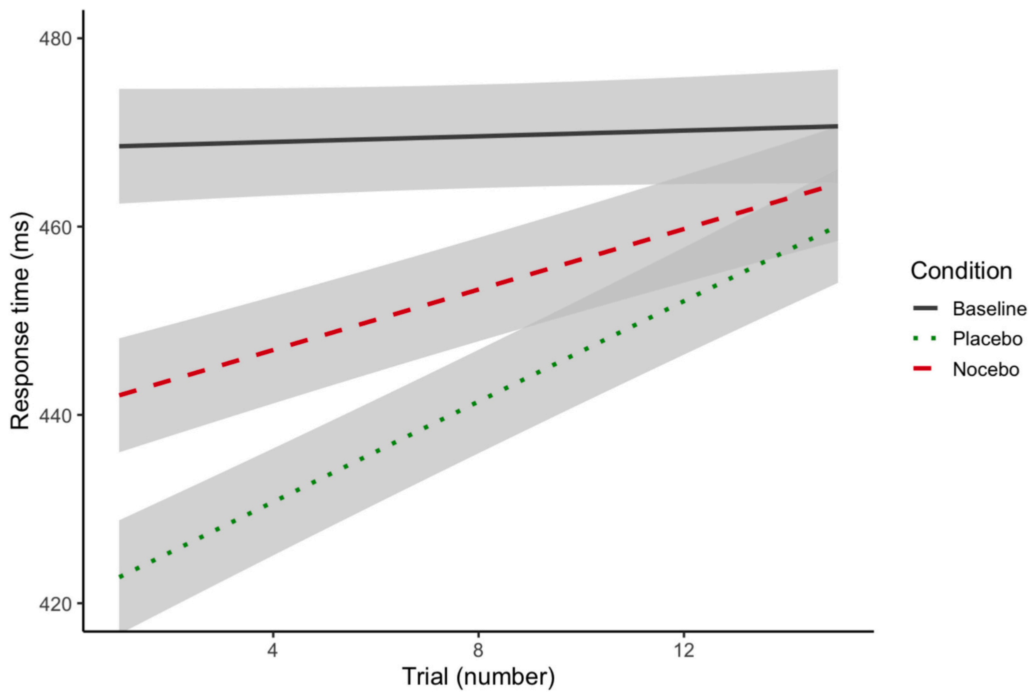

Fig. 5. The Condition by Number of trials interaction. Grey shadows represent standard errors.

effect persisted (β = −0.037, SE = 0.009, 95% CI [−0.055, −0.018], $t_{(181)} = -3.895$, $p < .001$), whereas the nocebo effect was no longer statistically different from baseline (β = −0.017, SE = 0.009, 95% CI [−0.034, 0.000], $t_{(203)} = -1.942$, $p = .054$).

4.2.2. *Accuracy*

The generalized mixed-effects model showed a marginal $R^2 = 0.252$ and conditional $R^2 = 0.365$ (see Supplementary materials). Lexicality had a significant main effect (β = 2.176, SE = 0.239, 95% CI [1.707, 2.646], $z = 9.093$, $p < .001$). As expected, the reading accuracy of words (mean = 0.99, SE = 0.002) was higher than pseudowords (mean = 0.94, SE = 0.006).

The Number of Trials also had a significant main effect on accuracy (β = −0.058, SE = 0.019, 95% CI [−0.095, −0.022], $z = -3.139$ $p =$ .002), indicating a small but systematic decline in performance across trials.

4.3. *Personality traits assessment*

4.3.1. *Vocal RTs*

Adding the Big Five personality traits to the linear mixed model on log-transformed RTs, the updated model shows marginal $R^2 = 0.128$ and conditional $R^2 = 0.468$ (see Supplementary materials). Analysis shows significant main effects of Openness and Agreeableness. Specifically, for each one-unit increase in Openness, response latency decreased by approximately 1.22 ms (β = −0.003, SE = 0.002, 95% CI[−0.006, −0.000], $t_{(94)} = -2.076$, $p = .041$). Higher Agreeableness, on the other hand, was associated with slower responses. For each one-unit increase in Agreeableness, response latency increased by approximately 2.47 ms. (β = 0.006, SE = 0.002, 95% CI[0.002, 0.010], $t_{(95)} = -2.701$, $p = .008$). None of the higher-order interactions between Condition and the Big Five personality traits reached significance, indicating that the effect of Condition on RTs was consistent regardless of individual personality differences.

4.4. *Heart rate mean*

The model shows marginal $R^2 = 0.003$ and conditional $R^2 = 0.948$, indicating that while fixed effects explained very little variance, the combination of fixed and random effects accounted for most of the variability in HR. The observed heart rate mean was: baseline mean = 80.30, (SE = 1.27), placebo mean = 79.25 (SE = 1.16), and nocebo mean = 78.74 (SE = 1.26). However, the main effects of Condition, Lexicality or their interaction were not significant (all ps > 0.072).

4.5. *Pupillometry*

The model showed marginal $R^2 = 0.058$ and conditional $R^2 = 0.974$ (see Supplementary material). Condition shows a significant main effect. Specifically, relative to the average of the expectation conditions, the baseline (mean = 3.016 mm, SE = 0.035) showed significantly larger pupil diameter (β = −0.141, SE = 0.019, 95% CI[−0.178, −0.105], $t_{(62)} = -7.624$, $p < .001$). The contrast between nocebo (mean = 2.877 mm, SE = 0.035) and placebo (mean = 2.873 mm, SE = 0.035) conditions was not significant (β = 0.004, SE = 0.008, 95% CI[−0.012, 0.021], $t_{(62)} = 0.539$, $p = .592$).

4.6. *Single question on subjective temporal frequency efficacy*

Of the entire sample, 91% (n = 93/102) indicated that Hz lenses manipulation had an impact on their word reading and pseudoword decoding performance.

5. Discussion

The primary aim of this study was to examine whether inducing positive or negative expectations affects reading speed and accuracy. Of the 102 participants in the experiment, 91% reported that they subjectively perceived the use of the sham glasses to have altered their performance. Behavioral data confirmed these subjective perceptions, showing that subjective and objective performance evaluations were aligned (Looby & Earleywine, 2011; Tracey, 2010). Indeed, the results of the experiment showed that induction of positive and negative expectations significantly influenced participants' reading performance. Vocal RTs were faster when positive expectations were induced, compared to no expectation (baseline) and negative expectations. As observed in another research on placebo in reading skills (Franceschini, Puccio, Bertoni, Mascheretti, et al., 2025), and similarly to what observed as meta-analytic result of reading training interventions (Galuschka et al., 2014), a significant small effect (Cohen's $d = 0.34$) allows to distinguish reading speed under positive and negative expectations. Although the results are statistically reliable, the magnitude of the effect is small. The observed differences in vocal reaction times were on the order of tens of milliseconds. These variations reflect subtle modulation rather than large-scale improvements in reading ability. However, even shifts of a few milliseconds can meaningfully influence the temporal coordination of cognitive processes underlying fluent reading (Breznitz et al., 2013; see Hancock et al., 2017 for a review). It should be noted that the most robust inference supported by the present design is that placebo instructions produce faster reading RTs than nocebo instructions under counterbalanced conditions, rather than that expectations broadly enhance reading relative to baseline. In the case of individuals with reading difficulties, the initial situation is typically characterized by low self-expectations regarding one's own performance, often accompanied by comparatively high expectations toward the potential effectiveness of a reading intervention (e.g., Franceschini, Puccio, Bertoni, Gori, et al., 2025; McArthur et al., 2020).

The influence of expectations was independent of the word reading versus pseudoword decoding. We hypothesize that a bottom-up mechanism, facilitating letter and syllable decoding, would primarily improve pseudoword decoding (Montani et al., 2015). In contrast, our data suggest that expectations operate as a top-down, rather than a bottom-up mechanism, in line with behavioral (Franceschini, Puccio, Bertoni, Gori, et al., 2025; Piedimonte et al., 2024; Vera et al., 2022), electrophysiological (Piedimonte et al., 2024), and neuroimaging findings (White et al., 2023).

In the present study, a significant difference emerged between the placebo condition and both the baseline and nocebo conditions. However, no significant difference was found between baseline and nocebo, although the effect was in the expected direction. This pattern is consistent with findings reported by Vera et al. (2022), who observed similar effects in experiments based on expectancy induction without a feedback-based learning session, assessing visual-perceptual abilities such as stereoacuity and ocular accommodation. Taken together, these results suggest that placebo effects may manifest more readily, whereas nocebo effects could require a longer time course to consolidate (Colloca et al., 2010). The interaction with trial progression reveals that, as the number of trials advances, the discrepancy in performance between the nocebo and placebo conditions progressively widens, with negative expectations exerting an increasingly pronounced influence and leading to performance deterioration. This pattern is evident both when performance under placebo condition is taken as the reference point as well as when compared to the baseline (absence of expectations) condition.

The initial relative acceleration observed in the nocebo condition with respect to baseline may be attributable either to participants' incomplete acquisition of task proficiency during the early test phase (notably, the baseline was always administered prior to the two counterbalanced experimental conditions), or to a non-specific initial activation response elicited by participants' awareness of being in an "active" phase of evaluation. The differential trajectories observed under positive versus negative expectation conditions appear to be consistent with the theoretical framework proposed by Piedimonte et al. (2024). In particular, it can be hypothesized that positive expectations induce a reward-like process that enables an immediate and more effective allocation of attentional resources, enhancing persistence and effort, thereby improving behavioral performance. In contrast, negative expectations do not protect against later fatigue effects, leading to a decline in performance. In this regard, while the placebo effect is readily elicited, the impact of negative expectations may require longer exposure and a greater number of trials to manifest (Piedimonte et al., 2024; Summerfield & Egner, 2009). In our task, it can be observed that although the reward effect appears to remain stable, its magnitude is gradually attenuated by the mere repetition of trials (relative to baseline). On the contrary, the difficulty in resisting task-related fatigue-driven by negative expectations seems to progressively increase, demonstrating a possible interaction of multiple factors whose relative relevance shifts over the course of the task.

An additional experimental aim of the present study was to investigate whether the expectancy effects observed during the experiment (Test phase) could be attributed to feedback-based learning processes elicited by our manipulation through colored feedback during the Training phase (see Fig. 1), or whether such effects were observed irrespective of this manipulation. Unlike conditioning paradigms that manipulate stimulus intensity (e.g., by employing easier tasks in placebo and more difficult tasks in nocebo conditions; Piedimonte et al., 2015, 2024; Parong et al., 2023; Vodyanyk et al., 2021), in the present study participants were conditioned exclusively through predetermined positive (green) or negative (red) performance feedback, while task difficulty was held constant relative to the baseline condition. Manipulating task difficulty - even through more subtle variables such as word frequency - would have entailed the risk of obscuring a causal link between expectancy and reading performance. Under such a manipulation, the effects observed in the experiment (Test phase) could be attributed, rather than to expectancy, to the preferential use of the lexical recognition (for high-frequency words, which may facilitate the perception of improvement) or the phonological decoding (for low-frequency words, which may render the task more difficult). Our design may therefore have attenuated the strength of potential training effects - which in the present study were null - and likely underestimates the magnitude of placebo responses that could be elicited by a conditioning (placebo) paradigm involving prolonged exposure to easier materials specifically designed to facilitate positive outcomes, as typically occurs in as usual reading training contexts.

The significant interaction between condition and lexicality (word versus pseudoword; see Fig. 4) in the Training phase, confirmed that positive and negative expectations had similar effects on response times for both words and pseudowords. However, it also revealed that in the pseudoword reading condition, both the placebo and - paradoxically - the nocebo conditions produced faster responses compared to the baseline. This effect was also observed in the word reading condition, although in a weaker form. A similar outcome was expected, given that the Training phase was primarily designed to familiarize participants with the task. Such familiarisation naturally exerts a stronger influence when the task involves the less common pseudoword decoding. Nevertheless, the potential role of a Hawthorne effect cannot be ruled out, whereby participants, particularly in the early stages of the active conditions (placebo and nocebo), may have felt under observation and thus attempted to enhance their performance, as evidenced by the significant condition by number of trial interaction. Finally, we cannot rule out the possibility that our manipulation only partially induced the nocebo effect, which may have been obscured by familiarisation with the task. Conducting an initial familiarisation phase with the computerized task without wearing the glasses could have resolved this issue.

Lastly, the significant type of stimuli by number of trials interaction in response times analysis, in combination with the slight decrease in accuracy in the last trials of the training phase, suggest that the last trials were slightly more difficult than the first ones, and the participants reduced their performance, particularly in pseudoword decoding. In any case, none of these effects indicate that the expectation effects observed in the experiment were attributable to the Training phase. Observed outcomes likely resulted from the activation of induced expectations through the contextual elements of the experimental setting (Crum & Langer, 2007; Frisaldi et al., 2015; Parong et al., 2023), rather than from any manipulation of feedback during the Training phase. Nevertheless, it is plausible to hypothesize that a prolonged duration of this phase, or a different kind of manipulation could have led to different effects (Colloca et al., 2010).

The third study aim was to investigate whether expectation effects on reading performance are associated with specific personality traits (Kern et al., 2020). The exploration of personality traits initially suggested that higher Openness was associated with slightly faster responses, whereas higher Agreeableness correlated with slower responses. However, none of the Big Five traits significantly interacted with Condition, indicating that personality did not meaningfully modulate expectancy effects on reading time. These findings are consistent with previous research showing that while specific aspects of personality like Openness can influence reaction times in cognitive tasks (e.g., Willoughby et al., 2023), their effects are often subtle and context-dependent (Colloca et al., 2010). The present results suggest that personality traits may modulate overall response tendencies in a nuanced manner, but do not deterministically alter the impact of expectancy on reading performance.

Lastly, the aim of the study was to investigate whether expectations modulate pupil diameter and heart rate as possible markers of norepinephrine/acetylcholine release and associated arousal modification (Grujic et al., 2024). The null effect observed in the heart rate data suggest that the regulatory mechanisms of arousal are unlikely to have been the primary systems responsible for the reading changes observed in relation to expectation.

On pupil diameter the only significant effect is a difference between baseline and placebo/nocebo conditions. We could suppose that while a habituation effect to the environment and the task is observed, expectations do not appear to influence this physiological response. This null effect on pupil diameter should be interpreted with caution, as pupillary responses index multiple processes (e.g., luminance adaptation, attention, cognitive effort, and affect), and the measurement was not collected during reading itself but immediately after the Training phase. It is therefore likely that the signal primarily reflected habituation or relaxation over time rather than expectancy-related neuromodulatory changes. In addition, due to instrumentation-related issues, a substantial number of recordings were lost, resulting in reduced statistical power. It is important to emphasize that participants were not provided with any specific expectation regarding any possible outcomes on pupil size. Gavrylyuk et al. (2010), directly inducing expectations in participants regarding an inert substance and its effects on pupil size, observed no immediate impact of expectations on pupil size or heart rate. This finding indirectly supports the results observed in our experiments and suggests that the regulation of other neurotransmitter systems – possibly those related to reward circuitry - may underlie the observed expectation effects.

The work we present certainly has limitations: despite the large sample involved in the study, it is not balanced with respect to the two sexes assigned at birth, with the majority of participants being female (4/1 ratio). This limits the ability to effectively assess the potential influence of sex on expectations. The purely exploratory analyses we conducted, including sex as a factor in the mixed models, show no statistically significant influence on expectations or on the interaction between the number of trials and expectations (see Supplementary materials).

The age of the participants is also certainly a limitation regarding the generalizability of the data to other populations. Indeed, it is possible that the effects could differ with increasing age.

An additional limitation is related to the structure of the experiment. In order to test both words and pseudowords, to ensure complete counterbalancing, and to avoid making the experimental session too long, participants were exposed multiple times in a short period to a change in expectations (low flickering frequency corresponded to improvement in pseudowords and deterioration in words; high frequency corresponded to improvement in words and deterioration in pseudowords). This may have weakened the effects of expectations. Although the large majority of participants reported that the use of the glasses altered their performance, they were not asked to specify whether this perceived alteration was in a positive or negative direction. Therefore, it cannot be excluded that, particularly in the negative condition, the manipulation may not have effectively elicited a genuine nocebo expectation.

5.1. Conclusion

Individuals' expectations appear to exert a significant influence on reading performance, whereas feedback-based learning through simple training alone is unlikely to play an active role. However, more robust feedback-based learning protocols need to be tested. The finding that reading ability can be improved merely by inducing expectations highlights the risk that many existing interventions for reading enhancement may, at least in part, rely on such effects (Franceschini, Puccio, Bertoni, Mascheretti, et al., 2025). These findings highlight the need to consciously harness such effects in clinical practice.

CRediT authorship contribution statement

Sandro Franceschini: Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Sara Bertoni:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Patrik Pluchino:** Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Anna Panzeri:** Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Giovanni Bruno:** Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Martina Mancarella:** Visualization, Validation, Investigation, Formal analysis, Data curation. **Giovanna Puccio:** Visualization, Validation, Investigation, Formal analysis. **Simona Carbone:** Validation, Supervision, Methodology, Investigation. **Matteo Lulli:** Validation, Methodology, Formal analysis, Data curation. **Cristiano Termine:** Visualization, Validation, Supervision, Resources, Methodology. **Andrea Spoto:** Validation, Supervision, Software, Methodology, Formal analysis, Data curation. **Simone Gori:** Validation, Supervision, Resources, Methodology, Funding acquisition. **Andrea Facoetti:** Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization.

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Declaration of competing interest

none.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2026.106776.

Data availability

Data will be made available on request.

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