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Accommodative dynamics and attention: the influence of manipulating attentional capacity on accommodative lag and variability

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Abstract

Purpose: There is evidence that attention can modulate ocular dynamics, but its effects on accommodative dynamics have yet to be fully determined. We investigated the effects of manipulating the capacity to focus on task-relevant stimuli, using two levels of dual-tasking (arithmetic task) and auditory feedback, on the accommodative dynamics at three different target distances (500, 40 and 20 cm).
Methods: The magnitude and variability of the accommodative response were objectively measured in 20 healthy young adults using the Grand Seiko WAM-5500 autorefractor. In randomised order, participants fixated on a Maltese cross while 1) performing an arithmetic task with two levels of complexity (low and high mental load); 2) being provided with two levels of auditory feedback (low and high feedback); and 3) without performing any mental task or receiving feedback (control). Accommodative and pupil dynamics were monitored for 90 seconds during each of the 15 trials (5 experimental conditions x 3 target distances).
Results: The lag of accommodation was sensitive to the attentional state ($p = 0.001$), where a lower lag of accommodation was observed for the high feedback condition compared to the control (corrected p-value = 0.009). The imposition of mental load while fixating on a distant target led to a greater accommodative response (corrected p-value = 0.010), but no effects were found for the near targets. There was a main effect of the experimental manipulation on the accommodative variability ($p < 0.001$), with the use of auditory feedback improving the accuracy of the accommodative system.
Conclusions: Our data show that accommodative dynamics is affected by varying the capacity to focus on task-relevant stimuli, observing an improvement in accommodative stability and response with auditory feedback. These results highlight an association between attention and ocular dynamics and provide new insight into the control of accommodation.

Introduction

Appropriate functioning of the ocular accommodation system is paramount to achieve a sharp retinal image at different distances, with the dynamic accommodation dependent on numerous factors (e.g., image blur, retinal disparity, optical aberrations).[1–3] In addition to optical signals, varying cognitive demand has been shown to alter ocular dynamics, possibly due to the overlap between the neural areas involved in processing cognitively demanding tasks and those controlling accommodation.[4,5] Recent studies have reported that a reduction in the level of attention/alertness promotes greater lags of accommodation,[5,6] and a less accurate accommodative response has been found in children with attention deficits when compared to age-matched controls.[7]

Evidence suggests that connections from the cerebellum via the Edinger–Westphal nucleus are targeted to the ciliary muscle, and thus control ocular accommodation.[8] Additionally, there are other brain areas that appear to play a role in driving the near triad (e.g., midbrain, frontal eye fields, extrastriate cortex or parietal cortex).[8–10] Similarly, some of these areas (i.e., cerebellum, midbrain and frontal cortex) also regulate the attentional state.[11–13] Based on the shared neural mechanisms between attention and ocular accommodation, an association between the level of attention (i.e., the ability to focus on task-relevant stimuli in order to optimise task performance) and the dynamics of the accommodative response seems plausible, as has been shown for the pupil dynamics and eye movements.[14–17]

Attentional state can be manipulated to enhance our capacity to focus on task-relevant stimuli (attention facilitators), as well as to reduce capacity (attention distractors). Indeed, previous studies have employed cognitive tasks directly related to the visual target while the subject accommodates in order to manipulate the attentional capacity (e.g., using attractive stimuli or tasks that required a higher concentration to focus attention),[6,18] as well as displaying mentally demanding tasks on a screen for limiting the attentional resources.[4,19,20] Additionally, some studies have assessed the impact of attentional state on ocular accommodation by manipulating mental activity with tasks independent of the stimuli, often resulting in mixed results.[21–27] Here, we aimed to alter the attentional resources without manipulating the visual target by using auditory feedback to facilitate attention,[28] and concurrent mental arithmetic tasks as distractors.[29]

The main objectives of the present study were: (1) to assess the short-term effect of attention distractors and facilitators on the dynamics of the accommodative response and pupil size, and (2) to test whether these changes are dependent on the level (low and high) of attention distractors and facilitators, as well as the accommodative demand (0 D, 2.5 D, 5 D). We hypothesised that accommodative and pupil responses will be sensitive to changes in attention, as has been shown in children with attentional deficits[7] and task disengagement or mental fatigue,[14,15] respectively.

Methods

Participants

Prior to data collection, we performed an *a-priori* power analysis with the G*Power 3 software (http://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower.html),31 assuming an effect size of 0.20, alpha of 0.05, and power between 0.80 and 0.90, for a repeated measures (within factors) analysis of variance (ANOVA). The calculation projected a required sample size between 16 (power 0.80) and 20 (power 0.90) participants. Consequently, 20 healthy young adults (13 women and 7 men; mean age $\pm$ standard deviation = 22.8 $\pm$ 4.5 years, range age = 18 – 30 years) were recruited. All participants were screened for the following inclusion criteria: (1) free of any ocular disease, as assessed by slit lamp and direct ophthalmoscopy examination; (2) normal or corrected-to-normal vision at far and near distances (visual acuity of 0.0 logMAR or better in each eye); (3) no significant uncorrected refractive error (myopia < 0.50 D, astigmatism and anisometropia < 1.00 D, and/or hyperopia of < 1.50 D);[31] (4) amplitude of accommodation (push-up method) within the normal range, as calculated by the Hofstetter's formula;[32] (5) near stereoacuity of 50 seconds of arc or better as measured with the Randot Stereotest,[33] and (6) be free of visual discomfort based on the scores of the Conlon survey.[34] Prior to data collection, participants were asked to avoid performing highly demanding physical exercise on the day of testing, and abstain from alcohol and caffeine ingestion for 24 and 12 hours, respectively.[35,36] The study adhered to the tenets of the Declaration of Helsinki, and was approved by the University of Granada Institutional Review Board (IRB approval: 546/CEIH/2018). Written informed consent was obtained from all participants.

Accommodative response and pupil dynamics assessment

A Grand Seiko WAM-5500 binocular open-field autorefractor (www.grandseiko.com) was used to assess objectively the dynamics of the accommodative response and pupil size.[37] The WAM-5500 acquires continuous recordings (temporal resolution of ~5 Hz) of accommodation and pupil size in its high-speed mode, with a sensitivity of 0.01 D and 0.1 mm, respectively. Accommodative response and pupil size were recorded continuously during the 90 s of each trial while participants fixated on the Maltese cross (Michelson contrast = 79%, base luminance = 31 cd m^{-2}). All measurements were performed under binocular conditions, and the dominant eye, as determined by the hole-in-card method,[38] was chosen for data acquisition.[39] Prior to starting the test, each participant was seated at the instrument with their head stabilised in the chin rest and forehead strap, and aligned with the fixation target to avoid off-axis errors. It should be noted that this position was kept constant across the different experimental conditions. For data analysis, data points varying more than $\pm$3 S.D. from the mean value were removed, to eliminate blinks or recording errors.[40] The remaining data points were used for further analyses (average percentage: 88%, range: 82 to 93%). For the calculation of the lag of accommodation, we subtracted the average accommodative response during the 90 seconds trial in dynamic mode from the accommodative demand at the different target distances (500 cm = 0.2 D; 40 cm = 2.5 D; and 20 cm = 5 D) (see Equation 1). The standard deviations from the continuous recording of accommodation and pupil were considered as the variability of accommodation and pupil size, respectively. Pupil data from four participants were lost due to recording failure, and thus, data from 16 subjects were used for the analysis of pupil dynamics.[41]

$$\text{Accomodative lag} = \text{Accomodative stimulus} - \text{Accomodative response} \quad (1)$$

Procedure

The experiment was conducted in a single session with 15 randomised trials (3 target distances × 5 experimental manipulations). Each trial lasted 90 seconds, with a 3-minute break given between two successive trials. Upon arrival, participants signed the consent form and an experienced optometrist performed the optometric tests required to ensure the inclusion criteria were met. Participants were seated at the autorefractometer, using the corresponding chin and forehead supports. At this point, participants were given clear written and spoken instructions about the experimental conditions, and then the main part of the experimental session started. Participants were asked to focus on the Maltese cross and keep it sharp and clear during the entire task.[42] Participants were told that the experimental conditions at each of the three distances comprised three blocks: Block 1, in which they were just asked to fixate on the Maltese cross; Block 2, in which they also had to do mental arithmetic tasks at two levels of complexity (easy and difficult); and Block 3, in which the instrument would provide auditory feedback when the accommodation was inaccurate using two different levels of instrument sensitivity for detection of accuracy. For Block 3, the instrument was actually incapable of monitoring accommodative accuracy (unbeknownst to the participants), but a series of either 8 beeps (more sensitive level) or 4 beeps (less sensitive level) would occur during the 90-second recording to create the illusion that accommodative accuracy was being monitored.

In all experimental conditions, participants wore their soft contact lenses when necessary and were asked to look at a high-contrast Maltese cross while positioned on the chin and forehead supports of the WAM-5500. Room illumination was kept constant during the entire experiment (~ 150 lx as measured in the corneal plane, using a T-10 Konica Minolta illuminance meter, www.konicaminolta.com).

The experimental manipulation was as follows:

1. Control: participants were asked to fixate and maintain focus on the Maltese cross for 90 seconds.
2. Low mental load: based on Siegenthaler *et al*., (2014),[29] participants were instructed to count forwards mentally, as fast and accurately as possible, in steps of two starting at a random three-digit number during the 90 seconds. At the same time, they were asked to maintain on focus the Maltese cross.
3. High mental load: in line with the instructions given by Siegenthaler *et al*., (2014),[29] and while fixating and maintaining focus on the Maltese cross, participants were asked to count mentally backwards, as fast and accurately as possible, in steps of 17 starting at a random four-digit number.
4. Low feedback: as auditory cues may enhance visual attention,[43] four auditory beeps were randomly introduced during the trial while fixating on the Maltese cross, which were previously described to participants as a type of feedback for inaccurate accommodation. Thus, one auditory beep meant an out-of-focus image detected by the instrument.
5. High feedback: eight auditory beeps were randomly introduced during the trial while participants kept in focus the Maltese cross, which were previously described to participants as a type of feedback for inaccurate accommodation.

Experimental design

A repeated measures design (3 target distances x 5 experimental manipulations) was used to explore the effects of manipulating the attentional resources on the accommodative response and pupil dynamics. The within-participants factors were the target distance (500 cm, 40 cm and 20 cm) and the experimental manipulation (control, low mental load, high mental load, low feedback, high feedback). The dependent variables were the lag and variability of ocular accommodation, and the magnitude and variability of pupil size.

Statistical analysis

Data normality was confirmed by the Shapiro-Wilk test ($p > 0.05$). Separate repeated measures ANOVAS, considering the target distance (500 cm, 40 cm and 20 cm) and the attentional resources manipulation (control, low mental load, high mental load, low feedback, high feedback) as within-participants factors, were performed for each dependent variable. *Post hoc* comparisons were corrected with the Holm-Bonferroni procedure, and the magnitude of the change was reported by means of partial eta squared (η_p^2) and Cohen´s d for F and T-tests, respectively. An alpha level of 0.05 was adopted to determine statistical significance.

Results

Data from seven myopes (mean spherical equivalent> −0.50 D, maximum value −2.25 D), five hyperopes (mean spherical equivalent> +0.75 D, maximum value +1.50 D), and eight emmetropes (mean spherical equivalent between −0.50 D and +0.75 D) were collected. Due to recording errors, pupil data of four participants were eliminated, leaving a total of 20 participants for accommodation analysis and a total of 16 for pupil data analysis. Additionally, we performed a repeated measures ANOVA for the percentage of data points used, considering the target distance and experimental manipulations, to determine whether different amounts of data were discarded across conditions. This analysis revealed no statistically significant differences for any of the two factors or the interaction (all *p*-values > 0.05).

The analysis of the lag of accommodation yielded a statistically significant effect for the target distance ($F_{2, 38} = 91.52$, $p < 0.001$, $\eta_p^2 = 0.83$), the experimental manipulation ($F_{4, 76} = 4.60$, $p = 0.002$, $\eta_p^2 = 0.20$), and the interaction target distance × experimental manipulation ($F_{8, 152} = 5.49$, $p < 0.001$, $\eta_p^2 = 0.22$). *Post hoc* comparisons between target distances exhibited greater lags of accommodation at 20 cm in comparison to 40 cm (corrected *p*-value < 0.001, d = 1.03) and 500 cm (corrected *p*-value < 0.001, d = 2.62), as well as greater lags at 40 cm when compared to 500 cm (corrected *p*-value < 0.001, d = 2.04). The comparisons between the different experimental conditions reached statistical significance for the comparison between the high-feedback and control conditions (corrected *p*-value = 0.010, d = 0.87), with the high-feedback condition leading to lower lags of accommodation (*Table 1*). Pairwise analyses for the values obtained in the low- and high-load conditions, as well as the low- and high-feedback conditions in comparison to the control condition at each of the three target distances are displayed in *Figure 1* (panel a).

Analysis of accommodation variability exhibited statistically significant differences for the target distance ($F_{2, 34} = 78.07$, $p < 0.001$, $\eta_p^2 = 0.82$), the experimental manipulation ($F_{4, 68} = 12.76$, $p < 0.001$, $\eta_p^2 = 0.43$), and the interaction target distance × experimental manipulation ($F_{8, 136} = 5.30$, $p < 0.001$, $\eta_p^2 = 0.24$). *Post hoc* comparison between the three target distances revealed a greater variability of accommodation at 20 cm in comparison to 40 cm (corrected *p*-value < 0.001, d = 1.63) and 500 cm (corrected *p*-value < 0.001, d = 2.26), as well as for 40 cm when compared with 500 cm (corrected *p*-value < 0.001, d = 2.70). A lower variability of accommodation was found for the high-feedback condition in comparison to the control (corrected *p*-value < 0.001, d = 1.30), low-load (corrected *p*-value = 0.013, d = 0.84) and high-load (corrected *p*-value < 0.001, d = 1.46) conditions. Also, the low-feedback condition induced a more stable variability of accommodation in comparison to the control (corrected *p*-value = 0.005, d = 0.98), low-load (corrected *p*-value = 0.011, d = 0.87) and high-load (corrected *p*-value = 0.002, d = 1.09) conditions (*Table 1*). Further pairwise comparisons at each of the three target distances are depicted in *Figure 1* (panel b).

Pupil size showed statistically significant differences for the target distance ($F_{2, 30} = 13.62$, $p < 0.001$, $\eta_p^2 = 0.48$) and the experimental manipulation ($F_{4, 60} = 39.85$, $p < 0.001$, $\eta_p^2 = 0.73$), but no differences were observed for the interaction ($F_{8, 120} = 0.25$, $p = 0.980$). *Post hoc* comparison between the different target distances demonstrated

Table 1. Descriptive values (mean ± standard deviation) of accommodative response (lag and variability of accommodation) and pupil size (pupil diameter and variability)

	Distance (cm)	Control	Low-load	High-load	Low-feedback	High-feedback
Lag of accommodation (D)	500	0.10 ± 0.46	0.01 ± 0.53	−0.04 ± 0.53	0.06 ± 0.44	0.07 ± 0.45
	40	0.84 ± 0.23	0.88 ± 0.23	0.80 ± 0.21	0.81 ± 0.17	0.78 ± 0.19
	20	1.21 ± 0.40	1.20 ± 0.47	1.21 ± 0.47	1.08 ± 0.48	1.04 ± 0.41
Variability of accommodation (D)	500	0.19 ± 0.07	0.18 ± 0.06	0.22 ± 0.08	0.18 ± 0.08	0.17 ± 0.07
	40	0.53 ± 0.16	0.52 ± 0.13	0.54 ± 0.15	0.41 ± 0.14	0.42 ± 0.17
	20	0.98 ± 0.33	1.01 ± 0.48	1.09 ± 0.35	0.75 ± 0.38	0.70 ± 0.33
Pupil diameter (mm)	500	5.59 ± 1.02	6.10 ± 0.99	6.29 ± 1.04	5.68 ± 1.03	5.69 ± 1.05
	40	5.57 ± 0.94	6.08 ± 0.97	6.17 ± 0.96	5.63 ± 1.06	5.59 ± 1.04
	20	4.99 ± 1.07	5.46 ± 1.04	5.62 ± 1.03	4.99 ± 1.28	5.01 ± 1.26
Pupil variability (mm)	500	1.57 ± 0.49	2.10 ± 0.91	2.12 ± 0.74	1.38 ± 0.62	1.35 ± 0.65
	40	2.05 ± 0.78	2.07 ± 0.81	2.25 ± 0.97	1.70 ± 0.68	1.61 ± 0.80
	20	1.56 ± 0.54	1.72 ± 0.55	1.84 ± 0.76	1.46 ± 0.76	1.33 ± 0.70

cm, centimetres; D, dioptres; mm, millimetres.

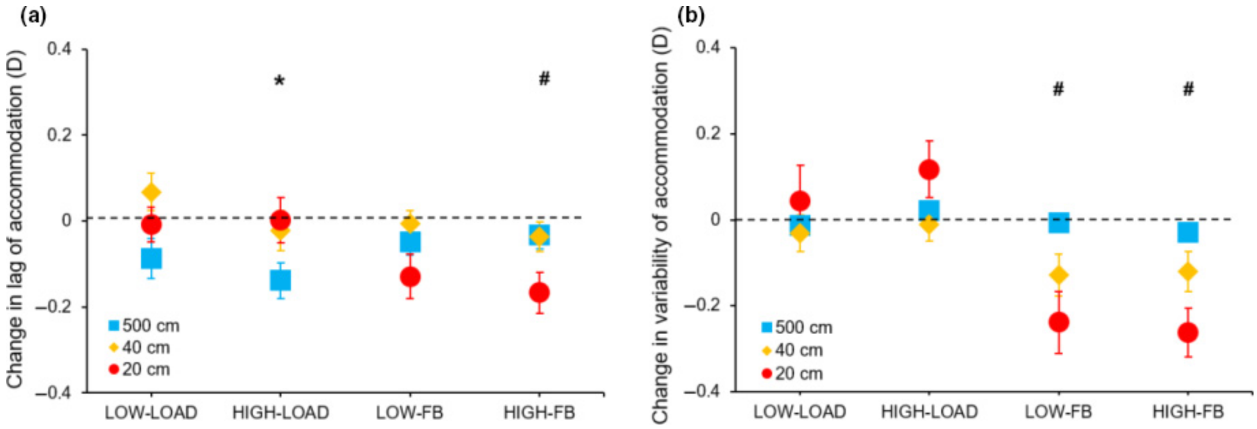

Figure 1. Effect of attentional resources manipulation on the lag (panel a) and variability (panel b) of accommodation. Values are calculated as the difference between each experimental condition and the control condition. * and # denote a statistically significant difference (corrected *p*-value < 0.05) in comparison to the control condition at 500 cm and 20 cm, respectively. Error bars show the standard error. All values are calculated across participants (n = 20). The low- and high-load conditions refer to the two levels of mental load, counting forward in steps of 2 and backwards in steps of 17, respectively. The low- and high- FB conditions indicate the two levels of auditory feedback, consisting of four and eight auditory beeps, respectively. [Colour figure can be viewed at wileyonlinelibrary.com]

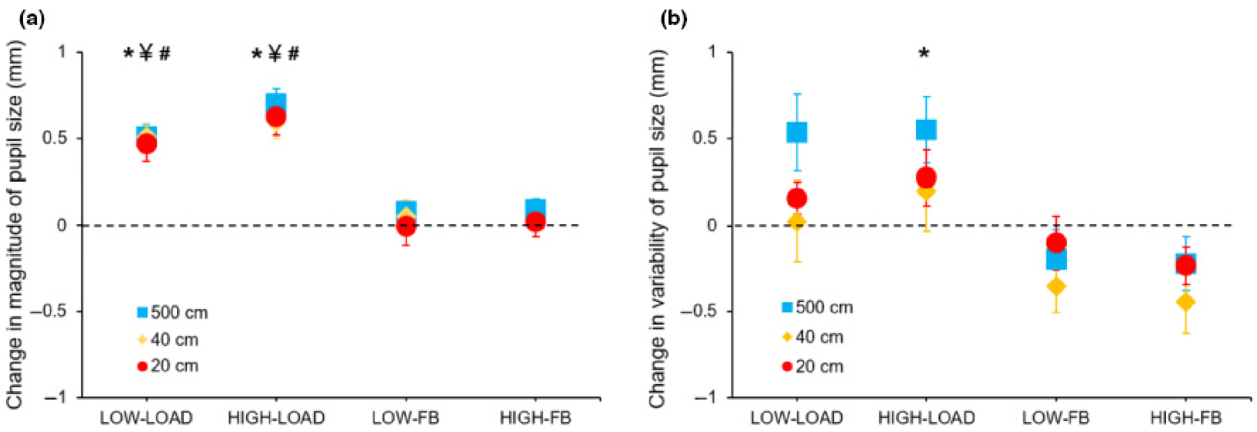

Figure 2. Effect of attentional resources manipulation on the magnitude (panel a) and variability (panel b) of pupil size. Values are calculated as the difference between each experimental condition and the control condition. *, ¥ and # denote a statistically significant difference (corrected *p*-value < 0.05) in comparison to the control condition at 500 cm, 40 cm and 20 cm, respectively. Error bars show the standard error. All values are calculated across participants (n = 16). The low- and high-load conditions refer to the two levels of mental load, counting forward in steps of 2 and backwards in steps of 17, respectively. The low- and high- FB conditions indicate the two levels of auditory feedback, consisting in four and eight auditory beeps, respectively. [Colour figure can be viewed at wileyonlinelibrary.com]

that there were lower pupil sizes at 20 cm in comparison to 500 cm (corrected *p*-value = 0.006, d = 0.88) and 40 cm (corrected *p*-value < 0.001, d = 1.43). However, no differences were reached for the comparison 500 cm versus 40 cm (corrected *p*-value = 0.585). The comparison between the five experimental conditions exhibited that there were greater pupil sizes in the low-load and high-load conditions in comparison to the control, low-feedback and high-feedback conditions (all corrected *p*-values < 0.001) (*Table 1*). *Figure 2* (panel a) shows the comparisons performed for the low- and high-mental load conditions, and the low- and high-feedback conditions with the control condition at each of the three target distances.

Lastly, the variability in pupil size was sensitive to the target distance ($F_{2,\ 30} = 5.06$, $p = 0.013$, $\eta_p^2 = 0.25$) and the experimental manipulation ($F_{4,\ 60} = 11.08$, $P < 0.001$, $\eta_p^2 = 0.43$). However, no differences were obtained for the interaction target distance × experimental manipulation ($F_{8,\ 120} = 1.01$, $p = 0.435$). *Post hoc* comparisons for the target distances revealed a greater variability at 40 cm in comparison to 20 cm (corrected p-value = 0.020, d = 0.78). *Post hoc* comparisons for the experimental manipulation showed that there were lower values of pupil size variability in the high-feedback condition in comparison to the control (corrected p-value = 0.009, d = 0.98), low-load (corrected p-value = 0.002, d = 1.19) and high-load (corrected p-value < 0.001, d = 1.35) conditions, as well as in the low-feedback condition when compared with the low-load (corrected p-value = 0.013, d = 0.93) and high-load (corrected p-value < 0.001, d = 1.31) conditions (*Table 1*). Also, further comparisons between experimental conditions at each target distance are displayed in *Figure 2* (panel b).

Discussion

The present study was designed to assess the impact of manipulating attentional state on accommodative and pupil dynamics. Our results incorporate novel insights into the short-term effects of auditory biofeedback on the lag and variability of the accommodative response. Auditory feedback improved both the lag and variability of accommodation, with these changes being significant at closer distances, while dual-tasking promoted a greater accommodative response at far distances. We also found that only dual-tasking altered the pupil dynamics, observing a greater magnitude of pupil size when performing arithmetic tasks and a higher variability of pupil size while performing the low- and high load conditions of dual-tasking. These findings open up new avenues for modulating the accommodative response, which may have important implications for the prevention and management of asthenopia.

Regarding the impact of attentional distractors, our data show that the imposition of an arithmetic task while fixating on a distance visual target alters the dynamics of ocular accommodation. Specifically, a greater accommodative response was found in the more mentally demanding task in comparison to the control condition (mean difference = 0.14 ± 0.18 D). Although previous studies have quantified the accommodative response profile during mental effort,[19,21,23,24,44] the direction and magnitude of the changes in accommodation have been unclear, which may be attributable to discrepancies in measurement methods, target distance, and individual differences. Our results are consistent with those reported by Davies and colleagues (2005)[4] who, using an open-view infrared autorefractor, found a reduction in the lag of accommodation while performing a two-alternative forced-choice task. Additionally, based on previous studies that observed that task distance may influence the direction of the accommodative response during cognitive tasks,[41] we included three accommodative distances (500 cm [0.2 D], 40 cm [2.5 D] and 20 cm [5 D]). This specific result is in line with Bullimore & Gilmartin (1988),[41] who found that mental effort caused a heightened accommodative response at the farthest stimulus (1 D), but no changes were observed at closer distances (3 D and 5 D). Based on the fact that the greater accommodative response with mental load was only evident at far distance, it cannot be attributable to sympathetic activity, since this branch is inhibitory and is only present with concurrent activity from the parasympathetic system (i.e., near-work).[45–48] Accordingly, there is evidence that changes in ocular accommodation seem to be associated with changes in systemic parasympathetic nervous system, with these changes being associated with cognitive effort.[49] As proposed by Toates (1972),[50] parasympathetic withdrawal is required for distance targets, and thus, the greater accommodative response observed in the high mental load condition may be due to an increased parasympathetic tone during cognitive effort.[51]

Returning to the present study, the use of auditory feedback reduced the lag and variability of accommodation at near distances, with these effects being more evident for the stability of the accommodative response (*Figure* 1). In agreement with Wagner *et al*., (2016),[52] we found a greater reduction in the lag of accommodation with auditory feedback at the closer target distance (5.00 D, 20 cm), observing a lower accommodative lag of 0.17 ± 0.21 D at the 20 cm target distance for the high-feedback condition in comparison to the control condition. Likewise, the most relevant outcomes of this study are probably those achieved in relation to the behaviour of accommodative variability with auditory feedback, since to the best of our knowledge, this is the first study assessing the impact of auditory feedback on stability of the accommodative response. Indeed, a significant improvement in the stability of accommodation was observed with both levels of auditory feedback at closer distances, with these changes ranging from ~0.10 D at 40 cm to ~0.25 D at 50 cm. In this sense, a better performance in visual tasks has been observed when adding auditory cues, supporting the capacity of the auditory system to capture visual attention.[53] This study seems to confirm this idea, and shows that auditory cues facilitate an enhancement of the accuracy of the accommodative response dynamics.

Complementarily, we assessed the impact of manipulating the attentional state on the pupil dynamics while the illumination and fixation were kept constant. The imposition of an arithmetic task while focusing on the visual target induced a substantial increment of the pupil size (~0.50 and ~0.65 mm for the low and high mental load conditions, respectively), showing a similar pupil dilation for the three target distances (*Figure 2*). Notably, there is extensive evidence that pupil dilation is a surrogate measure of cognitive effort,[54,55] and it may be used as an objective indicator of attentional lapses.[56] Our findings agree with the fact that mental load induces pupil mydriasis. Based on the fact that cognitive effort was associated with pupil dilation regardless of target distance, but the changes in ocular accommodation caused by the mental load conditions were dependent on target distance, it is reasonable to suggest that changes in pupil size appear to have little effect on ocular accommodation in this study. In fact, there is evidence that the accommodative response is only affected by changes in pupil size when the pupil diameter is less than 3 mm.[57] Our participants exhibited a pupil size ranging between 3.37 and 7.87 mm across experimental conditions and target distances, and thus, the accommodative changes induced by mental load or auditory feedback seem to be independent of variations in pupil diameter.

Attention is a selective process, which is related to limited cognitive and neural resources to process information imposed by the fixed amount of overall energy available to the brain.[58] In view of the observed results, the inclusion of attentional distractors (dual-tasking) may prove that the accommodative stimulus location become less relevant, whereas the preservation of all the attentional resources on the accommodative stimuli (auditory feedback condition) seems to optimise visual performance. As previously stated, the ocular dynamics are linked to neural areas controlling attention, and neural alterations in attention-related mechanisms may lead to changes in the accommodative response dynamics.[8,9,59] There is evidence that deficits in the magnitude and stability of the accommodative response seem to be associated with visual discomfort,[40,60,61] and thus, the manipulation of the attentional state should be considered for the prevention and management of asthenopia.

The present study incorporates novel insights into the association between the attentional state and accommodative dynamics, suggesting that increasing the level of attention on the visual target with auditory feedback may optimise accommodative accuracy. Nevertheless, this investigation is not exempt of limitations, and they must be acknowledged. First, we have speculated that there are common neural areas in the control of attention and ocular dynamics, and therefore, they may play a role on the changes in the dynamics of the accommodative response when manipulating the attentional state. However, future brain-imaging studies should be considered to determine the specific neural areas and mechanisms involved in this association. Second, our experimental sample was formed by a relatively small sample of healthy young adults, and it is our hope that future studies will include clinical populations (e.g., individuals with attentional or accommodative deficits) and children in order to ascertain the external validity of the current findings. Due to recording errors, the number of participants included in the analysis of the accommodative response (n = 20) and pupil size (n = 16) were different. Nevertheless, the results observed for the accommodative response (lag and variability) were very similar when considering the entire experimental sample (n = 20) or for the 16 subjects for whom pupil data were available. Third, there are controversial results about the mediating role of refractive error in accommodative dynamics.[61–63] The inclusion of larger sample sizes would allow grouping of the experimental sample according to refractive error, and ascertain the association between the attentional state and the accommodative response in different refractive error groups. Fourth, physiological reactivity and perceived mental load are subject to individual differences,[64] and thus, the two levels of mental complexity used in this study are unlikely to be equally difficult for all participants. Fifth, as accommodation is a physiological variable, some changes in its behaviour are possible by the influence of a variety of factors (e.g., environmental or situational aspects, subject characteristics). A recent study has observed that group behaviour is reasonably robust for the accommodative response when measured in two different days, although there was a low to moderate inter-session repeatability.[65] Therefore, this inter-day variability indicates that individual data should be cautiously interpreted in clinical and research settings. Lastly, we have investigated the short-term effects of manipulating the capacity to focus on task-relevant stimuli on the accommodative dynamics; however, future studies would be required to explore the long-term effects in clinical settings. In this regard, the possible learning effects associated with multiple repetitions should be considered.

Conclusions

Our data indicate that the accommodative response dynamics are sensitive to changes in the capacity to focus on task-relevant stimuli. The imposition of an arithmetic task while fixating on a distant target induced a greater accommodative response, whereas the use of auditory feedback to capture attention led to a reduction in accommodative lag. For the accommodative variability, there was a substantial stabilisation of the accommodative response at near distances with auditory feedback. These findings highlight the impact of the attentional state on the ocular dynamics, and may help in the development of strategies for the prevention and management of asthenopia.

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Conflict of interest

The authors report no conflicts of interest and have no proprietary in any of the materials mentioned in this article.

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