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Impairments of accommodation and convergence ability after one night of sleep deprivation in young adults

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Billions of people worldwide suffer from sleep disorders and it is important to investigate how the lack of sleep or poor sleep quality affects the visual system. The primary aim of this study was to evaluate the influence of 1 night without sleep on the near point of convergence (NPC) and accommodation parameters in young adults. Twenty three young (mean age: 23.3 ± 1.68 years) adult subjects were recruited. NPC, accommodative facility, and amplitude of accommodation were measured after normal habitual sleep and after 1 night of sleep deprivation. Both the mean amplitude of accommodation and accommodative facility were significantly reduced after one night of sleep deprivation. With respect to NPC, both the break and recovery points of fusion were significantly receded after a sleep-deprived night. Our results showed that even 1 night without sleep may affect visual function associated with near vision tasks. Our findings suggest that sleep habits should be considered during optometric/ophthalmic examinations, especially when convergence and/or accommodation disorders are observed.

Keywords: sleep deprivation, near point of convergence, accommodation.

1. Introduction

Although sleep plays a primary role in our health and normal brain function, billions of people worldwide suffer from sleep disorders. Recent research showed that sleep disorders are very common in young adults. MCARDLE *et al.* (2020) found that at least one sleep disorder was present in 41.0% of young females and in 42.3% of young males (mean age: 22.2 years) [1]. Apart from the obvious adverse effects of sleep disturbances on cognitive performance [2–6], mental health [7] or reaction time [8] in young adults, sleep deprivation may also affect the visual system. In addition, sleep disorders may increase the risk of accidents in many real-world safety-sensitive tasks including driving [9], aviation [10] or other jobs requiring good visual performance. Existing studies have shown, that sleep deprivation may reduce saccadic peak velocity [8], increase blink rate [11] or decrease smooth pursuit accuracy and gain [12] in normal young adults.

Furthermore, poor sleep parameters may be a risk factor for developing glaucoma [11], dry eye [15] or age-related macular degeneration (AMD) [15]. However, the influence of short (approximately 24 hours) sleep deprivation on binocular vision, near point of convergence (NPC) or accommodation system has not been adequately investigated. Thus, understanding how sleep deprivation influences visual function is important, especially among young adults where sleep disorders are very common [1]. BEHNKE (2001) found a significant decrease in NPC ability after a period of 24-hours without sleep, but no significant change in accommodative function [16]. Furthermore, BOEHME *at al.* (2019, Conference Poster) found clinically insignificant differences in amplitude of accommodation and response between 12 and 24 hours of wakefulness [17]. TONG *et al.* (2016) found that sleep deprivation degrades binocular coordination of the visual axis (especially in the horizontal direction) as measured by a visual tracking task [18]. Recently, WOI *et al.* (2024) showed that young adult subjects with poor sleep quality demonstrated a reduced ability to maintain binocular fusion with increasing convergence demand (positive fusional vergence test) at distance [19]. On the other hand, older studies performed on a very small group of subjects showed that sleep deprivation may reduce convergence ability and increase exophoria (the tendency to drift the eyes outward), especially during near vision [20]. The accommodative system in humans is mainly controlled by the parasympathetic nervous system (stimulating effect) and the role of the sympathetic component in accommodation control is still under debate. Although the majority of previous studies showed that sympathetic stimulation decreases the amplitude of accommodation (inhibitory effect), GILMARTIN (1986) concluded that sympathetic innervation may also provide a small, slow component to accommodation [21]. Interestingly, short sleep and poor sleep quality are often associated with sympathetic nervous system dysfunction [22]. Thus, it is of interest to explore the effects of 24 hours of wakefulness on the visual system, especially on accommodation and ocular convergence control. To test this hypothesis, we decided to compare several standard visual parameters associated with near vision (near point of convergence, accommodative facility, amplitude of accommodation, lateral phoria, visual acuity) before and after 1 night of sleep deprivation in young adult subjects.

The research was approved by the Bioethics Committee at the Poznan University of Medical Sciences (No.: 701/23) and was conducted in accordance with the tenets of the Declaration of Helsinki. All subjects provided written informed consent to the experimental procedure.

2. Materials and methods

2.1. Participants

Twenty three young (non-smokers) adult subjects (eight females) took part in this study (mean age 23.3 ± 1.68 years). The sample size was chosen pragmatically since, at the stage of this research project planning, the specific restrictions because of COVID-19 were still in force. For this reason, we decided to recruit mainly university students interested in participation in our research. Based on a medical interview, all subjects were healthy with no history of mental illness, neurological disorders, or significant ophthalmic problems. Additional exclusion criteria were a history of alcohol/drug/nicotine abuse or addiction, use of drugs acting on the visual or central nervous system, history of chronic disease or injury that may affect the oculomotor system. Inclusion criteria were: near and distance visual acuity of 6/6 or better in each eye with best refractive correction, orthotropia (normal binocular alignment of visual axis) – a cover test was used to exclude any significant ocular misalignment or strabismus, normal amplitude of accommodation – the Hofstetter's formula (15 – 0.25 × patient's age in years) was used to define the minimum amplitude of accommodation – only subjects who met these criteria were included and normal NPC values in relation to age – cut off value of 9 cm was used for objective NPC break. In all subjects refraction was checked and revised (if needed) before the examination. Thus, subjects wore their habitual optical correction or the optical correction was revised to ensure optimal conditions for accommodation and vergence responses.

2.2. Design and procedures

Subjects visited the laboratory two times: for a rested wakefulness session (control condition) and a sleep deprivation session. The night before the wakefulness session, participants slept at home to ensure normal sleep without disturbances. All subjects were additionally questioned about their usual sleep-wake behavior (the SATED sleep questionnaire) [23]. The SATED scale assesses five key dimensions of sleep that have been associated with health outcomes: satisfaction with sleep, alertness during waking hours, timing of sleep, sleep efficiency, and sleep duration. A SATED scale can be totaled to produce an individual score: 0 represents poor sleep health and 10 represents good sleep health. Subjects with scores below 5 were excluded from participation [23]. Both control (baseline) and sleep deprivation measurements were carried out in the morning between 8:00 AM and 11:00 AM, and in the case of two subjects, all measurements were carried out in the afternoon (about 5:00 PM). In all subjects, the ranges of hours awake were nearly the same (between 24 and 25 hours) because we performed both the baseline and sleep deprivation measurements at the same time of a day. All subjects reported a normal 7 to 9 hours of sleep at home the night before the first visit in the laboratory. During the first visit (baseline measurements), each subject underwent an optometric examination including visual acuity measurement (Snellen letter chart reading at far and near), prism cover test at far and near distance (magnitude and the direction of horizontal phoria), amplitude of accommodation (AA) assessment (push –up technique), accommodation facility (AF) measurements (using ±2.00 D flipper at Harmon Distance cm, binocularly), and near point of convergence (NPC) examination. The second visit in the laboratory (after sleep deprivation) was within 7 days from the first visit: 10 of the subjects had the second visit the day after the first visit, and 13 of the subjects were examined within 7 days from the first visit (because of professional duties or family responsibilities). The second visit was always performed at the same daytime as the first visit and included the same optometric procedures. The order of tests was the same at each visit. During the experimental night subjects stayed awake at their homes and were allowed to carry out their own preferred activities such as: reading, listening to music or audiobooks, watching TV, playing board games. As in prior research, all subjects were explicitly asked to tell the truth if they had slept during the night [11].

2.3. Near point of convergence (NPC) examination

NPC was measured in each subject four times in centimeters (cm) using a metal wand (Wolff Wand) by bringing the fixation target (silver polished ball) along the patient's midline toward the nasal bridge in high lighting conditions. The polished surface of the silver ball reflected the minified image of the subject and provided an additional stimulus for accommodation. Patients were instructed to look attentively at this minified image and to keep the target single as long as possible. At the beginning, the fixation target was placed at the distance of 50 cm from the subject and was then moved slowly (1–2 cm/s) toward the nasal bridge until the patient reported diplopia or the examiner reports the disruption of binocular vision – one eye stops converging and starts to move temporally (break point of fusion). The target was moved still several centimeters toward the nose and was then slowly moved away from the subject until fusion was reported (the fixation target was again single) or the examiner notices the recovery of single binocular vision by realignment of the eyes (recovery point of fusion). Since previous studies have shown that the use of non-accommodative targets such as a penlight with red/green glasses – Penlight Red/Green procedure (PLRG), may be useful for the diagnosis of ocular convergence disorders [24], we decided also to assess the NPC using a penlight with red/green filters. During PLRG procedure, subjects were asked to look at the light and to report when two separate color of lights (red and green) were seen. A penlight was placed at the distance of 50 cm from the subject and was then moved slowly (1–2 cm/s) towards the nasal bridge until the patient reports two separate lights (break point). Then, the pen torch was moved slowly away from the subject until the two lights were again reported as single (recovery point). Both break and recovery points of fusion were measured in a sitting position using the 50 cm long rule to the nearest centimeter.

2.4. Accommodative facility (AF) examination

Since multiple tests were performed on each subjects, we decided to simplify the procedure related to accommodation measurements and to examine facility and amplitude of accommodation only under binocular conditions. AF was measured with both eyes open by alternately presenting +2.00D or −2.00D lenses in front of both eyes using a manual lens flipper while the subject looks at a target at a set distance. The target for accommodation facility were a letters on the Snellen chart one line above the best visual acuity of the worst seeing eye. Subjects were asked to report when the letters will become clear through each set of lenses. The target for AF examination was presented at Harmon Distance to ensure more natural viewing conditions. The number of cycles per minute (cpm) were recorded: one cycle included clear vision by +2.00 and −2.00 D lenses.

2.5. Amplitude of accommodation (AA) examination

Amplitude of accommodation (AA) was measured four times under binocular condition using push–up method. Distance in centimeter at which the subject reports blur was converted to diopters (D). Target for AA was a row of letters on the Snellen Fixation Stick corresponding to the best visual acuity at near (usually 20/20). The order of procedures was the same at each visit.

2.6. Horizontal phoria (the direction and the magnitude)

Phoria was measured using prism cover test and expressed in prism diopters (PD). The patient was instructed to look at the target (usually a single spot or a single letter) and the prism bar was placed over the eye with the base in the appropriate direction: base in (BN) for exo and base out (BO) for eso until no movement was observed on the alternating cover test. The procedure was done both at distance and at 40 cm. The amount of prism required to neutralize the movement was recorded. Positive values referred to esophoria and negative values referred to exophoria in the analysis.

2.7. Data analysis

Statistical analysis was performed with MedCalc software. Shapiro-Wilk test was used to test normality of the data. The repeated measures t-test was used for normally distributed data and the Wilcoxon test for paired samples was used when data were not normally distributed.

3. Results

The mean accommodative facility (AF), amplitude of accommodation (AA), NPC and lateral phoria measurements before and after sleep deprivation are shown in Table 1.

Accommodative facility. The means for AF before (11.13 ± 5.11 cpm) and after (9.17 ± 4.34 cpm) sleep deprived night were significantly different ($p = 0.0011$, $t = -3.761$). One night of sleep deprivation reduced the facility of accommodation in our group (Fig. 1).

Amplitude of accommodation. Mean accommodation amplitude was significantly reduced compared to the mean accommodation amplitude when well-rested: 11.18 ± 3.23 D *vs*. 13.67 ± 4.40 D, respectively ($p = 0.0003$, $t = -4.300$, df = 22) (see Fig. 2).

Lateral phoria at far and near. Horizontal phoria values were non-normally distributed. Thus, Wilcoxon test for paired samples was used. Median exophoria at near was slightly increased ($p = 0.0005$) after sleep deprivation (−2.00 PD *vs*. −4.00 PD), the interquartile range (IQR): from −4.00 to −1,00 and from −8.00 to −2.00, respec-

Table 1. Mean values of NPC, AF, AA and lateral phoria after normal habitual sleep and after one night of sleep deprivation.

Visual parameters (mean or median)	Before sleep deprivation	After sleep deprivation	Statistical test
Mean AF [cpm]	11.13 ± 5.11	9.17 ± 4.34	A repeated-measures *t*-test; $p = 0.0011$
Mean AA [D]	13.67 ± 4.40	11.18 ± 3.23	A repeated-measures *t*-test; $p = 0.0003$
Median Phoria at near (PD)	−2.00 (IQR: from −4.00 to −1.00)	−4.00 (IQR: from −8.00 to −2.00)	Wilcoxon test for paired samples; $p = 0.0005$
Median Phoria at far (PD)	0.00 (IQR: from −2.00 to 0.00)	−2.00 (IQR: from −2.00 to 0.00)	Wilcoxon test for paired samples $p = 0.0391$
Mean NPC break (Wolff Wand) [cm]	3.78 ± 1.78	5.77 ± 2.62	A repeated-measures *t*-test; $p = 0.\ 0001$
Mean NPC recovery (Wolff Wand) [cm]	7.47 ± 3.23	9.79 ± 3.60	A repeated-measures *t*-test; $p = 0.0012$
Median NPC PLRG break [cm]	3.20 (IQR: from 2.43 to 5.38)	3.70 (IQR: from 2.85 to 8.28)	Wilcoxon test for paired samples; $p = 0.0204$
Median NPC PLRG recovery [cm]	7.00 (IQR: from 4.88 to 10.98	8.20 (IQR: from 5.66 to 13.53	Wilcoxon test for paired samples; $p = 0.0177$

Abbreviations: AF, accommodative facility; AA, accommodation amplitude; D, diopters; PD, prism diopters; NPC, near point of convergence; PLRG, Penlight Red/Green procedure.

tively. With respect to distance phoria, we also observed slight increase in exophoria after sleep deprivation (0.00, −2.00, $p = 0.0391$).

Near point of convergence (NPC). When measured with an accommodative target, mean value of NPC break after 1 night of sleep deprivation was significantly re-

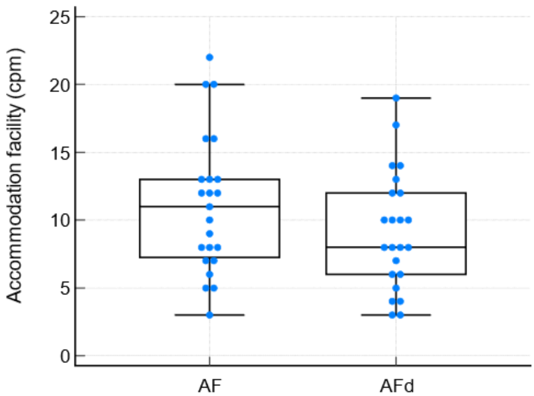

Fig. 1. Mean accommodative facility after normal habitual sleep (AF) and after one night of sleep deprivation (AFd). Solid middle line represents the median, lower and upper boundary of the box represents 25th and 75th percentiles ,respectively, the vertical black line extends from the minimum to the maximum value (excluding outliers). Each blue point represents the individual value of accommodative facility.

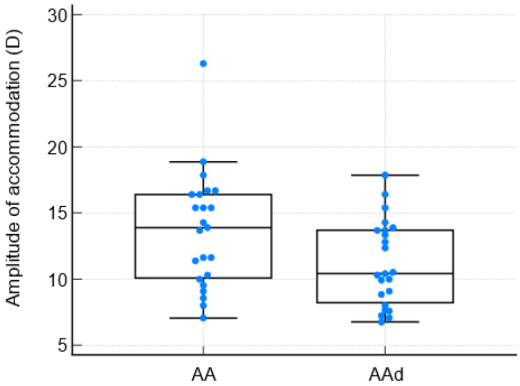

Fig. 2. Mean amplitude of accommodation after normal habitual sleep (AA) and after one night of sleep deprivation (AAd). Solid middle line represents the median, lower and upper boundary of the box represents 25th and 75th percentiles, respectively, the vertical black line extends from the minimum to the maximum value (excluding outliers). Each blue point represents the individual value of amplitude of accommodation.

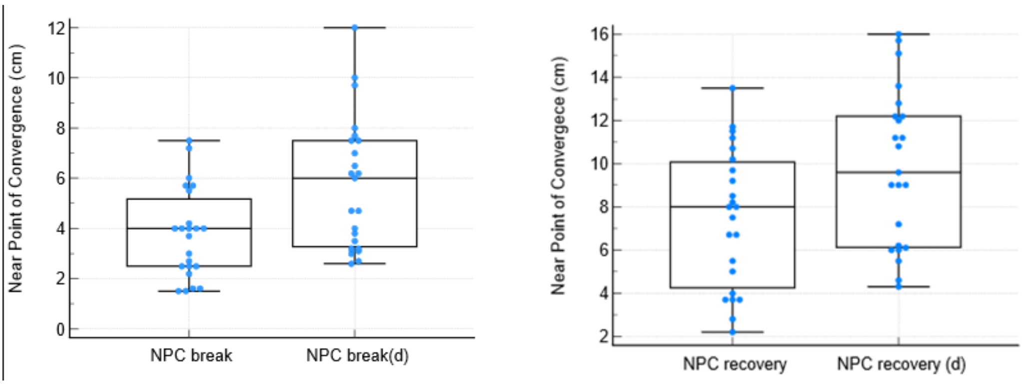

Fig. 3. Mean NPC break (left) and recovery (right) after normal habitual sleep and after one night of sleep deprivation (d) measured with Wolff Wand. Solid middle line represents the median, lower and upper boundary of the box represents 25th and 75th percentiles, respectively, the vertical black line extends from the minimum to the maximum value (excluding outliers). Each blue point represents the individual value of NPC break and recovery in centimeters (cm).

ceded, mean ± SD: 3.78 ± 1.78 cm *vs*. 5.77 ± 2.62 cm ($t = 4.660$, $p = 0.\ 0001$, $d = 22$). Similarly, mean value of NPC recovery after 1 night of sleep deprivation was significantly receded, mean ± SD: 7.47 ± 3.23 cm *vs*. 9.79 ± 3.60 cm ($t = 3.733$, $p = 0.0012$, $d = 22$), see Fig. 3.

When measured with a non-accommodative target, NPC values were non-normally distributed. Thus, Wilcoxon test for paired samples was used. Median values of NPC break and recovery were slightly reduced after sleep deprived night and reach statistical significance. Median NPC break before and after sleep deprivation was 3.20 *vs*. 3.70 cm ($p = 0.0204$), respectively; Interquartile Range (IQR) was from 2.425 to

5.375 and from 2.850 to 8.275, respectively. Similarly, the NPC recovery after sleep deprivation was slightly worse: 7.00 cm (IQR: from 4.875 to 10.975) *vs*. 8.20 cm (IQR: from 5.650 to 13.525), respectively ($Z = -2.372$, $p = 0.0177$).

4. Discussion

In this study we found that even 1 night without sleep may disrupt both near point of convergence and eye accommodation function. Convergence abilities were reduced after sleep deprivation – both break and recovery points of fusion were significantly receded after approximately 24 hours of no sleep. Similar, both accommodative facility and amplitude were significantly reduced after sleep deprivation. To interpret our findings, we must consider the influence of sleep deprivation on brain function associated with visual processing. Previous fMRI studies showed that short-term (approximately 24 hours) sleep deprivation may affect both subcortical and cortical structures involved in attention, alertness, and cognitive control [25,26]. TOMASI *et al*. (2009) found increased activation of the thalamus and decreased activation of the parietal and prefrontal cortical areas after 1 night with no sleep and concluded that this thalamic hyperactivation after sleep deprivation could underlie the reduced activation in parietal cortex, impairing the attentional networks engaged in visuospatial function [25]. CHEE *et al*. (2011) observed reduced activation in visual cortex, frontal eye field (FEF) and interparietal sulcus (IPS) following 24 h of no sleep as compared to normal sleep condition [26]. Furthermore, JACKSON *et al*. (2008) based on visual evoked potentials (VEP) results, found that sleep deprivation was related to slower processing of high spatial resolution details – increased P100 latency was observed for the parvocellular pathway stimulation [27]. In humans, the ciliary muscle is dually innervated by parasympathetic and sympathetic systems, but the role of sympathetic component in accommodation is still under debate. Ciliary muscle contraction (accommodation) and pupil miosis result from parasympathetic stimulation from the Edinger–Westphal (EW) nucleus of the midbrain [28]. The supranuclear control of accommodation reflex engage primary visual cortex, extrastriate visual cortex and frontal eye fields. In physiological condition, changes in accommodation cause changes in vergence (and *vice versa*) – near reflex triad. During the accommodative facility test, the visual system must quickly and accurate respond to retinal blur induced by either +2.00 D (accommodation relaxation) or −2.00 D (accommodation increase) lenses. Hence, any delay in the parvocellular pathway may affect accommodative ability. Although, the casual link between the impairments in attentional networks and convergence or accommodation control is not entirely clear, one may speculate that the ability to selectively maintain focus on visual stimuli was important to perform our experimental tasks where both mental and visual concentration on the targets are required. In clinical practice, sustained visual attention is crucial during most optometric or ophthalmic procedures, therefore any impairments of attention, mental fatigue or sleepiness associated with sleep disorders may obviously affect the outcomes. Consistent with our hypothesis, both accommodation and convergence abilities were reduced following 1 night without sleep. Boehme *at al*. (2019, Conference Poster) also studied the effect of sleep deprivation on amplitude of accommodation and responses in the group of young adult subjects [17]. They measured accommodative amplitudes and responses after approximately 12 hours and after approximately 24 hours without sleep in 38 healthy young adult graduate students. In contrast to our findings, Boehme *at al*. (2019) reported small and clinically unimportant (9.8 ± 1.8 D *vs*. 9.3 ± 1.8 D) difference in amplitude of accommodation between 12 and 24 hours measurements [17]. In addition, they showed no significant differences between 12 hours and 24 hours in accommodative responses. Yet, it is difficult to directly compare these results with our findings, as in that study the amplitude of accommodation was measured monocularly using the single "E" target on the fixation stick (push–up and pull–away technique). The visual target was much larger than our letters used for amplitude of accommodation measurements. Previous research showed that amplitude of accommodation may significantly vary for different target sizes using push–up method [29]. Furthermore, in contrast to our study, Boehme *et al*. (2019) tested amplitude of accommodation under monocular conditions. Surprisingly, we found a varied approach in the literature to assess the amplitude of accommodation (binocular or monocular) and finally we decided to measure the amplitude of accommodation only under natural, free space binocular viewing conditions (similar to everyday visual activities where accommodation is stimulated under binocular conditions). Similar approach was also suggested by Burns *et al*. (2020) [30]. In this study, the mean difference in binocular AA before and after sleep deprivation was nearly 2.50 D (Fig. 2) and should be rather considered as clinically important unlike to Boehme *et al*. (2019) study where the mean difference in monocular AA before and after sleep deprivation was only 0.50 D.

With respect to accommodative facility, it is worth to mention that during binocular testing, the subjects ability to make rapid changes (increase/relax) in accommodation while maintaining vergence response is measured. In addition, number of variables (*e.g.* size and position of the target, the reaction time to call out the letters/numbers/symbols, the magnification/minification factors induced by the lenses) may affect the results of accommodative facility [31]. The ability to see objects clearly and comfortably at various distances requires good dynamics of accommodation and vergence system and is essential to perform many everyday visual tasks. From clinical point of view, abnormal accommodative facility may produce real discomfort, blurred and unstable vision or eye strain symptoms. Thus, accommodative facility testing is important when screening patients with accommodation disorders and is a standard part of optometric examination. To our best knowledge, this is the first study to investigate the effect of sleep deprivation on accommodative facility. As expected, accommodative facility was reduced as a consequence of sleep deprivation (Fig. 1).

Unfortunately, data regarding accommodative facility test procedure and normative values in young subjects remain limited. Wajuihian [32] studied 1211 children between 13 and 18 years of age and found mean binocular accommodative facility (±2.00 flipper lenses) of 8.75 cpm. Zellers *et al*. [33] tested 100 adult nonpresbyopic subjects and found a mean binocular accommodative facility (±2.00 flipper lenses) of 7.7 cpm.

Our accommodative facility results both before and after sleep deprivation correspond with those mentioned above within the range of standard deviations (Table 1). However, we observed a significant trend towards the worse accommodative dynamics after sleep deprivation. Mean difference in the number of cycles per minute (cpm) before and after 24 hours of wakefulness was approximately 2 cpm and seems to be clinically relevant. Thus, based on our findings, one may speculate that even one night without sleep may affect both accommodative dynamics and amplitude leading to numerous visual complaints. REDONDO *et al*. (2020) showed that accommodative dynamics was sensitive to the attentional state – an improvement in accommodation response and stability was reported with auditory feedback [34]. Thus, if we assume that sleep deprivation affects attentional processes and the ability to respond to stimuli in timely fashion, the reduced accommodative facility observed in our cohort after sleep deprivation is rather unsurprising.

With respect to lateral phoria measurements, we observed that both near and distance exophoria were slightly increased after 1 night of sleep deprivation. In the 1970s, HORNE (1975) studied on a small group of subjects (six young males) the influence of sleep deprivation on lateral phoria [20]. He measured lateral phoria for near and far distance before, during and after sleep deprivation among young adults subjects (age between 22 and 25 years). Subjects were sleep deprived for 64 hours. Just like in this study, HORNE also observed the increase towards exophoria for both near and far vision with progressive sleep deprivation. The reduction of convergence ability was particularly observed for near vision and they concluded that the near phoria value appears to be more sensitive to the effects of sleep deprivation than the distance phoria measurements. In addition, TONG *et al*. (2016) showed, that sleep deprivation may affect oculomotor control (binocular coordination) especially in the horizontal direction what seems to be also in a good agreement with our findings [18]. They recorded objectively (500 Hz EyeLink device, SR Research) binocular eye position and concluded that sleep deprivation degrades the stability of both binocular coordination and gaze–target synchronization. Although we did not test the stability of binocular coordination in our cohort, we cannot exclude the influence of this variable on the results of phoria after sleep deprivation.

With respect to NPC, we found that both break and recovery points of fusion were significantly worse after sleep deprived night, particularly for Wolff Wand procedure. To our best knowledge, this is the first study comparing NPC before and after sleep deprivation among young adults. With respect to PLRG measurements, the NPC break values were also significantly receded after sleep deprivation but this differences were small (<0.5 cm) and therefore not clinically meaningful. The PLRG target reduce the meaning of accommodative-convergence component in the convergence response. Thus, one may hypothesize that the reduced accommodation abilities after sleep deprivation affect the NPC findings for accommodative targets to a greater extend compared to PLRG target. In addition, PLRG measurements were depended on subjective responses unlike the Wolff Wand measurements where the examiner could see the ocular alignment during convergence stimulation. In general, our findings showed that sleep deprivation impairs the convergence ability and may affect binocular vision during the activities done at short working distance. Although in our study the NPC values were still good after sleep deprivation (both the break and recovery points of fusion do not exceed 10 cm), there was a significant trend towards the worse convergence function following the 24 hours of wakefulness. With respect to normal findings for the NPC values in young adults, there is a huge variations in the literature. The few previous studies related to normative data of NPC and targets selection provided a varied results and conclusions. Scheiman *et al*. (2003) examined 175 optometry students (age range 22 to 37 years) and recommended a clinical cutoff value of 5 cm for the NPC break and 7 cm for the NPC recovery with either an accommodative and non-accommodative target [24]. On the other hand, Abraham *et al*. (2015) found the mean NPC break of 8.6 cm and the mean NPC recovery of 10.11 cm in young adults (50 subjects, age range 19 to 27 years) using penlight with red-green filters [35]. With respect to target selection for the NPC measurements, Pang *et al*. (2010) showed that NPC value does not depend on the target used for the subjects (18 optometry students) with normal binocular vision [36]. However, they found significant differences in NPC break and recovery values in the group with convergence insufficiency (18 optometry students) between the transilluminator with a red lens and accommodative target. On the other hand, Siderov *et al*. (2001) concluded that in young (non-presbyopic) subjects there is a small accommodative influence on the NPC value, which is target dependent [37].

However, little is known about the influence of sleep deprivation on vergence system. Neural control of vergence eye movements engage many brain regions including frontal eye fields, posterior parietal cortex and cerebellar vermis. Recent fMRI studies showed that sleep deprivation may not only reduce fMRI signal in the frontal and parietal brain areas but also affect activity in the extrastriate visual cortex during visuospatial attention tasks. Given the fact that sleep deprivation may affect the cortical areas involved also in vergence eye movements, we hypothesize that sleep deprivation may worse the convergence ability and affect the near point of convergence. In addition, Woi *et al*. (2024) showed that poor sleep quality in young adults subjects may reduce the ability to maintain fusion at distance with increasing convergence demand what seems to support our findings, suggesting that sleep deprivation may affect also neural control of vergence eye movements [19]. In a broader context, sleep disorders and fatigue are often associated with increased risk of accidents in many safety-sensitive tasks requiring good visual and cognitive control (*e.g.* driving, aviation, working at heights, operating heavy machinery). Thus, more research is needed to explore the influence of different sleep disorders on visual system and safety.

4.1. Limitations

We are aware that this study has several limitations. First, there was no randomization and masking. Both testing and sleep deprivation were not randomized and the examiner was aware whether the subject was sleep-deprived or not. Second, both the experimental night associated with sleep deprivation and the night with normal habitual sleep were not fully controlled in the laboratory (participants stayed at home). Third, we did not investigate the recovery effect after a normal habitual night's sleep. Fourth, the sample size was relatively small and included only young adult subjects (mainly university students). In addition, two participants were tested in the afternoon rather than morning, potentially introducing diurnal variations in visual parameters [38]. Thus, future and more lab-controlled research on a larger sample size including not only young but also older subjects are needed to explore the influence of sleep deprivation on different visual parameters.

5. Conclusions

This study demonstrated that even 1 night of sleep deprivation may affect convergence ability and accommodation parameters (amplitude and facility) among young adult subjects. To our knowledge, this is the first study to show reduced accommodative facility and amplitude in young subjects after sleep deprivation. In addition, receded near point of convergence and slight increase in exophoria was observed. Our findings suggest that sleep behavior should be considered during optometric or ophthalmic examination, especially when convergence and/or accommodation disorders are observed. Based on previous research, impairments of visual attentional network or the potentially slower processing of more detailed visual objects (parvocellular visual pathway) following the lack of sleep may underlie the reduced convergence and accommodation abilities observed in our study after sleep deprivation.

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