Attentional Function Following Partial Sleep Deprivation. Does Extraversion Make a Difference?

Preface

This graduate thesis is the final product of our process, starting with the first contact with our supervisor Ingvild Saksvik-Lehouillier in the fall of 2016. As we were both interested in sleep research and its significance for all humans, we were from day one excited to get the chance to be a part of a greater research project exploring the effects of sleep in the normal population. As the project was a pilot study contributing to the development of future research projects at the institute, we consider ourselves lucky to be a part of the process from scratch. By this, we got to influence the directions and procedures chosen. It has taught us about the stages of developing a project from a faint idea to an actual research procedure and ultimately a scientific paper. We have equally contributed and supported each other in all parts of the process, from the initial preparations to the final stages of writing, and we consider the partnership a valuable experience. We both trawled the literature for relevant background material, and participated in recruitment of participants, the handling of equipment, and the actual data collection. All data analyses were performed by us, with the supervision from Ingvild Saksvik-Lehouillier. The process has inspired us and expanded our view of future possibilities, and by closing the process now we feel that the challenges, tears and the feeling of mental exhaustion has finally paid off. Further, the laughs, reflections and late hours have also made this a time in our life we will never forget.

We would like to express gratitude to our supervisors Ingvild Saksvik-Lehouillier and Alexander Olsen. Thank you for your input, quick responding, and interesting conversations. Without Ingvild, her expertise and engagement, there would be no project and no thesis. Thank you for giving us a taste of how life can be as a researcher, and for supporting us through the different phases, the ups and downs, and the final touches that converged in a product we can both be proud of. A special thank you also goes out to our friends, loved ones and partners. Without your support, we would probably have stayed in bed. Finally, we would like to thank each other, for great support and friendship throughout this period of self-induced sleep deprivation.

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Abstract

Sleep is important for normal healthy functioning, and sleeping less than recommended is associated with various negative consequences. Obtaining less-than-sufficient sleep is common in various populations, and thus considered important to investigate. The negative effects of sleep loss are especially pronounced for attention. Inter-individual differences in the vulnerability to sleep loss is recognized in the literature. Previous research has documented that the declines in attentional function is more pronounced for extroverts than for introverts. Objectives: The present study explored how participants' attention was affected by sleeping two hours less than their habitual sleep length for three consecutive nights in their natural environment. Further, it investigated the contributing effects of the participants' scores on the personality trait extraversion. Method: A within group multiple baseline experimental design was applied. A sample of healthy, young adults (*n* = 30, aged 19 to 35) underwent a procedure of partial sleep deprivation based on their habitual sleep lengths. Habitual sleep lengths were calculated based on one week of normal sleep patterns recorded by an actigraph, the Actiwatch Spectrum Pro ©. Participants' attentional performance was measured by the use of CCPT-3 on five occasions in total. Personality was measured using the NEO-PI-3 at baseline. Statistical analyses were performed using raw scores of attentional performance in speed and accuracy from baseline, and comparing these to raw scores of speed and accuracy obtained after three days of partial sleep deprivation. Results: Statistical significant changes in speed and accuracy of small to moderate effects sizes were recorded after partial sleep deprivation compared to rested baseline. Participants' reaction times were shorter after the sleep deprivation. Their responses were more prone to errors, suggesting a speed-accuracy effect. Individual differences in decrements in attention were not related to participants' scores on extraversion. Conclusions: Healthy young adults exhibit more impulsive responding when partially sleep deprived, but their attentional impairment cannot be matched with deficits manifested in true attentional disorders. Limitations in the present study and directions for future research is discussed.

Keywords: Sleep, Partial Sleep Deprivation, Attention, Extraversion

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Introduction

There is extensive evidence in the literature documenting the negative cognitive consequences of insufficient sleep (Gunzelmann, Gross, Gluck, & Dinges, 2009; Lim & Dinges, 2010), which is a common phenomenon in the general population (Hintsanen et al., 2014; Hysing, Pallesen, Stormark, Lundervold & Sivertsen, 2013; Ursin, Bjorvatn & Holsten, 2005). Insufficient sleep particularly leads to declines in simple attention tasks, such as vigilance and sustained attention (Killgore, 2010; Lim & Dinges, 2010). Despite this general pattern, previous research has long been conclusive of the fact that individuals differ in the magnitude of sleepiness and cognitive performance impairment during periods of sleep deprivation (Van Dongen, Vitellaro, & Dinges, 2005). This individual variability is stable and highly replicable (Leproult et al., 2003; Morgan, Winne, & Dugan, 1980; Van Dongen, Baynard, Maislin, & Dinges, 2004a; Van Dongen, Maislin, & Dinges, 2004b). Identification of the variables or traits that can predict a vulnerability to sleep loss is therefore warranted (Van Dongen et al., 2005). Researchers have suggested that personality traits could represent markers for individual differences in sleep characteristics (Hintsanen et al., 2014; Killgore, Richards, Killgore, Kamimori, & Balkin, 2007). Within the literature, attention has centered on the personality trait extraversion. Higher scores on extraversion at rested baseline are related to more impairment of different cognitive performance tasks following sleep deprivation, compared to individuals with lower scores on the trait (Killgore et al., 2007; Taylor & McFatter, 2003). The present study was conducted on a sample of healthy, young adults; mostly university students, as these are readily available for research and represent a population known to be exposed to less than sufficient sleep (Steptoe, Peacey, & Wardle, 2006; Witkowski et al., 2015). It contributes to the established knowledge by answering two questions: 1) Are two hours of reduced sleep for three consecutive nights in an individual's natural environment enough to establish an effect on cognitive functions? and 2) can individual differences in this effect be attributed to differences in the personality trait extraversion?

Sleep

Sleep habits and recommendations. Aspects of sleep, such as length, depth, quality, and timing are important factors of sleep health (Hirshkowitz et al., 2015). Amongst them, sleep length is one of the factors most readily available for research, as subjective and objective measures of sleep length are relatively easy to obtain. For adults (18-64 years) the recommended sleep duration is seven to nine hours (Hirshkowitz et al., 2015), although individual differences in sleep requirement are recognized (Hirshkowitz et al., 2015; Kripke, Garfinkel, Wingard, Klauber & Marler, 2002; Van Dongen, Rogers, & Dinges, 2003b). In the Norwegian adult population, sleep durations usually fall within the lower range of these recommendations (Ursin et al., 2005). Sleeping less than this amount is also common practice for both adolescents and adults in Norway (Hysing et al., 2013; Ursin et al., 2005). The prevalence of sleep disturbances in Norway significantly increased in recent times; amongst other things, people more frequently report sleep onset insomnia, more dissatisfaction with sleep, and more daytime impairment due to sleep loss, than they did in the year 2000 (Pallesen, Sivertsen, Nordhus & Bjorvatn, 2014). This supports the notion that insufficient amounts of sleep is common in the general population in Norway.

Sleep regulation. The regulation of sleep depends upon complex interactions of temporal, behavioural, and psychological processes. Sleep mechanisms are often described in terms of the two-process model of sleep regulation proposed by Borbély in 1982 (as cited in Borbély & Achermann, 1999). According to this model, the timing and structure of sleep is determined by the interaction of the homeostatic process and the circadian process (Borbély, Daan, Wirz-Justice, & Deboner, 2016). In short, the circadian process regulates the rhythm of sleep and wakefulness from an approximate 24-hour cycle controlled by the circadian pacemaker: the suprachiasmatic nuclei. Typically, markers of this process are rhythmical changes in body temperature and melatonin levels affecting the propensity to sleep. The homeostatic process regulates the need for sleep based on the amount of previous wakefulness, with slow wave brain activity on electroencephalography (EEG) representing the principal measurement of this process (Borbély et al., 2016). This two-process model of sleep regulation has later been used to describe the temporal profiles of sleep and wakefulness (Van Dongen & Dinges, 2000, 2003). Sleep homeostasis and circadian rhythmicity have been shown to modulate brain responses, as measured by fMRI (Muto et al., 2016).

Behavioral factors also play an important role in sleep regulation. Exercise, nicotine, alcohol, and noise are factors known to affect sleep (Irish, Kline, Gunn, Buysse, & Hall, 2015). Increased movement, exposure to light, and caffeine intake are examples of behaviors that can prolong wakefulness, and these behavioral factors can interfere with, or overrule, the homeostatic and circadian factors (Bjorvatn & Pallesen, 2009).

Sleep debt. Another commonly used theory of explanation for sleep mechanisms and the adverse effects of sleep deprivation is that of sleep debt (Borbély et al., 2016; Van Dongen et al., 2003b). Sleep debt is defined as the cumulative hours of sleep loss relative to individual sleep need (Short & Banks, 2014). It is thus a result of extended wakefulness that often comes at a neurocognitive “cost” (Van Dongen, Maislin, Mullington, & Dinges, 2003a). Sleep debt is closely related to the homeostatic process: sleep debt accumulates during extended wakefulness as the homeostatic pressure increases, and decreases during sleep (Borbély et al., 2016). However, sleep debt is not just expressed by physiological markers of homeostasis (i.e., slow wave brain activity), but also through sleep latency (i.e., the propensity to fall asleep), subjective sleepiness, and neurobehavioral performance (Van Dongen et al., 2003b). Results from studies examining the effects of accumulating sleep debt show that for each additional hour awake there is a cumulative decline in performance estimates, when taking interindividual variability in both sleep need and vulnerability to sleep loss into account (e.g., Belenky et al., 2003; Van Dongen et al., 2003b). On the other hand, theories of sleep debt fails to explain why losing eight hours of sleep for one night results in significantly greater declines in performance than losing a total of eight hours sleep over four consecutive nights (Drake et al., 2001). This latter observation suggests that waking functions are not only affected by the amount of sleep obtained, but indicates a neurobehavioural cost associated with sustained wakefulness (Van Dongen et al., 2003a). In summary, even though sleep debt may provide a somewhat simple explanation to sleep regulation in itself, it offers a basic framework for investigating sleep loss and its effects on neurobehavioral functions.

Partial sleep deprivation. In experimental research, the average amount of sleep needed to prevent the cumulative neurobehavioral deficits produced by less-than-optimal sleep is estimated to be 8.16 hours (Van Dongen et al., 2003a). In line with this, restriction of sleep to < 7 hours per night is often termed partial sleep deprivation (Durmer & Dinges, 2005). Still, there are great variations in waking functions depending on how much sleep is restricted, and the successive number of days the sleep restriction is maintained. Generally, greater restriction of sleep (0-3 hours of sleep per night) is associated with greater neurocognitive impairment compared to mild or moderate restriction (5-7 hours of sleep per night; Belenky et al., 2003; Drake et al., 2001). When partial sleep loss is maintained over consecutive nights, there is a statistically robust increment in reported mood disturbances, sleepiness, fatigue, and mental stress among participants (Dinges et al., 1997).

Obtaining less than sufficient amounts of sleep can have serious consequences due to the sleepiness and neurobehavioral deficits that follow. When investigating college students’ sleep durations in the United States, it is evident that this group is more prone to sleeping less than what is recommended (Steptoe et al., 2006), and shorter sleep times occur more often towards the end of a semester compared to during the early stages of a semester (Witkowski et al., 2015). For students, this temporal disparity could be both an effect of, but also exert an effect on, work related to exams. More importantly, in 10 % of the more serious traffic accidents in Norway from 2005 to 2008, the accidents were caused by the driver falling asleep (Nordtømme, Moe & Øvstedal, 2010). Previous reports have reported that in 30 % of the cases, collisions or driving off the road were caused by sleepiness of the driver (Moe, 1999).

Sleep deprivation, cognition, and personality

A substantial amount of research has been carried out in an effort to understand the impact of sleep deprivation on cognition (Killgore, 2010; Kleitman, 1963, pp. 215-229; Pilcher & Huffcutt, 1996; Pilcher & Walters, 1997). There is broad consensus that sleep deprivation generally affects cognition in a negative manner (Dorrian, Rogers, & Dinges, 2005; Durmer & Dinges, 2005). Since there is a strong relation between neural activity and behavior (Kandel & Hudspeth, 2013), the impact of sleep deprivation on different cognitive functions are likely to reflect the impact sleep deprivation has on the neural areas that are responsible for these functions (Short & Banks, 2014). Numerous neuroimaging studies have contributed with evidence that there is a marked change in brain activity following sleep deprivation (Drummond et al., 2005; Durmer & Dinges, 2005; Killgore, 2010). Some emphasize that the regime of sleep deprivation applied can influence the resulting neurobehavioral responses (Belenky et al., 2003; Van Dongen et al., 2003a). That is, acquiring no sleep (total sleep deprivation) will cause different neurobehavioral changes than acquiring some sleep (partial sleep deprivation). As most neuroimaging studies to this date have been concerned with acute total sleep deprivation (continuous wakefulness for 24-48 hours; Krause et al., 2017), less is known about the neurocognitive consequences of partial sleep deprivation, despite its known prevalence. A recent study investigating neurocognitive changes in college students ($N = 24$) following chronic partial sleep deprivation, found that cortical arousal was negatively affected by even minor sleep deficits (Witkowski et al., 2015). That is, cortical arousal decreased as a consequence of sleeping less and further led to deficits in different cognitive functions, in line with previous research (Durmer & Dinges, 2005).

A well-established effect of sleep deprivation is decrements in the attentional domain (Dorrian et al., 2005; Durmer & Dinges, 2005; Killgore, 2010; Krause et al., 2017; Scullin & Bliwise, 2015; Short & Banks, 2014). Considering attention is not a unitary process, but rather a collective term of different cognitive processes, including different aspects of gathering and processing information (De Weerd, 2003; Gopher & Iani, 2003; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991), there is no unifying definition of attention. Yet, attention is most commonly referred to as the ability to selectively process sensory information (De Weerd, 2003; Gopher & Iani, 2003; Krause, 2017). The different aspects of attention range from simpler forms (e.g., alertness, vigilance) to more complex processes demanding higher-order cognitive functions, like learning, memory, and executive functions (Durmer & Dinges, 2005; Killgore, 2010; Lim & Dinges, 2010). Various attentional tests are designed to tap these different attentional processes.

Speed and accuracy. Two aspects of performance are particularly important to investigate when measuring attention: speed and accuracy (for a review, see Alhola & Polo-Kantola, 2007). Speed is frequently reported by measures of reaction times, that is, the time it takes to respond to a stimulus in milliseconds from the stimulus is first presented (Dorrian et al., 2005). Accuracy is often reported by measures of errors in a performance, both frequency and type. The error estimate varies depending on the test and theories being used, but can generally be separated in two categories when it comes to tasks of vigilance and sustained attention. When an individual fails to respond to a target in a timely manner when a target is present, this is often referred to as *lapses* or *omissions* (Basner & Dinges, 2011; Durmer & Dinges, 2005). When an individual indicates that a target is present when it in fact is not, this is termed *commissions* or *premature responses* (Basner & Dinges, 2011; Durmer & Dinges, 2005). Reaction times are used as a speed measure in most assessment tools for attention, making it easily comparable across studies. Accuracy is a term with more diversity. In sleep research, cognitive performance variability involving more errors of omission and commission when individuals are sleep deprived compared to rested, are frequently reported in the literature (Belenky et al., 2003; Dinges et al., 1997; Drake et al., 2001; Killgore et al., 2007; Killgore, 2010; Lim & Dinges, 2008; Van Dongen et al., 2003a).

Individual differences in vulnerability to sleep loss. Individuals differ in their magnitude of sleepiness and cognitive impairment during sleep deprivation, and a trait-like resistance to sleep loss has been proposed (Krause et al., 2017; Van Dongen et al., 2004a; Van Dongen et al., 2005). This individual variability cannot be ascribed solely to individual differences in performance at baseline (Van Dongen et al., 2004a), and has proved to be stable and highly replicable (Leproult et al., 2003; Morgan et al., 1980; Van Dongen et al., 2004a; Van Dongen et al., 2004b). Some of these differences may be rooted in genetics (Dijk & Archer, 2009; Goel, Basner, Rao, & Dinges, 2013; Kuna et al., 2012; Landolt, 2008).

It has been suggested that personality traits could represent markers for individual differences in responses to sleep deprivation (Killgore et al., 2007). The background for this interest in personality draws on research using functional neuroimaging, showing that individuals with lower levels of tonic cortical arousal in prefrontal areas at baseline are more vulnerable to the effects of sleep loss than those with higher arousal levels (Caldwell et al., 2005). In resistant individuals, this activation is both higher at baseline than in the vulnerable group, and the activation is sustained during periods of extended wakefulness (Vandewalle et al., 2009). If certain personality traits are related to such biological arousal, this could represent meaningful groups to explain individual differences in vulnerability to the effects of sleep deprivation.

Personality refers to the individual differences in the relatively stable set of characteristics that makes each individual unique (Goldberg, 1993). These individual characteristics are referred to as personality traits. The Five Factor Model (FFM) is one of the most recognized trait models of personality (Goldberg, 1993). The FFM differentiates individuals in lasting emotional, interpersonal, experimental, attitudinal, and motivational ways based on five overarching personality traits (McCrae & John, 1992). The hierarchical model consists of the factors neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness, each factor comprised of a number of facets statistically related to the factor itself (McCrae & Costa, 2010). Neuroticism is a reversed emotional stability-factor, and refers to the tendency to experience negative emotions. The trait extraversion is easily thought of as sociability, but is also associated with being active, energetic, and optimistic. Openness to experience measures the individual's openness to both the inner and outer world, and a preference for variety. Agreeableness is associated with being altruistic and sympathetic, and conscientiousness refers to individual differences of self-control (McCrae & Costa, 2010). Studies examining the relationship between personality and sleep deprivation have to a great extent been focused on the trait extraversion. This is due to prevailing personality theories of differences in arousal as an underlying mechanism of individual differences. Extraversion consists of six facets: warmth, gregariousness, assertiveness, activity, excitement-seeking, and positive emotions (McCrae & Costa, 2010). Warmth is related to interpersonal intimacy, gregariousness refers to the preference for other people's company, assertiveness is associated with dominant and forceful behavior, activity is typically related to a sense of energy and a need to keep busy, excitement-seeking refers to cravings of excitement and stimulation, and positive emotions is a facet denoting the tendency to experience emotions such as joy and love (McCrae & Costa, 2010). The traits of neuroticism, openness to experience, agreeableness, and conscientiousness are not associated with individual differences in the effects of sleep deprivation (Killgore et al., 2007; Rupp, Killgore & Balkin, 2010; Taylor & McFatter, 2003).

Extraversion and arousal. Hans Eysenck proposed that differences in high and low scorers on the personality trait extraversion could be explained by different thresholds in the ascending reticular activating system, and thus be related to cortical activation (for a review, see Eysenck, 2016). In short, Eysenck's theory states that extroverts (i.e., high scorers) would be described as chronically under-aroused, whereas introverts (i.e., low scorers) demonstrate higher levels of basal activity and thus need less stimulation to reach their optimum level of arousal. Drawing on previous research, Eysenck proposed that cortical arousal is related to performance in an inverted U-shaped curvilinear function, with moderate levels of arousal resulting in optimal performance. Further, he suggested that introverts and extroverts normally would be located at each side of the peak of this curve, placing extroverts' optimal performance at a lower arousal level than that of introverts (Eysenck, 2016). Research examining levels of arousal in extroverts and introverts has documented a tendency for extroverts to have lower arousal levels than introverts as measured by EEG (Beauducel, Brocke, & Leue, 2006) and physiological markers (Matthews, 1987). Some researchers have reported that the differences in arousal are small in magnitude (Matthews & Amelang, 1993). Others have argued that differences observed between extroverts and introverts should rather be ascribed to differences in physiological reactivity to sensory stimulation, with introverts exhibiting greater responses than extroverts (Stelmack, 1990). It has been suggested that regardless of how the differences in arousal are explained, one would expect that inducing dearousal would be more detrimental for an extrovert's performance than that of an introvert (Taylor & McFatter, 2003).

Effects of sleep deprivation on attention

Sleep deprivation markedly affects an individual's capacity to sustain attention and maintain vigilance (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005; Lim & Dinges, 2008; Short & Banks, 2014), and these negative effects are most prominent for simple attention tasks (Killgore, 2010; Lim & Dinges, 2010). In a meta-analysis investigating the relative magnitude of these effects, Lim and Dinges (2010) found that sleep deprivation exerted moderate to large effects on such simple attentional tasks. Further, effect sizes for complex attentional tasks were moderate (Lim & Dinges, 2010). Typical tests for simple attentional functions are psychomotor vigilance tests (PVTs) and continuous performance tests (CPTs). Different PVTs and CPTs vary in their range of measurements and outcome variables, enabling researchers to apply test protocols appropriate to investigate different attentional processes. Tests measuring the effects of sleep deprivation on attention should in general be easy to learn, easy to perform, and not be affected by abilities (Dorrian et al., 2005). The different test paradigms (PVTs and CPTs) each consists of a number of specified and prototyped versions, all of them requiring sustained attention over prolonged periods of time, and for responders to mark their detection of a target on a screen as quickly and accurately as possible.

Specific tests will differ in attentional requirements both within and between each paradigm. The PVT presented by Dinges and Powell (1985) and the CTP presented by Conners (CCPT; 1994) are relevant options when studying basic attentional functions as they are both proved to be valid and reliable (Conners, 2014; Dorrian et al., 2005). These two tests are similar in some aspects, but differ in others. For example, the PVT presented by Dinges and Powell (1985) has longer inter-stimuli intervals and a lower ratio between targets and non-targets than the CCPT-3 presented by Conners in 2014. Further, CCPT-3 requires individuals to inhibit responses to non-targets (Conners, 2014), while no such inhibition is required in the PVT (Dinges & Powell, 1985). As such, some would argue that CCPT-3 should be regarded as a more complex attentional task than the PVT (e.g., Lim & Dinges, 2010). Yet, the CCPT-3 holds no requirements of memory or working memory, and neither does the PVT presented by Dinges and Powell (1985). Without basic attentional processes like vigilance and sustained attention abilities, performing any task in a goal-directed manner becomes difficult (Killgore, 2010; Krause et al, 2017). The effects of sleep deprivation on these basic processes can thus be assumed to potentially have severe real life consequences, as staying vigilant and attentive is important both in traffic and other high-risk situations.

A trade-off between speed and accuracy has been suggested to explain deteriorating attentional performance (Rinkenauer, Osman, Ulrich, Müller-Gethmann, & Mattes, 2004). This speed-accuracy trade-off is thought to occur when individuals focus primarily on improving one aspect (e.g., faster responses), which in turn leads to deterioration of the other (e.g., more inaccurately responses; Alhola & Polo-Kantola, 2007). As attentional performance is markedly disrupted by sleep deprivation, it is interesting to examine the potential speed-accuracy trade-off in sleep deprived individuals. The literature is scarce on studies that explicitly explore the possible impact of sleep deprivation on the speed-accuracy trade-off, and the few studies that exist have yielded somewhat fluctuating results. Several studies have found that sleep deprivation leads to a decrease in accuracy measures (i.e., more errors) and an increase in reaction times (i.e., slower reaction times; Jennings, Monk, & van der Molen, 2003; Smith, McEvoy, & Gevins, 2002). Others report a decrease in accuracy measures after sleep deprivation, whereas performance speed remains unchanged (Gosselin, De Koninck, & Campbell, 2005). Others again, have found a slowing in speed measures while the accuracy remains the same (De Gennaro, Ferrara, Curcio, & Bertini, 2001). Typically, these studies have explored the effects of sleep deprivation on the speed-accuracy trade-off measuring higher-order cognitive functions (De Gennaro et al., 2001; Gosselin et al., 2005; Jennings et al., 2003; Smith et al., 2002). In their meta-analysis on the impact of total sleep deprivation on different cognitive variables, Lim and Dinges (2010) found no significant effect of this speed-accuracy trade-off (Lim & Dinges, 2010). This is in line with research showing that typical attentional outcomes in more basic attentional processes, as measured by a PVT, following both partial and total sleep deprivation are slowing of reaction times and increased numbers of errors (i.e., lapses/omissions/commissions; Belenky et al., 2003; Drake et al., 2001; Killgore et al., 2007; Killgore, 2010; Lim & Dinges, 2008). As such, sleep deprivation affects both speed and accuracy for basic attentional processes. However, sleep deprived individuals usually manifest a slowing of speed *and* decreased accuracy compared to when rested, suggesting no speed-accuracy trade-off effect.

Temporal changes in attention following sleep deprivation. In studies on partial sleep deprivation, restricting sleep to five hours per night has been shown to affect the speed of responding in a negative manner after only two (Dinges et al., 1997) or three nights (Belenky et al, 2003). In both of these studies, reaction times slowed as sleep debt accumulated (Belenky et al., 2003; Dinges et al., 1997). The number of lapses has been shown to increase as days with partial sleep deprivation continue, reaching significant changes after two nights (Dinges et al., 1997). Several sleep dose-response studies have been conducted to examine the effects on attentional performance as sleep debt accumulates (e.g., Belenky et al., 2003; Van Dongen et al., 2003a). In these studies, participants are assigned to groups with different “doses” of sleep per night (e.g., four hours, six hours or eight hours; Van Dongen et al., 2003a), and effects of sleep deprivation are compared after several days across the different groups. When mild to moderate sleep deprivation is applied, the performance of the participants in cognitive tests is often affected initially (during the first 1-3 nights). After this, cognitive performance gradually stabilizes at a lower-than baseline level (Belenky et al., 2003, Drake et al., 2001), sometimes with further decline when exceeding six or seven nights (Dinges et al., 1997). A near linear dose-dependent relationship emerges from this research when severe sleep restriction is applied. That is, as days with partial sleep deprivation continues and sleep debt accumulates, effects on attentional functions are affected increasingly in a negative manner (Belenky et al., 2003; Van Dongen et al., 2003a; Van Dongen et al., 2003b). When total sleep deprivation is applied, the negative linear effect is typically steeper than that observed in partial sleep deprivation (Belenky et al., 2003; Van

Dongen, et al., 2003a). This highlights the importance of studying partial sleep deprivation as a distinct phenomenon and its effects on attention, as the fact that partial sleep deprivation is more common in the general population than total sleep deprivation makes this knowledge highly warranted.

The sleep deprived extrovert. In general, healthy sleep is found to be positively related to higher scores of extraversion when habitual sleep is examined (Gray & Watson, 2002; Hintsanen et al., 2014; Williams & Moroz, 2009). Research suggests that this association changes when sleep is experimentally restricted. As discussed previously, it is hypothesized that depriving humans of sleep in general will lead to lower levels of cortical arousal (Witkowski et al., 2015) and reduced cognitive performance (Dorrian et al., 2005; Durmer & Dinges, 2005). This decay in performance is assumed to be more pronounced in extroverts compared to introverts, either because they start off with lower arousal levels than introverts, or because they exhibit less physiological reactivity to sensory stimulation than introverts (Taylor & McFatter, 2003). In one study examining this relationship, higher scores of extraversion at rested baseline was associated with greater declines in performance compared to lower scores on the PVT measuring alertness and vigilance after one night of total sleep deprivation (Killgore et al., 2007). After the first night, higher scores on the facets of warmth, gregariousness, assertiveness, and activity were significantly predictive of these negative changes. After three nights of total sleep deprivation, only higher scores of gregariousness and activity were still negatively related to vigilant performance (Killgore et al., 2007). The main effect of extraversion as a whole was not significant for the second and third night in the experiment (Killgore et al., 2007). Significant negative links between extraversion and the effects of sleep deprivation have also been reported for other cognitive tasks. Higher scores of extraversion were found to exert an overall negative effect on accuracy in time estimation, abilities of immediate and delayed recall, and accuracy in digit span-tasks following sleep deprivation (Taylor & McFatter, 2003). Others have found that extroverts performed significantly worse than introverts on a PVT after 22 hours of continued wakefulness, but only when both groups were exposed to socially enriched environments (Rupp et al., 2010).

Although previous research shows various effects of sleep deprivation, there is generally consensus of the fact that sleep deprivation impairs attentional performance. Most studies on sleep deprivation to this date have focused on the effects of total sleep deprivation, even though partial sleep deprivation is more likely to occur in the general population outside laboratory settings. A tendency towards shorter sleep durations has been documented in the

Norwegian population (Hysing et al., 2013; Sivertsen, Øverland & Pallesen, 2011; Ursin et al., 2005). The negative consequences of sleeping less-than-optimal can have serious consequences, like increasing the risk of traffic accidents (Moe, 1999; Nordtømme et al., 2010). This emphasizes the importance of examining the effects of partial sleep deprivation. Generally, individuals exhibit greater intraindividual and interindividual variability in their attentional performances when sleep is deprived, compared to results at rested baseline (Frey, Badia & Wright, 2004). As mentioned, previous research has documented a tendency for extroverts to be more susceptible to the decrement in cognitive performance following total sleep deprivation than introvert. Additionally, there is some evidence that the facets gregariousness and activity are of particular relevance. However, the literature on this subject is scarce, and has only explored such relationships when participants acquired no sleep at all. To this end, more research is needed to support or reject these theories.

Research questions

This study set out to investigate whether partial sleep deprivation of two hours less than habitual sleep for three successive nights in an individual's natural environment is enough to induce the changes reported previously, in healthy young adults. Since previous research has reported effects in attentional functions after two to three days, we wanted to compare baseline measures with attentional measures obtained after three days of partial sleep deprivation. We were specifically interested in how such sleep restrictions affected speed and accuracy measurements, as these are well known characteristics of attention. Further we wanted to examine whether the personality dimension of extraversion-introversion was in any way related to individual differences in response to sleep deprivation. For this part, exploring the possible contributions of the extraversion facets was of interest. Based on our predictions, we had the following hypotheses:

H_1: Partial sleep deprivation of participants by subtracting two hours of sleep from their baseline sleep duration over three consecutive nights in their natural environment will lead to decline in both speed and accuracy. That is, a slowing of speed and increased error rates are predicted to occur.

H_2: High scores on the trait extraversion will be negatively related to attentional functioning after three days of partial sleep deprivation. More specifically, high scores on the facets of gregariousness and activity will contribute to this effect.

Methods

Sample

The original sample consisted of 44 individuals (males = 10, females = 34), who participated in a larger pilot study. The participants age ranged from 19 to 33 years (mean age = 22.9, SD = 3.0). In line with previous research (Dettoni et al., 2012), sleeping > 30 minutes more than the individually assigned sleep time for partially sleep deprived participant led to exclusion on grounds of failing to conform to the sleep restriction protocol. This exclusion was performed to make sure there was a significant difference between the participants habitual sleep length and the experimental sleep length. Other formal exclusion criteria were personality disorders; alcohol or drug abuse affecting the ability to obey a research protocol; mental disability, autism or other severe developmental disorders; stroke or other acquired brain injuries; progressive neurological illness (e.g., Parkinson's disease; MS); cancer, heart- or respiratory diseases, or other somatic conditions that affect normal functioning. The participants were informed of the exclusion criteria by e-mail after their initial approach and request to enter the research project. Of the 44 participants, 30 of them were examined in the present study (males = 8, females = 22). The participants age ranged from 19 to 31 years (mean age = 22.5, SD = 2.8). The 14 participants that were excluded, either failed to conform to sleep restrictions (n = 11), withdrew due to unrelated illness (n = 1), or were excluded due to technical issues with the research equipment (n = 2). The participants were drawn by consecutive sampling. The participants were recruited through posters on social media (Facebook) and at NTNU campuses in Trondheim, in addition to presentations in lectures. The only prerequisite, besides being within the age range (18-35 years), was sufficient knowledge of the Norwegian language to understand and complete the questionnaires. The participants were offered a summarized view of their personality profile and sleep data at the end of the experiment. A within group multiple baseline experimental design was applied. The research project was approved by the Regional Committee for Medical and Health Research Ethics in Midt-Norge.

Instruments

Questionnaires. The questionnaires were filled in on test day 1 and recorded demographic information; the participants' use of caffeinated drinks; alcohol consumption; self-reported symptoms of depression and anxiety, metacognitions and executive functioning; subjective feeling of pain and fatigue; and different aspects of sleep and sleepiness. The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Bergman & Kupfer, 1989) was used to measure, amongst other things, self-reported sleep length by asking when the participants normally go to bed and get up on a regular weekday, and how many hours of sleep they usually obtain during a normal night of the week. In addition, the participants' negative and positive emotions were measured subsequent to each attention task.

Individual differences in personality were measured using the NEO Personality Inventory-3 (NEO-PI-3; McCrae & Costa, 2010). The NEO-PI-3 consists of 240 statements that represent different attitudes and thoughts, and respondents answer by a 5-point Likert scale ranging from "strongly disagree" to "strongly agree". The inventory measures the five major dimensions of personality: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. As an example, a question regarding the facet activity in the trait extraversion is "I'm not as lively as other people" (McCrae & Costa, 2010, p. 104). Each dimension is assumed to represent a fundamental personality trait, validated in different populations, across languages, and with a range of instruments (McCrae, 2010; McCrae & Costa, 2010). The traits are shown to be durable across age groups (McCrae & John, 1992). Only the trait extraversion was examined in the present study, as previous research indicates that no relations are to be expected with regard to sleep deprivations and the other traits (Killgore et al., 2007; Rupp et al., 2010; Taylor & McFatter, 2003). Data collected from the NEO-PI-3 were scored by the automated software package provided with the test, providing summary t-scores with a mean of 50 and a standard deviation of 10 for each of the traits, adjusted for gender and age (McCrae & Costa, 2010). The NEO-PI inventories have been shown to be useful in measuring the major dimensions of personality (i.e., neuroticism, extraversion, and psychoticism) suggested by Eysenck (Barelds & Luteijn, 2002; Costa & McCrae, 1995).

Actigraphy. Both habitual and restricted sleep lengths were measured objectively by actigraphy. The present study used the Actiwatch Spectrum Pro © (Philips Respironics, Murrysville, PA, USA), which measures the participants' pattern of activity and rest with the help of a watch, an accelerometer, and a data store unit placed on the wrist. It records data relevant to circadian rhythms and sleep parameters (Philips Healthcare, 2013). Using actigraphy as a measure of sleep is considered to have high ecological validity, since it allows evaluation of sleep to happen in the participant's usual sleep environment (Sánchez-Ortuño, Edinger, Means, & Almirall, 2010). In the present study, it was important to get a close-to-normal estimate of the habitual sleep length from the first week, as this was later used to calculate individual sleep length for the rest of the experiment. Previous models of the Actiwatch Spectrum Pro © have shown good sensitivity (i.e., detecting sleep), but poorer specificity (i.e., detecting wakefulness; Marino et al., 2013; Meltzer, Walsh, Traylor, &

Westin, 2012). The Actiwatch Spectrum Pro © is compatible with the earlier version of the device (i.e., Actiwatch Spectrum ©; Phillips, 2014). Some researchers recommend subjective sleep data as a supplement to actigraphy data (Ancoli-Israel et al., 2003; Kushida et al., 2001).

Data was collected from the watch during the whole test period, both during weekdays and weekends. At termination of each test period, actigraph data was transferred to the project's database and analyzed using the software Philips Actiware (version 6.0.9; Philips Respironics, Murrysville, PA, USA). In cases where the discrepancy between the computer-generalized sleep reports based on actigraphy and the sleep diary filled out by the participant was more than 15 minutes, the actigraphy data was manually corrected. This was done by two independent raters according to a set procedure. No previous research has presented a validated or inter-rater reliable procedure to perform this manual correction. The correction procedure used in the present study is therefore to be regarded as new, drawing on procedures previously used (see Chow et al., 2016; Dean et al., 2016; Ugland & Landrø, 2015). Two separate procedures were developed, one for establishing sleep onset, and one for wake-up time. The flowchart that was used in the procedure will be published in a later article. After manually correcting most of the sleep onset and wake-up times, the $ICC_{(2, 2)}$ consistency on data from the two raters ranged from 0.877 to 1. The manually corrected actigraph data was used when examining normal sleep length and sleep length when partially sleep deprived.

Sleep diary. Sleep was measured subjectively through a sleep diary, a procedure considered as the gold standard of subjective sleep assessment (Carney et al., 2012). All participants were asked to log their sleep throughout the 10 test days, using a modified version of the sleep diary published by Morin (1993). The sleep diary provides detailed information, ranging from participants' bedtime and sleep-onset latency, to the use of medications and other substances to enhance sleep (Bjorvatn et al., 2006).

Conners' Continuous Performance Test 3rd Edition. In the present study, the Conners' Continuous Performance Test 3rd Edition (CCPT-3; Conners, 2014) was used to assess the effects of partial sleep deprivation on attentional functioning. The CCPT-3 is a standardized computer-administered test (Conners, 2014), and is one of many paradigms in the large family of continuous performance tests (CPTs; Conners, 2014). CCPT is one of the most widely used measures of attentional problems in Norway (Egeland, 2014, p. 183). Participants are required to respond when any letter, except the letter X, appears on the screen in front of them by pressing the spacebar on the keyboard (Conners, 2014). Letters were presented in a pseudorandom fashion in six blocks. In accordance with the procedure provided by Conners (2014), participants were instructed to respond as quickly and correctly as possible. Each letter is presented for 250 milliseconds and the inter-stimuli intervals (i.e., time between the presentation of each new letter) varies between one, two, and four seconds. The test lasts for 14 minutes, not counting the one-minute trial round. In total, 324 targets and 36 non-targets were presented, giving it a high signal-to-noise ratio (Conners, 2014).

The CCPT-3 has proved to have strong internal consistency and a high test-retest reliability (Conners, 2014), the latter being a valued criterion in the present study considering the frequency of attentional tests administered. It is also regarded as a test of high discriminative validity in terms of differentiating clinical groups from healthy controls, in addition to being highly generalizable across different samples (Conners, 2014). The normative data of the CCPT-3 is based on a large general population sample in the United States (*N* = 1400; Conners, 2014). The test provides performance results shown in both raw scores and standardized t-scores, with the t-scores being adjusted for age and gender. In the present study, raw scores were used in the statistical analysis due to its higher resolution of speed and accuracy (i.e., speed in milliseconds and error rates in %). The test provides several output scores, but in the present study analyses were performed on measures of mean hit reaction times (HRT), errors of omission (OMI), and errors of commission (COM). As defined by Conners (2014), HRT is a measure of speed indicating the time it takes to respond to a stimulus in milliseconds from the stimulus is first presented**.** OMI and COM are measures of accuracy, the first one referring to failure to respond to a target when a target is present (i.e., missed target), and the second occurring when indicating that a target is present when it in fact is not (i.e., wrong response to a non-target; Conners, 2014). The error rates of OMI and COM was kept separate as it has been indicated that they tap different aspects of attentional deficits in previous versions of the CCPT (Conners, 2014; Egeland & Kovalik-Gran, 2010a).

Data collection

Data was collected over three subsequent periods during the spring term, with the whole data collection taking place between March 13th and May 4th, 2017, during which the sunrise varies from 6:43 a.m. to 4:45 a.m. in Trondheim (63.45°N), Norway. Data was collected for eleven consecutive days, each test period lasting from Monday through Thursday the following week. There were a maximum of 15 participants in each period. In the first week of testing, participants were asked to stick to their habitual sleep patterns. This week served as a baseline for all measures. Participants were tested five times during the eleven days: on day one, four, and eight with normal sleep (i.e., test days 1, 2, and 3), and on day nine and eleven after undergoing partial sleep deprivation (i.e., test days 4 and 5). For an overview of the procedure including administration time estimates and instruments, see table 1. The individual test times of each day were centered around 9 a.m. (± 90 minutes), keeping variables such as individual test time, location, and test leader as stable as possible for each participant throughout their test period. Participants were instructed not to drink coffee or other caffeinated drinks before they were done testing.

On test day 1, after receiving information about the study and signing their written informed consent, the participants were given the necessary equipment and instructions on how to use it to carry out the experiment. This included an Actiwatch © and a sleep diary. Next, the participants completed the CCPT-3. Before and after the attentional test, they answered the following two questions: “On a scale from 1-10, how tired are you?” and “On a scale from 1-10, how much pain are you in?” After the test, they were additionally asked to rate their own performance and effort on the CCPT-3 on a scale from 1-10. Lastly, the participants filled in the questionnaires described above.

On test day 2 the participants completed the attention task, in addition to answering the same questions before and after, as explained above. This procedure was repeated on test days 4 and 5. The CCPT-3 results from test day 5 were used as a measure of the effects of partial sleep deprivation, as previous research suggest that we could expect the effects of partial sleep deprivation to be apparent by this point in time (Belenky et al., 2003, Drake et al., 2001). On test day 3 (after one week of normal sleep), the CCPT-3 and the related questions were administered as usual and the average sleep length of each participant was calculated using sleep data from the Actiwatch Spectrum Pro ©. CCPT-3 results from test day 3 were used as baseline measures in data analyses, as they were obtained closer in time to the experimental manipulation than the prior attentional measures. This is in line with previous recommendations, to minimize practice effects (Collie, Maruff, Darby, & McStephen, 2003). The participants were then instructed to sleep two hours less than their individual average, calculated from their Actiwatch Spectrum Pro ©, over the next three nights. After completing the procedure on test day 5 (i.e., the final day of the experiment), they were offered their personality profile from the NEO-PI-3 (as seen in McCrae & Costa, 2010, p. 28) and sleep data from the Actiwatch for the first week of normal sleep. The personality profile included age and gender corrected t-scores on all traits and facets. All participants were informed on how to interpret the scores. The sleep report included information about sleep efficiency, sleep quality, sleep length, and general activity levels.

Table 1.

Detailed overview of the procedure.

Test day 1 1st day of the experiment, Monday Time estimate: 1 hour, 30 minutes	Test day 2 4th day of the experiment, Thursday Time estimate: 20 minutes	Test day 3 8th day of the experiment, Monday Time estimate: 20 minutes	Test day 4 9th day of the experiment, Tuesday Time estimate: 20 minutes	Test day 5 11th day of the experiment, Thursday Time estimate: 20 minutes
Information and written consent, Demographic questions, CCPT-3 and questions about fatigue and performance, PANAS, ISI, PSQI, ESS, Diurnal Scale, HADS, AUDIT-C, FSS, BPI, BRIEF-A, MCQ, NEO-PI-3, Information and distribution of sleep diary and Actiwatch Spectrum Pro ©	CCPT-3 and questions about fatigue and performance, PANAS	CCPT-3 and questions about fatigue and performance, PANAS, Calculating sleep-deprivation time based on data from the Actiwatch Spectrum Pro ©	CCPT-3 and questions about fatigue and performance, PANAS	CCPT-3 and questions about fatigue and performance, PANAS, Handing out personality profile and sleep data.

Note. CCPT-3: Conners' Continuous Performance Test 3rd Edition, PANAS: Positive and Negative Affect Schedule, ISI: Insomnia Severity Index, PSQI: Pittsburgh Sleep Quality Index, ESS: Epworth Sleepiness Scale, HADS: Hospital Anxiety and Depression Scale, AUDIT-C: Alcohol Use Disorders Identification Test Consumption, FSS: Fatigue Severity Scale, BPI: Brief Pain Inventory, BRIEF-A: Behavior Rating Inventory of Executive Function - Adults, MCQ: Metacognitions Questionnaire, NEO-PI-3: NEO Personality Inventory-3. Area shaded in grey indicates application of partial sleep deprivation protocol.

Data analyses

The means and standard deviations were examined for all relevant variables, to give us an idea of how the sample relates to a general population in measures of sleep length, extraversion, and attentional variables. For this, the samples t-scores are of primary interest. As a preliminary analysis, we were interested in knowing whether the sleep duration in the baseline week represented a normal week for our participants. This was done by checking

Pearson's Correlation Coefficient between the self-reported habitual sleep length (from the PSQI; Buysse et al., 1989) and the participants average sleep duration from the baseline week measured by manually corrected actigraphy data.

As described in the procedure, personality data was only recorded at the first day of testing. For the attentional variables, the scores used in the analyses were the ones obtained on test day 3. Further, statistical analyses were performed on raw scores, as they offer higher resolution of speed and accuracy (i.e., milliseconds and error rates in %) than the t-scores. The distributional shape of HRT, OMI, and COM was examined to determine the extent to which the assumption of normality was met, which it was not. Consequently, three Wilcoxon signed-rank tests were performed, each checking temporal differences within the three attentional variables.

The main effects of sleep deprivation. To test whether partial sleep deprivation for three consecutive nights would lead to lower speed and accuracy (H_1), we compared the samples' raw scores on HRT, OMI, and COM from baseline to the raw scores obtained after three days of partial sleep deprivation (i.e., mean hit reaction time in milliseconds, error rates of omissions and commissions in %). The Wilcoxon signed-rank tests were used to compare differences in scores obtained at baseline and after three days of partial sleep deprivation (i.e., test day 5), for the three variables individually.

Relationship between personality and attention. To test whether high scores on the trait extraversion would be negatively related to attentional outcomes after three days of partial sleep deprivation (H_2), we examined the relationship between scores of extraversion and the scores of HRT, OMI, and COM. To assess the effects of partial sleep deprivation on attentional variables, a change score was calculated for each individual by subtracting the raw scores obtained after three days of partial sleep deprivation from the raw scores at baseline. This was done separately for the variables HRT, OMI, and COM. To examine whether there was a relationship between scores of extraversion and the change scores of HRT and COM, Pearson's Correlation Coefficients were calculated. As the OMI variable violated the assumptions of normality and linearity, the relationship between change scores of OMI and the other variables was examined using the Spearman's Correlation Coefficient. Similarly, the analyses Pearson's and Spearman's Correlation Coefficients were further applied to examine the correlations between the facets warmth (E1), gregariousness (E2), assertiveness (E3), activity (E4), excitement-seeking (E5), positive emotions (E6), and their relations to change scores of HRT, OMI, and COM. A negative correlation would indicate that higher scores on extraversion or the facets were related to slower reaction times, and more errors of commission and omission after sleep deprivation compared to baseline. Bootstrapping was performed on all correlation coefficients.

As this is a pilot study aiming to explore trends and effects, no efforts were made to counteract the problem of multiple comparisons in any of the analyses. A correction like the Bonferroni was considered, but was dismissed, due to the inflated risk of rejecting a true effect (Perneger, 1998). Effect sizes were converted from *z*-scores to the effect size estimate *r* using the following equation (from Rosenthal, 1991, p. 19):

$$r = \frac{z}{\sqrt{N}}$$

in which *z* is the standardized *z*-score produced by SPSS, and *N* is the size of the study (i.e., the number of total observations) on which *z* is based. Effect sizes were described as small, medium, or large, depending on whether their values exceeded .10, .30, or .50 accordingly (Cohen, 1992). A two-tailed $p < 0.05$ was accepted as statistically significant for all statistical tests.

Results

The sample

Table 2 shows the means and standard deviations of relevant variables measured for our sample as a whole. As indicated, sleep restriction was successfully carried out, as the average sleep duration in the experimental condition falls within what is recognized as partial sleep deprivation (i.e., < 7 hours of sleep; Durmer & Dinges, 2005). For extraversion, on a group level the sample falls within the range conceptualized as average (t = 45-55) by McCrae and Costa (2010, p. 17). Further, on a group level, our participants' attentional performance never fell below what is categorized as average performance (t-scores in the range 45-54 for all variables) by Conners (2014) on any of the attentional variables, neither at baseline, nor after partial sleep deprivation. Additionally, participants performed a little faster than average at baseline on hit reaction time (t = 40-44; Conners, 2014), and atypically fast after partial sleep deprivation (t < 40; Conners, 2014). The Pearson's Correlation Coefficient showed that the participants' average sleep length from the baseline week measured by manually corrected actigraphy data correlated positively with participants' self-reported habitual sleep length ($r = .48$, $N = 30$, $p = 0.01$).

The effects of partial sleep deprivation on HRT, OMI, and COM

The Shapiro-Wilk test indicated violations of normality at baseline for HRT ($S\text{-}W = .915$, $df = 30$, $p = .020$), OMI ($S\text{-}W = .626$, $df = 30$, $p = .000$), and COM ($S\text{-}W = .882$, $df = 30$, $p = .003$). When comparing the raw scores from baseline to the raw scores after three days of partial sleep deprivation, the Wilcoxon signed-rank test indicated a statistically significant change in HRT from baseline (*Mdn* = 342.0) to day three of partial sleep deprivation (*Mdn* = 339.3), $T = 131.0$, $p = .037$, $r = -.270$. Further, statistically significant changes were observed in COM raw scores from baseline (*Mdn* = 22.92) to day three of partial sleep deprivation (*Mdn* = 31.25), $T = 339.5$, $p = .008$, $r = .341$. Examining OMI from baseline (*Mdn* = 0.00) and day three of partial sleep deprivation (*Mdn* = 0.00), resulted in no statistically significant differences, $T = 59.0$, $p = .954$, $r = -.007$. The median scores show that HRT decreased (i.e., faster responses) and COM increased, following partial sleep deprivation. The change in HRT had a small to medium effect, whereas the difference in COM had a medium effect.

Table 2
Means and standard deviations of measures at baseline, and following three days of partial sleep deprivation

	Baseline	**Sleep deprived**
	M (SD)	M (SD)
Sleep length calculated by actigraphy (hours)	7.49 (0.85)	5.0 (0.82)
Self-reported habitual sleep length (hours)	7.68 (0.72)	-
Extraversion (t-scores)	52.0 (12.5)	-
HRT (ms)	347.0 (32.47)	339.8 (31.5)*
HRT t-score	40.0 (5.9)	38.9 (5.8)
OMI (%)	0.27 (0.45)	0.66 (2.4)
OMI t-score	45.5 (1.9)	46.9 (8.4)
COM (%)	26.9 (18.9)	33.8 (20.5)**
COM t-score	49.5 (11.0)	53.5 (12.0)

Note. Baseline sleep length refers to the samples' mean sleep duration averaged across all 7 baseline nights, calculated by manually corrected actigraphy. Self-reported sleep length at baseline refers to the samples' average sleep duration as reported in the PSQI (Buysse et al., 1989) on test day one. Measures of personality are presented in a gender corrected t-score. Performance on hit reaction time (HRT), errors of omission (OMI), and errors of commission (COM) are based on the whole sample and reported in raw scores (i.e., milliseconds; error rates in %), and age and gender corrected t-scores. The baseline scores of these measures were obtained on test day 3. Numbers marked with asterisks indicate a statistically significant change in scores from baseline to after sleep deprivation. * $p < .05$. ** $p < .01$

The effect of personality on attentional variables after sleep deprivation

The correlation matrix displayed in table 3 shows the correlation coefficients between the personality variable extraversion, the facets of extraversion, and the change scores of HRT, OMI, and COM. As shown, no significant correlations were found between extraversion and attentional outcomes. Nor were there any statistically significant relationships between any of the facets and the attentional change scores. Note that although these correlation coefficients do not reach statistical significance, the positive relationship between the trait extraversion and both HRT and COM has a small to medium effect size. The facet gregariousness is positively related to HRT and COM, with small to medium effect sizes. The facet warmth is negatively related to COM with a medium effect size. The facet assertiveness is positively related to OMI with a small to medium effect size. A statistically significant negative relationship was found between the two attention variables HRT and COM, showing that as HRT decreased, there was an increase in errors of COM.

Table 2

Extraversion (E), Warmth (E1), Gregariousness (E2), Assertiveness (E3), Activity (E4), Excitement Seeking (E5), Positive Emotions (E6), change scores for Hit Reaction Time (HRT), Omissions (OMI) and Commissions (COM): Correlation Coefficients, Means (M) and Standard Deviations (SD).

(N = 30)

Variables	***M***	***SD***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8[1]**	**9**	**10**
1. E	51.9	12.5	-									
2. E1	52.6	15	.83**	-								
3. E2	49.1	12.6	.84**	.76**	-							
4. E3	53	11.8	.49**	.21	.29	-						
5. E4	48.2	0.1	.77**	.55**	.53**	.35	-					
6. E5	51.4	11.4	.63**	.38*	.59**	.01	.33	-				
7. E6	53.7	0.1	.78**	.64**	.44*	.26	.67**	.37*	-			
8. HRT	7.2	17.1	.24	.19	.24	.19	.15	.03	.22	-		
9. OMI[1]	-0.4	2.5	.16	.22	.20	.24	-.09	.17	-.18	-.03	-	
10. COM	-6.9	12.6	-.20	-.30	-.29	.01	-.05	-.11	-.08	-.69**	.03	-

Note. Correlation Coefficients are computed using Pearson's Correlation Coefficient when nothing else is noted. Scores used for Hit Reaction Time, Omissions and Commissions are change scores. Scores presented for Extraversion and extraversion facets are age and gender corrected t-scores.

[1] The Correlation Coefficient between OMI and other variables are computed using Spearman's Correlational coefficient.

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

Discussion

Speed and accuracy

Our results indicated that reducing sleep to two hours less than habitual sleep length for each of three consecutive nights in healthy young individuals was enough to induce statistically significant changes in two out of three measures of speed and accuracy. Performance on the CCPT-3 showed a significant decrease in accuracy (i.e., increase in errors of commission) as partial sleep deprivation was applied, in line with our hypothesis and previous research (e.g., Belenky et al., 2003; Drake et al., 2001; Killgore et al., 2007). However our participants showed a significant *decrease* in reaction times, meaning that they performed faster after sleep deprivation than they did at baseline. This was contrarily to our hypothesis, and to previous research, predicting an overall decline in measurements of speed as the sleep restriction protocol is applied (Lim & Dinges, 2008, 2010). By indicating improved performance in speed and a decline in accuracy, our results support a speed-accuracy trade-off, where participants primarily focus on improving speed at the cost of accuracy (i.e., more errors of commission). This is in line with what has previously been suggested by Lim and Dinges (2010). Some have suggested that this trade-off between speed and accuracy on CCPT tests can be an indication of impulsivity (Conners, 2014; Egeland & Kovalik-Gran, 2010a). A factorial analysis of the outcome variables of the previous version of the CCPT, showed that increases in errors of commission and faster reaction times were markers for the attentional factor “hyperactivity-impulsivity” (Egeland & Kovalik-Gran, 2010a). Further, when developing the CCPT-3, Conners (2014) drew on the findings from Egeland and Kovalik-Gran (2010a) and suggested similar groupings of the different outcome measures in the CCPT-3, making commissions and hit reaction time two important measures in the category “impulsivity”. Thus, our results could indicate that on a group level, our participants became more impulsive when they were partially sleep deprived than when rested.

The results indicated no significant change in the accuracy measure of omissions. This is contrary to our hypothesis, and previous findings showing an increase in errors of omission after sleep deprivation (e.g., Killgore, 2010; Lim & Dinges, 2008; Van Dongen et al., 2003a). However, the design of the CCPT-3, with a high signal-to-noise ratio, makes errors of omission less likely to occur than errors of commission (Egeland & Kovalik-Gran, 2010b). This low probability of making errors of omission is reflected in the low frequency of omissions in the normative data of a non-clinical sample provided by Conners (2014), suggesting a ceiling effect in the healthy population. Consequently, when recording omissions after partial sleep deprivation in a healthy sample, it seems a significant change would not render visible, unless the sleep manipulation led to decrements in attention comparable to that observed in a clinical sample.

A typical result from previous studies investigating attention following sleep deprivation, is increased numbers of lapses on the PVT compared to rested baseline. Consequently, we were asking why our results did not show increased numbers of errors of omission on the CCPT-3 when the participants were sleep deprived. As mentioned previously, omissions and lapses are often referred to as the same phenomenon (Basner & Dinges, 2011; Durmer & Dinges, 2005). However, when exploring the associated definitions, differences appear that may account for the lack of effect on omissions in our study. A *lapse* is a response to a target that exceeds 500 milliseconds (Dinges & Powell, 1985), whereas an *omission* in the CCPT-3 is recorded when there is no response to a target at all before the next target it displayed (Conners, 2014). This could mean that slower reaction times are allowed in the CCPT-3 compared to the PVT, without being registered as an omission, as long as the lapse does not exceed 1000, 2000 or 4000 milliseconds referring to the different inter-stimuli intervals. As such, it seems that when relating omissions to the term lapses in attention, a more precise term would be *prolonged* lapses. The differences in criterias for making one of the two errors makes direct comparisons of results of lapses and omissions challenging.

The lack of development in omission scores seen in our sample could be a reflection of two things: 1) Sleep debt in the quanta presented here does not exert the same effect on attentional variables as that of total sleep deprivation, or other restrictions of sleep, or 2) the CCPT-3 error estimate of omissions is not sensitive enough to pick up on attentional lapses following sleep deprivation. This latter point could reflect the hypothesized ceiling effect on this variable. It should also be highlighted that our sample as a whole never performed beneath what is considered as average in the general population on any of the measures. This could in turn indicate that our sample holds some sort of resistance to the previously documented negative effect sleep deprivation has been shown to exert on attentional variables. Others have suggested that minimal effects following sleep deprivation could reflect some kind of adaptation to partial sleep deprivation when sleep loss is accumulated slowly (Drake et al., 2001). This could also be the case in our sample, withdrawing only two hours from the participants' habitual sleep. Consequently, determining precisely what factors that could explain the relatively small decrements in attentional variables in our sample, is at this point challenging.

Extraversion and attention

There were no statistically significant relationships between scores on the trait extraversion or its facets (i.e., warmth, gregariousness, assertiveness, activity, excitement-seeking, and positive emotions), and change scores of performance on the attentional variables. This is contrary to our hypothesis that there would be a difference in performance after partial sleep deprivation, with extroverts performing worse than introverts, either because they start off with lower cortical arousal levels than introverts, or because they exhibit less physiological reactivity to sensory stimulation than introverts. This lack of effect could be a consequence of our modest sample size. A larger sample would allow extracting scores from "true introverts" and "true extroverts" without reducing the participants included in analysis to a marginal number. Further, a more specified sample could be obtained by screening the participants before inclusion based on their scores on extraversion. One previously published study has performed such an initial screening before actual admission to the experiment (Rupp et al., 2010). In the present study, the trait of extraversion was close to normally distributed, making "true extroverts" and "true introverts" rare. This could have affected the lack of correlations reported between personality and attentional outcomes after partial sleep deprivation.

The fact that we did not find significant interactions of extraversion in the present study could imply that this trait does not exert the same effect when individuals are partially sleep deprived as that reported when total sleep deprivation is applied (Killgore et al., 2007; Rupp et al., 2010). Again, this could be a question of whether the participants in the present study obtained "sufficient" sleep debt to exert the expected effect. As the main effect of partial sleep deprivation was not as deteriorating on attentional variables in the present sample as previously reported by others, this could affect the lack of significant relationships between extraversion and the change in scores of speed and accuracy. On the other hand, the effects of extraversion following total sleep deprivation are not always evident either. In line with our results, it has previously been reported that individual differences in extraversion failed to predict the interindividual variability observed in PVT results after total sleep deprivation for 36 hours (Van Dongen et al., 2004a). No published studies to this date have explored the role of personality when partial sleep deprivation is applied. Thus, one cannot be certain what the lack of effect observed here can be attributed to.

Strengths and limitations

The sample. In the present study, consecutive sampling was used to recruit participants, mostly from the NTNU university campus in Trondheim. It has been noted that studies investigating the impact of sleep deprivation on cognition, often are carried out with relatively small sample sizes (Olaithe et al., 2017). When comparing this study with other similar ones, we find that sample sizes are often similar, or smaller than that what has been applied in the present study (e.g., *N* = 12; Drake et al., 2001; *N* = 23; Killgore et al., 2007; *N* = 43; Van Dongen et al., 2003a). The recruitment procedure resulted in a sample consisting of mostly university students. Although consecutive sampling by recruiting from university campuses is convenient, care must be taken when using this method of sampling, as the participants can be expected to be more homogenous than in a randomized sample. Although investigating consequences of partial sleep deprivation in this population is highly relevant, as students are known to acquire less-than-optimal sleep (Steptoe et al., 2006), students cannot automatically be assumed to be a normal representation of all healthy, young adults. In this respect, it is important to consider whether the sample at hand represents a somewhat higher-functioning group than the average general population. The results indicate that our participants performed average or above average on all attentional variables at baseline. The age range and the recruitment from a university environment could be assumed to have contributed to this, considering the fact that this level in academia requires high cognitive functioning. The determined cognitive function at baseline could contribute to the suggested resistance to the negative effects of partial sleep deprivation mentioned previously.

Exclusion due to symptoms of mental illness, sleep disturbances or heavy caffeine use was not performed in the present study, but is frequently reported in other research exploring consequences of less-than-optimal sleep. As depression (Tsuno, Besset, & Ritchie, 2005), anxiety (Fuller, Waters, Binks, & Anderson, 1997), and caffeine (Bjorvatn & Pallesen, 2009) are factors known to affect sleep, including this in our study could have affected our results. On the other hand, anxiety and depression are amongst the most prevalent mental health disorders in Norway (Mykletun, Knudsen, & Mathisen, 2009). As such, it is argued that including factors expected to affect sleep and attention in the daily life of the general population should strengthen the ecological validity of the results in the present study. Regarding personality, the use of NEO-PI-3 is considered a strength, as it provides a solid measure of the participants' personality profiles. Yet, it should be highlighted that generalization of the results should be limited to populations comparable to the present sample, as the present sample cannot be assumed to reflect the general population in all aspects.

Partial sleep deprivation versus total sleep deprivation. Our results differed from those obtained by previous research, both by indicating faster reaction times compared to the slowing of reaction times previously reported, and in terms of the relatively modest effect sleep deprivation had on the attentional outcomes. The majority of previous studies of sleep deprivation have been conducted on total sleep deprivation (Killgore et al., 2007; Lim & Dinges, 2008; Rupp et al., 2010). By definition, it could be argued that total sleep deprivation implies studying effects of sustained wakefulness rather than effects of partial sleep deprivation. Drawing on research highlighting the cost of sustained wakefulness (Krueger & Tononi, 2011; Van Dongen, Belenky, & Krueger, 2011; Van Dongen et al., 2003a), it is reasonable to assume that this difference in experimental design might contribute to such differing results. Yet, research on the neurocognitive effects of accumulating sleep debt suggests that the differences in detrimental effects of total sleep deprivation versus partial sleep deprivation is quantitative, but not qualitative (Belenky et al., 2003; Van Dongen et al., 2003a; Van Dongen et al., 2003b). Our results support the notion of quantitative differences between total and partial sleep deprivation, but also suggest that the effects of partial sleep deprivation could be qualitatively different from those of total sleep deprivation.

Measurement and control of sleep. Using actigraphy to measure sleep is considered to be of high ecological validity (Sánchez-Ortuño et al., 2010). Measuring sleep by actigraphy enabled us to study reactions to sleep deprivation under close-to-normal conditions as the actigraph is expected to have little impact on an individual's daily routines. This is considered as a strength in our research. Compared to overnight polysomnography (PSG), actigraphy is in general found to be a reliable and valid instrument to assess sleep (De Souza et al., 2003; Kushida et al., 2001; Meltzer et al., 2012), and its use is recommended when PSG measures are difficult to record (Ancoli-Israel et al., 2003). Additionally, the process of manually correcting actigraphy data is assumed to improve the quality of the data used in the analyses in the present study.

By studying sleep in a natural environment we had less control of the participants' behavior than one would have when using a sleep laboratory, both regarding wakefulness and sleep. In the present study, one-fourth of the sample was excluded as they failed to follow sleep restriction as instructed. This dropout rate might be due to motivational factors, but could also be a reflection of individual differences in vulnerability to sleep loss. Further, a limitation when leaving participants to follow their normal routines, is that we had little to no influence on how they spend their waking time. As mentioned, waking behavioral factors can interfere with, or overrule, the homeostatic and circadian factors (Bjorvatn & Pallesen, 2009). As baseline data was collected from a supposed normal week, it would be ideal if participants behaved in their habitual manner when undergoing the experimental procedure. This was however not controlled for. Considering that baseline sleep duration was averaged across seven days, it included one weekend. Previous research has pointed to an increasing discrepancy between sleep durations on weekends and weekdays (Sivertsen et al., 2011), although this is expected to vary across age groups (Hysing et al., 2013; Ursin et al., 2005). Thus, including weekend sleep in the baseline sleep duration could provide a slightly longer baseline than that acquired if only examining weekdays. Still, the baseline sleep duration was shown to correlate sufficiently with the self-reported habitual sleep length, and was thus regarded representative of normal sleep in our sample. In summary, the data collected on sleep measures in the present study is considered as having high ecological validity.

The use of CCPT-3 in partial sleep deprivation studies. One of the great advantages of the CCPT-3 is that it yields many useful attentional measures, related to different aspects of attentional function. A factorial analysis performed on the CCPT-2, the previous version of CCPT-3, supports the notion of there being no overall measure of attention, but rather distinct attentional dimensions comprised of the different outcome variables from the test (Egeland & Kovalik-Gran, 2010a). Because of its relative novelty, fewer studies have been conducted on the CCPT-3. Improvements made in the CCPT-3 have made it more sensitive to errors of commissions, in addition to expanding the range of provided scores on different attentional processes, from impulsivity and inattentiveness, to also separate scores measuring sustained attention and vigilance. Hence, using the CCPT-3 provides plenty of interesting attentional measures tapping different attentional functions. However, as most previous studies on the effects of sleep deprivation on attention have analysed more basic measures of speed and accuracy, we chose to do so in the present study as well. Still, we recognize the value of studying more complex attentional aspects, and the CCPT-3 offers great advantages in this regard.

As the fact that this is the first time CCPT-3 is used to measure the effects of sleep deprivation in healthy participants, comparisons of our results to studies using different attentional measures are unavoidable. Different versions of PVTs are widely used attentional measures in sleep deprivation studies, the most common being that introduced by Dinges and Powell (1985). This PVT have proved to be highly sensitive and valid to measure the effects of both total and partial sleep deprivation on attentional functions (Dorrian et al., 2005). As mentioned, the CCPT-3 and the PVT presented by Dinges and Powell (1985) have some aspects in common, but also differ in many ways. Considering that both tests use reaction times as a primary metric, this allows certain comparisons of these estimates. Further, the CCPT-3 error parameter omission can be expected to share qualities with the error parameter in the PVT, typically reported in lapses (Basner & Dinges, 2011; Dorrian et al., 2005; Lim & Dinges, 2010). However, as discussed earlier, as discussed previously, they are not equivalent. As for commissions, one would expect most shared properties with the PVT measure of premature responses (Dorrian et al., 2005; Lim & Dinges, 2010). However, although the PVT provides this estimate, premature responses are seldom reported in studies investigating the effects of sleep deprivation on attention (e.g., Drake et al., 2003; Van Dongen et al., 2003a). This might be because the PVT does not comprise any discrimination between targets and non-targets, exemplifying yet another important difference as the CCPT-3 is a go/no-go task, requiring inhibition of responses. Further, the tests differ in their inter-stimuli intervals, creating potential differences in how intrinsically engaging participants experience the tasks to be. The CCPT-3 has a higher stimuli rate than the PVT (Dinges & Powell, 1985). One could thus argue that the two assessments are sensitive to different aspects of attention, reflecting sustained attention in low versus moderately stimulating environments. It has been theorized that monotonous or intrinsically less engaging tasks are more severely affected by sleep deprivation than when rested (Pilcher, Band, Odle-Dusseau, & Muth [2007] as cited in Lim & Dinges, 2010), but also that tasks with very low signal rates can affect the results, due to effects of boredom and reduced motivation (Dorrian et al., 2005).

It seems that results obtained from the CCPT-3 cannot automatically be assumed to correlate with results obtained when using a PVT. In the present study the CCPT-3 proved to be sensitive to partial sleep deprivation by detecting changes in hit reaction times and errors of commission. Introducing the CCPT-3 to studies of sleep deprivation of a healthy sample is thus considered a strength in our research. If future investigations support the use of CCPT-3 in sleep research, this could yield more nuanced insights into how attention is affected by less-than-optimal sleep as it offers measurement of different attentional dimensions in one single easily administered test.

It is worth mentioning that in our search through the literature, we encountered numerous classifications of different attentional processes. Even when recognizing that attention is not a unitary process and thus needs specific terms to address the different functions (Lim & Dinges, 2010; Mirsky et al., 1991), the process of reviewing the literature was complicated by the apparent fact that researchers tend to address the same underlying processes using different terms, or to use the same term to address processes thought to be distinct. To illustrate, some refer to sustained attention and vigilance as equivalents (e.g., Killgore, 2010), while others argue that these are distinct attentional processes (e.g., Conners, 2014; Egeland & Kovalik-Gran, 2010a, 2010b). This lack of agreement in terms of labels, can easily lead to confusion, especially when comparing results of different tests, all claiming to measure sustained attention. However, as attention does indeed consist of several different processes (Mirsky et al., 1991), it is useful to examine what part of attention is actually being affected by sleep deprivation. The previously cited factorial analysis performed with the CCPT-2 is a good example of the potential in identifying such distinct attentional processes. As of yet, no published factorial analysis has replicated the factors identified in Egeland and Kovalik-Gran's (2010a, 2010b) study, on data from CCPT-3.

Practice and expectation effects. One possible limitation in our study is the presence of practice effect on performance on the CCPT-3. Practice effects are generally known as improvements in performance from one administration to the next in the absence of any interventions. In the present study, one can argue that due to the short time interval between tests and the number of repeated measurements, practice effects are inevitable (Horne & Wilkinson, 1985). Yet, previous research on cognitive tests including estimates of simple reaction time, continuous performance, and go/no-go performance have reported that practice effects are most prominent between the first and second test administrations when assessing neurocognitive normal individuals at brief test-retest intervals (Collie et al., 2003). We aimed to overcome this issue by selecting test day three as our baseline measure. Additionally, the CCPT-3 has proved to have a high test-retest reliability (Conners, 2014). Still, we recognize the possible influence practice effects might have had on our results.

It is also possible that expectancy effects may have affected our participants' performance in the CCPT-3. Due to the frequently occurring media reports about the importance of adequate sleep, one can assume that most of the participants would intuitively regard sleep restriction as having a negative impact on daily functioning. This could contribute to an expectancy effect of sleepiness and degraded performance in the CCPT-3 after three nights of partial sleep restriction for the participants, enhancing these effects. Yet, on the contrary, an expectancy effect could also have contributed to increased effort from participants to avoid declines in performance, masking the negative effect of partial sleep deprivation. The ability to do this could in turn be an expression of some kind of resistance to sleep deprivation. As participants' attention was only measured at one time point every day, and for a limited period of time, it would be interesting in the future to investigate whether the performance would be stable if tested later that same day. That is, if mobilizing effort does affect the CCPT-3 scores, would participants be able to keep this level of performance over prolonged periods of time? On the other hand, one could reason that subjective measures (such as self-reported mood, fatigue, and performance) would be a greater target for expectancy effects than an objective measure of attention, since individuals seem to be unaware of their level of cognitive impairment (Van Dongen et al., 2003a). Deficits in cognitive performance after sleep deprivation is assumed to reflect progressive neurocognitive dysfunctions in systems underlying sustained attention (Van Dongen et al., 2003a). This could be taken as an argument implying that there is less conscious effort involved in attentional tasks, as opposed to other tasks demanding more conscious awareness. As such, the use of an objective measure of attention as opposed to asking the participants how they subjectively experience their attentional functioning is regarded as a strength in our research. As no measures were taken to explore or counter the possible issue of expectancy effects in the present study, it is not possible to determine whether participants' expectations or the potential increased effort did in fact contribute to the results.

Directions for future research

As this study suggests, more research is warranted on partial sleep deprivation as a distinct phenomenon. Future research is encouraged to study larger samples, and research applying similar procedures should explore the effects partial sleep deprivation has on attention in samples more representative to the general population, or in different populations. Future research is encouraged to investigate the possible effect of partial sleep deprivation on the speed-accuracy trade-off in more basic attentional functions, and how this is manifested. Exploring the association between sleep debt and impulsivity further should be of interest to future research, as partial sleep deprivation is fairly common in daily life and increased impulsivity could influence decision making and behaviour in otherwise stressful or risky situations (Bıçaksız & Özkan, 2016; Martin & Potts, 2009; Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara 2005).

Our results should not be interpreted as implying that further research on the effects of personality when studying sleep deprivation is irrelevant. The effects of partial sleep deprivation were not related to extraversion or its facets in the present sample, but given that our main effect of sleep deprivation on attention differed from previous research by indicating increased impulsivity after sleep deprivation, traits and facets tapping this attentional impulsivity could still be of interest. We encourage future researchers examining the effects of personality to perform initial screenings of participants, allowing more defined groups of high and low scorers on different personality traits. As most people can be assumed to have a rough idea of what the recommended sleep durations are, insights into markers of vulnerability and resistance to the negative consequences of sleep loss could be beneficial to many.

Lastly, CCPT-3 offers great advantages in measurements of attention, ranging from simpler dimensions like speed and accuracy, to more “pure” forms of sustained attention. Future research is urged to document and replicate evidence of the underlying attentional processes measured by the CCPT-3, and explore the use of this attentional estimate in sleep research. As sleep research in general often requires tests to be administered on multiple occasions, future researchers are encouraged to better document, and report on, how practise effects could be assumed to influence results under such circumstances.

Conclusion

Partial sleep deprivation is a commonly occurring phenomenon in the general Norwegian population. Given its relevance, it is important to investigate the resulting cognitive effects due to their potentially severe consequences. The results presented in this study indicate that depriving healthy, young adults of two hours of sleep over each of three consecutive nights, leads to shorter reaction times and more errors of commission than when rested. As this is contrary to most previous findings, more research on the topic is required before any firm conclusions should be drawn. It is hypothesized that the trade-off between speed and accuracy observed in the present study may be an indication of increased impulsivity when participants are deprived of sleep. The effects observed indicate that this impulsivity is not detrimental for highly functioning young adults. Further, the applied sleep restriction protocol did not affect the participants’ errors of omission. There seems to be a ceiling effect in this metric in the CCPT-3, making significant changes after partial sleep deprivation in omissions in healthy individuals unlikely. Thus, it is suggested that omissions in the CCPT-3 and the much used measure of lapses are not equivalents, contrarily to what has been customary in previous research. The present study indicates that CCPT-3 scores of speed and accuracy are sensitive to the effects of partial sleep deprivation. However, more research is required on the sensitivity of the CCPT-3 in partial sleep deprivation studies in a non-clinical sample. Furthermore, individual differences in the trait of extraversion were not related to the changes observed in the present study. While this could be due to the lack of “true extroverts” and “true introverts” in the present sample, it might also indicate that extraversion does not play a role in the effects of partial sleep deprivation. As partial sleep deprivation seemed to affect participants' impulsivity, future research should explore other personality traits and facets that might be more relevant to this behavioral change. Despite a somewhat modest sample size, the present study is considered as having high ecological validity. The results can thus be assumed to represent real-life consequences of acquiring less-than-optimal sleep, primarily in high-functioning, young, and healthy adults. The present study can hopefully inspire further investigations of the effects of partial sleep deprivation on attentional function.

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