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Videoconferencing and Sleep Quality in Slovenian University Students: Is There a Mediating Role of Zoom Fatigue?

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Given the expanding utilisation of technology in educational settings, online learning has become a common teaching method. It prevailed during the Covid-19 pandemic, but the effects of attending videoconferences with active participation on psychological functioning have not yet been studied in detail. This article aimed to evaluate the relationship between videoconferencing and sleep quality – one of the crucial mechanisms promoting physical and mental well-being. Additionally, we were interested in the potential mediating role of videoconferencing fatigue in this relationship. The survey took place during the Covid-19 epidemic (in Spring 2021). Our results show a negative relationship between videoconferencing/screen device use and sleep quality and that this relationship is mediated by videoconferencing fatigue. Results of the further analysis revealed that perceived study suitability plays a significant role in determining to what extent the duration of videoconferences relates to feelings of videoconferencing fatigue. Our findings aid in understanding the relationships between videoconferencing, Zoom fatigue, and sleep better. They may be helpful in optimising remote learning today, as they remain frequently used in higher education worldwide.

Keywords: Online learning, sleep quality, university students, videoconference fatigue, Zoom fatigue

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Udeležba na videokonferencah in kakovost spanja pri slovenskih študentih: mediacijska vloga Zoom izčrpanosti

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S porastom rabe tehnologij v izobraževanju je spletno učenje postalo pogosta metoda poučevanja. Prevladovalo je med epidemijo covida-19, vendar učinki aktivne udeležbe na videokonferencah na psihološko delovanje niso bili podrobneje raziskani. Namen tega članka je bil preučiti odnos med udeležbo na videokonferencah in kakovostjo spanja, enega ključnih mehanizmov za spodbujanje telesnega in duševnega počutja. Zanimala nas je tudi mogoča mediacijska vloga videokonferenčne utrujenosti v tem odnosu. Vzorec je vključeval 529 slovenskih študentov, raziskava pa je potekala med epidemijo covida-19 (spomladi 2021). Naši rezultati kažejo negativno razmerje med uporabo videokonferenc/zaslonskih naprav in kakovostjo spanja ter potrjujejo, da je videokonferenčna utrujenost mediatorka v tem odnosu. Rezultati nadaljnjih analiz so razkrili, da ima zaznana ustreznost študija pomembno vlogo pri določanju, v kolikšni meri se trajanje videokonferenc povezuje z občutki videokonferenčne utrujenosti. Naše ugotovitve pripomorejo k boljšemu razumevanju odnosov med videokonferencami, t. i. Zoom izčrpanostjo in spanjem. Lahko bi bile koristne pri optimizaciji učenja na daljavo, ki se še vedno pogosto uporablja v visokošolskem izobraževanju po vsem svetu.

Ključne besede: spletno učenje, kakovost spanja, univerzitetni študentje, videokonferenčna utrujenost, Zoom izčrpanost

Introduction

The Covid-19 pandemic prompted an unprecedented shift to remote learning, with online platforms and videoconferencing becoming vital for education (Revilla-Cuesta et al., 2021). This transition raised concerns about 'Zoom fatigue' and its impact on students' well-being (Nadler, 2020; Riedl, 2022). Additionally, extensive screen device use has sparked questions about its effects on sleep quality (Levenson et al., 2017; Touitou et al., 2016). This study explores the interplay between online learning, Zoom fatigue, and sleep patterns among university students. By investigating the relationships between screen device usage, videoconferencing behaviours, and sleep quality, we seek to provide insights to enhance students' experiences in virtual learning environments.

Online Learning During the COVID-19 Epidemic

The rapid development of information communication technology (ICT) has led to changes and redesigns of educational processes. A shift from traditional classroom-based learning to online modes has been observed in recent years (Allen & Seaman, 2016). This transition was accelerated during the Covid-19 epidemic when face-to-face means of knowledge delivery were impossible due to public health measures (Mohamed Hashim et al., 2022; Rafsanjani et al., 2022; Unver & Sungur, 2022). As a result, the educational process in the majority of institutions was conducted in online learning mode, in which videoconferencing platforms have been regularly applied as a means of lecture delivery (Gabrovec et al., 2021; Massner, 2021; Student Organization of Slovenia, 2020). Additionally, class sessions were recorded, enabling students to revisit the content at a later time (Unver & Sungur, 2022). In light of digital transformation, ICT-based assisted learning modes are increasingly becoming part of hybrid or stand-alone online practices of knowledge delivery in higher education institutions, and some study programmes are solely delivered online (Allen & Seaman, 2016). Research indicates that videoconferencing is a frequently implemented online learning tool (Ng et al., 2023). However, the possible effects of such learning modes on students' well-being and overall psychological functioning still need to be fully understood.

Available research indicates several advantages and disadvantages of ICT-based assisted learning modes. On the one hand, it allows students and educators to interact interactively in real-time, enhance teacher-student or multiway engagement, and expand access to remote learning (Al-Samarraie, 2019). In primary school students, distance learning had a beneficial contribution to

the development of self-regulated learning skills, as well as facilitated proficiency in utilising ICT (Drvodelić & Domović, 2022). On the other hand, studies indicate that online education via screen devices poses specific challenges compared to traditional in-person education, such as the lack of interaction during lectures, difficulty understanding the content, and the lack of regular daily routine (Gabrovec et al., 2021).

Despite students having mixed impressions of online learning in general, a few negative consequences of videoconferencing have been identified. In times of the Covid-19 pandemic, when the use of videoconferencing sharply rose, there were reports of exhaustion, fatigue, and the need for recovery before embarking on the next activity following prolonged usage of videoconferences (Nadler, 2020; Riedl, 2022). This phenomenon has been referred to as 'videoconferencing fatigue' or 'Zoom fatigue' (Nadler, 2020). Riedl (2022) proposes the following definition:

> Zoom fatigue (synonym: videoconference fatigue) is defined as somatic and cognitive exhaustion that is caused by the intensive and/or inappropriate use of videoconferencing tools, frequently accompanied by related symptoms such as tiredness, worry, anxiety, burnout, discomfort, and stress, as well as other bodily symptoms such as headaches'. (p. 157)

The consequences of videoconferencing fatigue are evident across various dimensions of individuals' functioning, such as physical (e.g., physical exhaustion, eyestrain), emotional (e.g., anxiety, irritableness, moodiness, emotional exhaustion, elevated stress), cognitive (e.g., disengagement, inability to focus) and social (e.g., disconnectedness, isolation) (Li & Yee, 2022).

As Zoom fatigue represents a relatively new construct, research examining different aspects of this phenomenon is still emerging. However, available data indicate that Zoom fatigue is prevalent among students using videoconferences. Oducado et al. (2022b) reported that 66.7% of nursing students experienced Zoom fatigue during virtual meetings. Additionally, students might be a vulnerable population as data implicate that individuals who use videoconferences primarily for study purposes report a higher level of videoconferencing fatigue compared to those who use it in the work context (Queiroz et al., 2021). Despite the recognition that Zoom fatigue is a prevalent problem amongst students, a scarce amount of research on the determinants of this phenomenon exists. Nevertheless, the available evidence indicates that Zoom fatigue is related to aspects of conferences *per se* (interval between and duration of videoconferences) and environmental aspects (ergonomics during online sessions) (Ghanem et al., 2023; Salim et al., 2022). Potential mechanisms underlying this

phenomenon in student populations include a perception of physical confinement, cognitive overload associated with generating non-verbal cues, and mirror anxiety (Ghanem et al., 2023; Oducado et al., 2022a).

Screen Device Use and Its Impact on Sleep

Sleep is a central tenet of physical and mental well-being and academic success (Alvaro et al., 2013; Buysse, 2014; Itani et al., 2017; Jike et al., 2018). Specifically, poor sleep health negatively affects cognitive processing across different cognitive domains, such as executive functioning, sustained attention, and long-term memory, which are vital components of efficient encoding, storage, and retrieval of information presented during the education process (Diekelmann & Born, 2010). Research shows that university students who prioritise sleep are likely to see an improvement in academic performance (Hershner, 2020) and are better able to cope with stress (Killgore et al., 2008).

Research indicates that one risk factor for poor sleep is the extensive use of screen-based technology; daily screen time is negatively associated with both sleep quality and quantity (Levenson et al., 2017). The predominant focus of research on the association between digital media use, screen time, and sleep pertains to children and adolescents (Hale & Guan, 2015), but a few studies have confirmed an association between screen time and sleep quality and sleep duration among young adults and university students (Fossum et al., 2014; Levenson et al., 2016; Rosen et al., 2016). Most studies examined the relationship between evening screen use and sleep, while comparatively fewer studies delve into the broader scope of daytime screen exposure, including videoconferencing, and its impact on sleep patterns. For example, Pham et al. (2021) emphasised that those students who used the devices within one to two hours before bedtime reported poorer sleep quality. Findings from other studies highlight the effects of shorter screen time; for example, social networking use even as early as 30 minutes before bedtime is associated with disturbed sleep in young adults (Levenson et al., 2017). Majumdar et al. (2020) reported that heavy screen use among college students is associated with disrupted sleep patterns, particularly a shorter sleep duration, with most participants reporting feeling sleepy during the day, which the authors suggest is also due to exposure to screen devices before bedtime.

Several possible underlying mechanisms, such as heightened physiological arousal and hormone suppression due to blue light emission (e.g., Touitou et al., 2016), contribute to the impact of screen use on sleep. However, findings have not been consistent, as some studies have not confirmed the effects of blue

light or screen brightness in general on sleep quality and other sleep parameters (e.g., Higuchi et al., 2005; Pham et al., 2021). Therefore, researchers agree that there are significant associations between screen use and sleep, but little is known about the type of relationship and other potential confounders. This is partly because few studies have examined how screen use directly affects sleep over time (Scott & Woods, 2018).

Limited research explores how overall screen device usage throughout the day, including videoconferencing, impacts sleep quality. To the best of our knowledge, no prior research has examined the mediating role of Zoom fatigue in relation to electronic media usage and sleep quality. Given the increasing prevalence of videoconferencing in current and possible future educational processes, investigating these relationships is of great importance. Thus, this paper aims to determine relationships between screen device usage, videoconferences, and sleep quality and to establish the potential mediating role of Zoom fatigue. In this paper, we interchangeably employ the terms 'Zoom fatigue' and 'videoconference fatigue'. The terms delineate individuals' experience of fatigue during and/or following participation in a videoconference, irrespective of the specific videoconferencing platform utilised.

Aim and Hypotheses of the Current Study

The primary aim of this study was to assess the relationship between videoconferencing and sleep quality. Moreover, our study aimed to explore the potential mediating role of videoconferencing fatigue on this association. Additionally, we assess whether study type preference served as a moderator in these relationships. Building upon prior research, we hypothesised a negative relationship between videoconferencing duration/screen time and sleep quality. Furthermore, we predicted a negative relationship between videoconferencing fatigue and sleep quality. Finally, we expected that videoconferencing fatigue would mediate the relationship between videoconferencing duration and sleep quality.

Method

Participants

Initially, our sample consisted of 719 Slovenian university students. Considering our main research question and to ensure the validity of the data, we first reviewed our data. We excluded participants who reported no

videoconferences in this period and/or participants who reported that an individual videoconference lasted longer than the total time spent on videoconferences. The analyses were therefore performed on a sample of 529 participants. Most (81.3%) were women; most were undergraduate university students (75.4%); 23.6% were postgraduate students, and 0.4% were enrolled in a PhD programme. The majority of participants were enrolled in a public university (98.1%). The majority, 51.2%, of participants were studying at the University of Ljubljana, 41.8% were studying at the University of Maribor, 4.9% were studying at the University of Primorska, and 0.4% were studying at the University of Novo Mesto. The few remaining participants were studying at other colleges. On average, participants were 21.9 years old (*SD* = 2.0). In terms of medical background, the majority of participants did not report any chronic somatic (86.8%) or mental (89.2%) illness or diagnoses of sleep disorder (99.6%).

Instruments

Sleep quality. Sleep quality was assessed with the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). The PSQI, a self-reported questionnaire, evaluates sleep quality and disturbances. It comprises nineteen individual items, which yield seven 'component' scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The scoring of the answers is based on a 0 to 3 scale, whereby '3' reflects the negative extreme on the Likert Scale. The global PSQI score ranges from 0 to 21, with higher scores indicating more severe sleep disorders/ lower sleep quality (Buysse et al., 1989). The Slovene version of PSQI has been proven reliable and valid in the Slovene population (Košir, 2021). The present study's reliability coefficient was satisfactory (Cronbach's alpha = .77).

Videoconferencing fatigue. Videoconferencing fatigue levels of the faculty were determined using the Zoom Exhaustion & Fatigue Scale (ZEF Scale; Fauville et al., 2021), which consists of a set of fifteen questions, answerable on a 5-point Likert scale (1 = 'not at all/never' to 5 = 'extremely/always'). The scale is categorised into five domains: overall, visual, social, motivational, and emotional (Cronbach's alpha between .81 and .88). The scale assesses potential detrimental psychological effects or harm following online interactions, both in educational and professional contexts. In the original study, 'Zoom Fatigue' was defined as the fatigue individuals may experience during or after engaging in videoconferencing based on the ZEF total score. In the present research, we utilised the variables continuously, which was in line with the developers'

instructions for scale usage. The Slovene version of ZEF was obtained for the present study using standardised translation procedures. Exploratory factor analysis using the Principal axis factoring method demonstrated that extracting a single factor explains 55.7% of the total variance. A scree plot supported the one-factor solution. Furthermore, the eigenvalue associated with the subsequent factor marginally exceeded 1 (1.17), contributing only an additional 7.77% to the overall variance. Factor loadings for the single-factor solution ranged from .60 to .84. Subsequent confirmatory analysis (CFA) was conducted in R (R core team, 2024) using the lavaan package (Rosseel, 2012). The results of the second-order CFA analysis with the overall ZEF score as a second-order factor and five abovementioned first-order factors indicated a satisfactory fit to the data, $\chi^2(85) = 409.24$, $p < .001$, CFI = 0.95, TLI = 0.94, RMSEA = .09, SRMR = .05. The reliability coefficient in our sample was good (Cronbach's alpha = .88 for ZEF total score).

Digital Media Usage and Videoconferencing

Additionally, the participants answered four open-ended questions about the frequency and characteristics of digital media use based on the study on digital media use before bedtime in university students (Orzech et al., 2016). We asked about the average total daily screen time, the average amount of screen time in the last two hours before sleep, the average total daily duration of videoconferences, and the average duration of an individual videoconference.

Research Design

This prospective cross-sectional study occurred amid the officially declared Covid-19 pandemic in Slovenia (18th May until 20th June 2021). Most universities officially switched from in-person teaching to remote learning during this time, and most of the education was done using web-based platforms. University students were invited to participate in our online-based study through social media platforms, university newsletters, and email. Each participant provided informed consent prior to the commencement of the study. All subjects reported their demographic data and general health-related information, data related to remote learning, videoconferencing, and overall digital media use, and completed two standardised questionnaires that assessed their sleep quality and videoconferencing fatigue. To ensure anonymity, no personally identifiable information was collected from participants. They had the option to withdraw from the survey at any time without needing to provide a reason, and

this would not affect their academic status. The study was conducted in compliance with the principles outlined in the Declaration of Helsinki and received approval from the National Medical Ethics Committee.

First, descriptive statistics and frequency analyses were performed to describe the demographic, health-related, remote learning, overall digital media use, and videoconferencing data in the Slovenian university student population. We identified a few outliers in videoconferencing variables. The outliers were identified using the criteria of $z > \pm 3$. We identified 11 cases, and performing an analysis omitting these cases did not affect the conclusions (see Appendix), so results for the whole sample are reported. Next, we performed correlational analyses to analyse the relationship between the variables. Lastly, we performed a mediation analysis using the Process Macro ver. 4.2 (Hayes, 2012). We also performed a moderated mediation analysis to test whether a mediational process is conditional on another variable (Muller et al., 2005). In our case, the variable was how well this (remote learning) approach fits or suits the individual compared with the conventional type of study. The moderated variable was added to the model as an un-centred binary variable with 0 = suits less/much less and 1 = suits equally and more/much more. We tested moderated mediation using model 7 of the Process Macro by Hayes (2012). All analyses were performed using the IBM Statistical Package for Social Sciences (SPSS) ver. 26 (IBM Corp, 2019).

Results

Descriptive Statistics and Correlations Between Daily Screen Time, Videoconferencing, Videoconferencing Fatigue, and Sleep Quality

First, we introduce a table containing descriptive statistics encompassing measures of central tendency (mean), dispersion (standard deviation), asymmetry (skewness), kurtosis, and internal reliability (Cronbach α coefficient) for the study variables.

Table 1

Descriptive statistics of the study variables

	n	*M*	*SD*	*S*	*K*	α
Daily screen time[a]	529	7:08	2:59	0.51	-0.27	-
Screen time in the last two hours before sleep[a]	490	1:20	0:32	0.11	-1.06	-
The average duration of individual videoconference[a]	529	1:51	0:51	3.15	20.02	-
The average total duration of videoconferences[a]	529	4:50	2:08	1.48	4.06	-
Zoom exhaustion and fatigue	529	41.34	13.74	0.08	-0.62	.89
Global PSQI score	529	7.50	3.67	0.59	-0.08	.77

Notes. [a] = hh:mm format, *n* = number of participants, *M* = mean, *SD* = standard deviation, *S* = skewness coefficient, *K* = kurtosis coefficient, α = Cronbach alpha coefficient.

As shown in Table 1, the average daily screen time was about seven hours a day. Of that, almost an hour and a half of screen time usage was in the last two hours before bedtime. The average duration of an individual videoconference was nearly two hours a day, together almost five hours a day on average. After excluding outliers (see Appendix), the average time spent on videoconferences lowered slightly. We also analysed how participants perceived online learning compared to the conventional study approach. Almost half of the participants (44.2%) answered that distance learning suits them less or much less compared to the conventional form of study, a little over 10% (11.5%) answered that this kind of study fits them equally, and 36.1% answered that this form of study fits them more or much more, compared to the conventional study approach. Eight per cent of the participants did not answer this question since they were not a part of the conventional study approach, so they could not compare the forms of study.

Due to some outliers in the average duration of total and individual videoconferences, as indicated by the values of skewness and kurtosis coefficients (Table 1), we re-ran the descriptive analysis and correlations without those outliers (for the procedure of identifying outliers, please see Statistical analysis in the Methods section of this paper). The results of these analyses (n = 518/n = 479) can be found in Appendices (Tables 1 and 2). As we can observe from correlational analyses, the overall pattern of results is similar to those of the whole sample. Based on these results, we continued our analysis based on the entire sample (n = 529/490).

Next, we performed a correlation analysis on the study variables. The results are presented in Table 2.

Table 2
Correlational matrix of the study variables

		1	2	3	4	5	6
1	Daily screen time	-					
2	Screen time in the last two hours before sleep	.31**	-				
3	The average duration of individual videoconference	.11*	.15**	-			
4	The average total duration of videoconferences	.22**	.09*	.36**	-		
5	Zoom exhaustion and fatigue	.12**	.16**	.20**	.27**	-	
6	Global PSQI score	.22**	.19**	.09*	.17**	.44**	-

Notes. * $p < .05$; ** $p < .01$

The results show low but significant correlations between variables of screen time use, specifically daily screen time, screen time two hours before bedtime, the average duration of an individual videoconference, and the average time spent on videoconferences. Due to the non-normal distribution of variables, measuring time spent on videoconferences, we re-ran the analysis using the Spearman rank-based correlation. The results show only minimal changes. The correlation between screen time and duration of individual conferences was no longer significant, $r_s = .04$, $p = .324$. The same goes for the correlation between screen time before bedtime and total time spent on videoconferences, $r_s = .06$, $p = .220$. Other correlations showed a similar overall pattern of results and led to the same conclusions.

Relationship Between Videoconferencing and Screen Time With Videoconferencing Fatigue and Sleep Quality

In this paper, we mainly focus on the relationship between time spent on videoconferences with measures of videoconferencing fatigue and sleep quality. As expected, all four measures of screen time and duration of videoconferences were positively related to videoconferencing exhaustion and fatigue, with the lowest ($r = .12$, $p < .01$) but still significant correlation with overall screen time and the highest ($r = .27$ $p < .01$) with the total time spent on videoconferences a day (on average).

Similarly, there was a positive correlation with the global PSQI score (higher scores reflect lower sleep quality (Buysse et al., 1989), indicating that more time spent on videoconferences and on screens was generally related to lower sleep quality. The correlation coefficient ranged from .09 ($p < .05$) with the average duration of individual videoconference to .22 ($p < .01$) with overall screen time.

Lastly, we were interested in whether the relationship between screen time/videoconferencing and sleep quality was mediated by videoconferencing fatigue. Please note that all reported effects are unstandardised. The relationship between the duration of an individual videoconference and sleep quality (total effect: c = 0.38 ± 0.36, p = .040) was mediated by videoconferencing fatigue (direct effect: c' = -0.02 ± 0.33, p = .932). The bootstrapped 95% confidence interval (CI) revealed that the indirect effect was significantly different from zero (CI 0.24-0.60). It was further shown that the association between the total duration of videoconferences a day and sleep quality (c = 0.29 ± 0.14, p < .001) was mediated by videoconferencing fatigue (c' = 0.09 ± 0.14, p = .196). The CI of indirect effect was significantly different from zero (CI 0.13-0.28). The overall pattern of results remained after controlling for overall screen time.

Additionally, we were interested in the role of study suitability in these relationships, so we performed a moderated mediation analysis. For the purpose of this analysis, we divided the variable of study suitability into two categories: (0) for those who answered that distance learning suits them less or much less compared to the conventional form of study and (1) for those who answered that this type of study suits them equally or more or much more, compared to the conventional. Those who did not answer this question (n = 43) were omitted from this analysis (so we performed the moderated mediation analysis on 486 participants).

The results revealed that the relationship between the duration of an individual videoconference and videoconferencing exhaustion was moderated by study suitableness (b = -4.49, SE = 1.43, p = .002). The analysis of simple slopes revealed that the relationship was stronger for those who reported that this type of study was less suitable to them (b = -5.88, SE = 1.00, p < .001) compared to those who answered that it was equally or more suitable for them (b = 1.38, SE = 1.02, p = .176). Next, we tested if there is a conditional indirect effect (Preacher et al., 2007) using the Index of moderated mediation (Hayes, 2015). The index of moderated mediation was -0.54 (95% CI: -0.98, -0.18), suggesting that the suitability of the study moderated the indirect effect of the duration of individual videoconference on sleep quality. Probing the two indirect effects showed that the indirect effect was significant for those who answered that this kind of study did not suit them (IE = 0.70, 95% CI: 0.45, 1.07) but not significant for those who answered that distance learning was equally or more suited from them, compared to conventional type of study (IE = 0.17, 95% CI: -0.09, 0.44).

Similar results can be drawn from the analysis of the total videoconference duration. The study suitableness moderated the effect between duration of videoconferences and videoconferencing exhaustion (b = -1.29, SE = 0.52, p =

.014) so that this effect was significant for both but stronger for those who answered that this type of study was less suitable for them (b = 2.29, SE = 0.37, p < .001), compared to those for whom this type of study was equally or mode suitable (b = 0.99, SE = 0.37, p = .008). The Index of moderated mediation showed that the mediation was moderated by study suitableness (Index = -0.15, 95% CI: -0.28, -0.03). Both indirect effects were positive (at 0, IE = 0.26; at 1, IE = 0.15) and significant (the 0 did not fall between the lower and the upper limit of the 95% CI for both effects).

In addition, we analysed the mediating role of videoconferencing fatigue in the relationship between screen time and sleep quality. The results revealed only partial mediation. The relationship between daily screen time and sleep quality (c = 0.27 ± 0.10, p < .001) was partially mediated by videoconferencing fatigue (c' = 0.21 ± 0.09, p < .001). The indirect effect was significantly different from zero (CI 0.02-0.09). The results were similar for screen time two hours before sleep. The relationship with sleep quality (c = 1.32 ± 0.59, p < .001) was partially mediated by videoconferencing fatigue (c' = 0.45 ± 0.27, p = .002); the bootstrapped CI was different from zero (0.18–0.73).

Discussion

Our study aimed to investigate the relationship between videoconferencing/screen use and sleep quality, with a particular focus on understanding the role of videoconferencing fatigue in this association. Additionally, we were interested in study type preference as a possible moderator in the relationship between videoconferencing and videoconferencing fatigue. In this present study, videoconferencing/screen use was related to lower sleep quality. In agreement with our expectations, this relationship was mediated by videoconferencing fatigue. Further analyses also showed that study type preference acted as a moderator in relation to videoconferencing and videoconferencing fatigue.

Our study was conducted during the Covid-19 epidemic in Slovenia when online learning was the primary method of teaching curriculum in universities. Our results show that participants spent about seven hours on display devices daily, almost an hour and a half in the last two hours before bedtime. Until today, no universally agreed-upon recommended daily screen time specifically for adults exists, but research consistently shows that excessive screen time can have adverse effects on various aspects of one's health and well-being, such as physical activity and health, sleep quality, and social interactions (Lissak, 2018; Pardhan et al., 2022; Nakshine et al., 2022; Tang et al., 2021). At the same time, little is known about the effects of videoconferencing.

Notwithstanding the benefits and usability of videoconferencing tools during the Covid-19 epidemic (Riedl, 2022), recent studies have highlighted concerns regarding the significant increase in videoconferencing usage in educational settings, particularly due to its potential impact on the physical and mental well-being of students during virtual meetings (de Sobral et al., 2022).

As expected, videoconferencing exhaustion and fatigue were positively related to all four measures of screen time and duration of videoconferences in our study, with the lowest but still significant correlation with overall screen time and the highest with the total time spent on videoconferences a day (on average). This means that among the factors explored, the most robust relationship between Zoom exhaustion and fatigue was found for the total time on videoconferences, with participants spending more time on videoconferences reporting more videoconferencing exhaustion and fatigue. Results are in accordance with recent studies (Oducado et al., 2022a; Salim et al., 2022) demonstrating that the duration of videoconferencing time might significantly predict videoconferencing fatigue among higher education faculty. Overall, screen time (including videoconferencing time) still relates to videoconferencing fatigue. However, as it evidently includes other activities besides videoconferencing (i.e., social media, video games, reading news), the relationship with videoconferencing fatigue is less strong than for videoconferencing itself.

Although research on videoconferencing fatigue is still emerging, an increasing number of researchers are endeavouring to elucidate the underlying causes and factors that contribute to this fatigue experienced during and following videoconferences. On the one hand, technical difficulties, such as incorrectly functioning platforms, audio or video glitches, screen sharing problems, or unstable Internet connection, can increase frustration and stress during videoconferencing (Nadler, 2020). Additionally, some scholars have suggested that videoconferencing, as a component of computer-mediated communication exhaustion (Nadler, 2020), imposes greater psychological demands compared to face-to-face interaction (de Sobral et al., 2022; Williams, 2021) and even exceeds the demands of meetings conducted via other mediums (Shoshan & Wehrt, 2022). Several factors might contribute to that. Prior research has underscored the heightened cognitive effort required in videoconferencing settings to interpret nonverbal cues, including facial expressions, vocal intonations, and body language of participants (Bailenson, 2021; Baker & Murphy, 2021; Wiederhold, 2020). Non-verbal cues are essential in communication, but in videoconferencing, these cues might be limited or more challenging to interpret accurately due to pixilation, video delays, or participants being in different locations. As a result, individuals may have to concentrate more to understand these cues,

leading to cognitive load, greater energy consumption, and exhaustion (Bailenson, 2021). Cognitive overload might further be increased, as videoconferencing requires individuals to process multiple information streams simultaneously, including visual and auditory cues, chat messages, and screen sharing. This continuous need to pay attention, absorb information, and actively participate can overwhelm cognitive resources, leading to mental fatigue (Bailenson, 2021). Moreover, in conventional face-to-face interactions, individuals typically do not sustain continuous eye contact, nor do participants consistently fixate on the speaker throughout the conversation. Conversely, in videoconferencing, continuous direct gaze is frequently maintained (Bailenson, 2021). Maintaining prolonged eye contact might create an intensity that is ordinarily reserved for close relationships but unusual for work colleagues (Bailenson, 2021), which can be mentally exhausting and create a feeling of being constantly watched.

Considering all these possible factors that might contribute to Zoom fatigue and exhaustion in videoconferencing, our finding that longer daily videoconferencing time relates to more prominent videoconferencing fatigue in university students is not surprising. We also speculate that the length of an individual conference might have played a part in itself. Our results show that the average reported time of an individual videoconference in our sample was nearly two hours. Previous research has suggested that videoconferences should not last more than approximately 40 to 45 minutes in order to protect the well-being of participants (Baker & Murphy, 2021), so the length of individual videoconferences might have increased the vulnerability of participants to experience more fatigue during/after the meetings. For further assessment of factors contributing to videoconferencing fatigue, see Döring et al. (2022).

Prior research suggests that persistent symptoms of virtual meeting fatigue, if unaddressed, could pose challenges to various facets of students' well-being and potentially undermine the effectiveness of the teaching and learning environment (García-Bullé, 2020). Nevertheless, almost nothing has been known about the relationship between videoconferencing, videoconferencing fatigue, and sleep, with the latter being well-known as one of the crucial mechanisms promoting the mental and physical well-being of university students and their academic success (Orzech et al., 2011).

In our study, the results reveal that the subjective sleep quality total score in our sample was relatively high and beyond the threshold for healthy sleep (Buysse et al., 1989), reflecting relatively low subjective sleep quality in participants at the time of the study (please note that higher PSQI scores indicate lower sleep quality). As mentioned, it is not insignificant that our study was undertaken during the Covid-19 epidemic, when the mental and physical

vulnerabilities (Li et al., 2021; Peng et al., 2023) of university students, including healthy sleep (Valenzuela et al., 2023), were aggravated. Thus, the low sleep quality might not be representative of the sleep of Slovenian university students in times beyond the Covid-19 epidemic. Among diverse factors contributing to sleep problems during the epidemic, such as increased general stress and anxiety (Grubic et al., 2020; Kavčič et al., 2020), profound health behaviour changes (i.e., unhealthy eating behaviours (Du et al., 2021) and lower physical activity levels (Rodríguez-Larrad et al., 2021)), and disruption of the regular schedules and routines (Liu et al., 2021), the enormous increase in digital media use and screen time was seen as one of the main detrimental factors (Watanabe et al., 2022). More specifically, it was found that increased screen time during the Covid-19 epidemic led to prolonged sleep latency, shorter sleep time, lower sleep quality, and more symptoms of insomnia in the general population (Krishnan et al., 2020; Salfi et al., 2021) and in students as well (Majumdar et al., 2020). Consequently, students were also more tired and less vigilant during the day (Majumdar et al., 2020).

As expected, the results of our study reveal significant correlations between sleep quality and all measures of screen time and duration of videoconferences. While almost nothing has thus far been written on the relationship between videoconferencing specifically and sleep, the extensive use of screen-based technology has previously already been linked to poor sleep in university students and young adults before (Levenson et al., 2016; Orzech et al., 2016; Thomée et al., 2011) or during the Covid-19 pandemic (Dhir et al., 2021; Krishnan et al., 2020; Lastella et al., 2020; Salfi et al., 2021). Previous studies have mainly focused on-screen use around bedtime, investigating various mechanisms through which digital media usage could affect sleep (Cain & Gradisar, 2010). As our study confirms the significant negative relationship between screen usage before bedtime and sleep quality, we sum up these possible mechanisms. First, the duration spent engaging with digital media could directly substitute sleep time or other behaviours conducive to better sleep, thereby delaying the onset of sleep (Lastella et al., 2020). Second, engaging in screen-based activities in the evening can lead to cognitive and emotional arousal, potentially resulting in sleep disturbances through physiological responses (Cain & Gradisar, 2010; Gregory & Sadeh, 2016; Scott & Woods, 2018). Moreover, electronic screens emit short-wavelength or blue light, which can impact physiological functions by enhancing alertness and delaying the circadian rhythm through the suppression of melatonin secretion, a hormone typically released in the evening (Dijk & Cojachen, 1997; Chang et al., 2015). Thus, to protect sleep from the negative impact of screens, basic sleep hygiene rules recommend turning off

screen devices at least one to two hours before bedtime. In our study, the average screen time before sleep was almost one hour and a half in the last two hours, so participants violated this fundamental sleep hygiene rule, possibly contributing to lower sleep quality.

We also found that longer total daily videoconferencing time and the duration of a single videoconference negatively correlate with sleep quality. As the mechanisms between videoconferencing and sleep have not been widely explained before and, knowing the adverse effects of Zoom fatigue on various aspects of one's well-being, we were specifically interested in the possible role of Zoom fatigue in this relationship. The results of our mediation analyses reveal that the relationship between the duration of an individual videoconference and sleep quality is mediated by videoconferencing fatigue, and the same mediating effect of Zoom fatigue was found in the association between the total duration of videoconferences a day and sleep quality. When Zoom fatigue was included, the association between videoconferencing length and poorer sleep quality was no longer statistically significant. When general screen devices were used, Zoom fatigue was found to mediate the relationship only partially between the length of videoconferences and sleep quality. This is probably due to the fact that screen device use is a much broader concept and only partially includes active participation in videoconferences and/or lectures.

Furthermore, we tested whether the online studying preference can further explain the relationship between the length of videoconferences and Zoom fatigue. Namely, previous research has already shown that the subjectively/individually perceived suitability of studying determines students' well-being (Butnaru et al., 2021). The results of our moderated mediation showed that the association between the time spent on videoconferences and Zoom fatigue was stronger for those who did not find online studying suitable. In addition, the mediation or indirect effect was found to be stronger for those who found online studying less suitable. It shows that alongside all the objective factors of Zoom fatigue mentioned above; it is also important to take into account individual/subjective factors that can either improve or worsen feelings of Zoom fatigue.

Limitations

The study was undertaken during the COVID-19 epidemic, when online learning was introduced practically overnight, and students were forced to make rapid transitions from face-to-face to remote learning. We do not know, on the basis of our results, what the specific effects of the epidemic were and

if remote learning and videoconferencing do have the same impact on videoconferencing fatigue and sleep in times beyond the Covid-19 epidemic. Furthermore, our study commenced in May and June 2021, coinciding with the conclusion of the summer semester, amid the realisation that the global pandemic's duration extended beyond initial expectations. Students might have experienced exhaustion and a sense of being overwhelmed due to the epidemic's ongoing impact, compounded by the typical stress and fatigue associated with the semester's end. Thus, the results of our study might not be generalisable to online learning in general. A study examining the potential role of Zoom fatigue in the current online learning programmes would thus be beneficial in exploring these relationships further and better understanding them.

In our study, we did not have objective control over videoconferencing, meaning that participants retrospectively reported the time spent on videoconferences but did not define what kind of videoconferences they attended and for what purpose exactly they were used. Thus, we do not know whether university students actually attended online meetings or just participated in online lectures with mostly one-sided communication and their cameras turned off. We also do not know whether the videoconferences were used for studying purposes only. Thus, we can only speculate about the exact mechanisms of prolonged videoconferencing that contributed to Zoom fatigue in our sample.

We also do not know whether similar relationships exist between the length of the lectures/seminars, exhaustion related to attending the lectures or classes, and sleep for face-to-face learning. As we did not compare online and face-to-face learning, we cannot be sure that this effect is unique to online learning. Conducting a study focusing on face-to-face meetings or lectures would be interesting to see if the patterns are similar.

In this study, we highlighted the subjective suitability of the online study as a factor significantly determining the relationship between Zoom fatigue and sleep. Nevertheless, we did not explore what factors contribute to this subjective evaluation of the 'suitability' of the online study. We thus cannot make any inferences about the characteristics of students who evaluated online study as more suitable than face-to-face learning compared to those who evaluated online study as less suitable. We can only speculate that factors such as personality differences, other obligations, or social skills might have contributed. Also, students from various study programmes may have differed in the degree of obligations in online learning, thus experiencing different levels of comfort in online study. Factors contributing to the suitableness and comfort of online study should be addressed and better explored in the upcoming research.

Conclusions

In conclusion, our study contributes to the growing body of research examining the impact of videoconferencing and screen device use on sleep quality and well-being among university students. As anticipated during the Covid-19 pandemic (Zackal, 2021), many universities and colleges persist in conducting meetings through web-based platforms, with some institutions exclusively utilising online learning modalities to this day. By elucidating the mediating role of videoconferencing fatigue and the moderating effect of study type preference, our findings provide valuable insights for educators, institutions, and policymakers in optimising online learning practices. To decrease the likelihood of videoconferencing fatigue and exhaustion and to promote well-being and healthy sleep in the students, meeting length should be considered when planning online learning. If videoconferences are used, efforts should be made to ensure that an individual conference, as well as total videoconferencing time, is not overly long. A threshold of 45 minutes per videoconference has been proposed in previous research (Bailenson, 2021) to mitigate the adverse effects of videoconferencing. However, whether this threshold is most suitable also in the context of the adverse effects of videoconferencing on sleep remains to be determined. Additionally, as our results reveal, Zoom fatigue is more likely in students who find online learning less suitable than in-person learning compared to those who find online learning more suitable. When planning a study process, students' preferences should be taken into account. While the precise factors influencing learning mode suitability in our study remain uncertain, it is conceivable that providing classes or training to enhance familiarity with web-based meeting platforms could enhance the suitability of online learning and bolster the well-being of students or other videoconferencing users. The outcomes of our study offer insights into the connections among videoconferencing, Zoom fatigue, and sleep, providing valuable implications for the design of educational practices. These findings can inform strategies for navigating future public health crises, like the Covid-19 epidemic, by optimising remote learning approaches. Additionally, they contribute to the ongoing enhancement of online learning methods in higher education settings, ensuring their effectiveness and adaptability in today's context. Ultimately, our study underscores the need for ongoing research and proactive measures to address the challenges associated with online learning, with a focus on promoting student well-being and academic success in an increasingly digitalised educational landscape.

Disclosure Statement

The authors have no conflict of interest to declare.

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Appendices

Appendix 1

Table 1

Descriptive statistics of the study variables without the outliers

	n	*M*	*SD*	*S*	*K*	α
Daily screen time[a]	518	7:07	2:55	0.45	-0.40	/
Screen time two hours before sleep[a]	479	1:20	0:32	-0.21	-1.05	/
The average duration of individual videoconference[a]	518	4:42	1:50	0.73	0.41	/
The average total duration of videoconferences[a]	518	1:49	0:43	1.43	3.24	/
Zoom exhaustion and fatigue	518	41.24	13.77	0.10	-0.61	.95
Global PSQI score	518	7.51	3.68	0.60	-0.07	.77

Notes. [a] = hh:mm format, *n* = number of participants, *M* = mean, *SD* = standard deviation, *S* = skewness coefficient, *K* = kurtosis coefficient, α = Cronbach alpha coefficient.

Appendix 2

Table 2

Correlational matrix of the study variables without the outliers

		1	2	3	4	5
1	Daily screen time	-				
2	Screen time in the last two hours before sleep	.31**	-			
3	The average duration of individual videoconference	.08	.04	-		
4	The average total duration of videoconferences	.29**	.14**	.32**	-	
5	Zoom exhaustion and fatigue	.12**	.16**	.28**	.20**	-
6	Global PSQI score	.23**	.20**	.21**	.09*	.44**

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