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Development and validation of the antecedents to videoconference fatigue scale in higher education (AVFS-HE)

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Abstract
Despite the post-COVID return to face-to-face teaching and learning, many higher educational institutions continue to utilize videoconferencing due to its numerous benefits. Along with this increased adoption, reports have surfaced regarding videoconference fatigue (VF), a phenomenon characterized by exhaustion from using videoconference platforms. Despite this, there is a substantial gap in our understanding of the antecedent factors contributing to VF. Our study aims to develop and validate a research instrument for the study of the antecedents to VF in the context of whole-class teaching in higher education, which we term the AVFS-HE. We developed and tested this scale across three studies: first with 21 undergraduates in the substantive validity phase, and a further 508 undergraduates in the structural validity and external validity phases. The final 17-item AVFS-HE encompassed five key antecedents to VF: psychological, technical, social, productivity (engagement), and productivity (distraction) antecedents. The measure was shown to demonstrate good validity both internally and in relation to VF constructs. Recommendations for future research and practical recommendations for educators are discussed.

Keywords Online education · Higher education · Scale development · Videoconference fatigue · Zoom fatigue · Antecedents · Factors

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1 Introduction

The COVID-19 pandemic set in motion various shifts in the way people approached their everyday lives. With cyclical lockdowns and erratic lulls between outbreaks and waves of infection, many countries mandated stay-home orders to stymie the spread of the disease. This quickly led to videoconferences becoming a key tool for organisations and institutions to maintain business continuity and in turn, to the widespread use of these technologies. As schools shut down across the world – affecting 1.2 billion students across 186 countries – lessons moved fully online with the use of videoconference platforms as a primary mode of communication to facilitate classes (Li & Lalani, 2020). Even as offices and schools reopen, many changes initiated during the lockdown era – including the widespread use of videoconferencing solutions – remain.

Along with this increased adoption, many reports of videoconference fatigue (VF) soon began to surface as everyday usage of the technology peaked (Jiang, 2020; Murphy, 2020). This phenomenon is characterized by general exhaustion from using videoconference platforms, and its symptoms seem most pronounced in heavier users (Bennett et al., 2021). The experience of VF has sparked research into how it affects workplaces and employees (Bennett et al., 2021). While the scope of this research continues to expand, most inquiries have centered on how VF has affected employees in videoconference work meetings, or on general videoconference-platform use (Fauville et al., 2021; Elbogen et al., 2022). As for the difference in fatigue levels between those using videoconference platforms as a conferencing tool in work and those using them in education, Queiroz et al.'s (2021) study indicates that participants videoconferencing mainly for study purposes experience higher levels of VF than those who use it mainly for work. Another study has found higher levels of VF among participants who were enrolled as higher education students than participants who were not (Montag et al., 2022).

Scholars have raised concerns regarding the effects of VF on higher education students. A study using a mix of document analysis, surveys, and interviews found that a majority of higher education students who used videoconferencing for educational purposes experienced difficulty in learning and reported greater emotional, cognitive and/or physical problems compared to face-to-face instruction (Massner, 2021). Deniz et al. (2022) found that the experience of VF among Turkish university students is linked to increased anxiety, depression and stress, and lower life satisfaction and academic well-being. Fatigue as a result of videoconference lessons can cause students to feel worried that they are unable to understand lesson content, avoid speaking up or answering questions and consequently hamper their learning (Salsabila et al., 2021). A recent investigation showed VF can negatively impact learning engagement among university students, and as a result harming perceived achievement and class satisfaction (Cho & Im, 2024). Despite this, there has been a lack of research that systematically examines the possible variety of factors which drive VF among students in the higher education setting.

In this study, we rely on existing syntheses of research on VF to develop and test a research instrument examining the antecedent factors contributing to VF among higher education students as they take part in whole-class teaching activities. The

goal is to provide educators and researchers with an empirically validated instrument to explore and examine the extent of the factors impacting VF among higher education students. To provide a comprehensive and empirically validated instrument, we employed a mixed-methods approach which utilizes comprehensive qualitative and quantitative (focus group discussions and surveys) methods to develop the scale, which we entitle the Antecedents to Videoconference Fatigue Scale in Higher Education (AVFS-HE). Beyond the AVFS-HE, we hope that there would be similar measures developed in the context of work.

2 Literature review

2.1 Videoconference fatigue among students

Videoconferencing refers to a manifestation of computer-mediated communication phenomena which "comprises video and audio elements that transmit in real-time" (Li & Yee, 2022, p. 797). Teaching and learning with videoconferencing can include direct instruction, whole class discussions, group discussions, student presentations, peer critique, collaborative problem solving and resource sharing. Such teaching and learning are commonly supported by videoconferencing tools such as *Zoom* and *Microsoft Teams*. Although videoconferencing has been increasingly adopted in education over the last two decades, the closure of educational institutions worldwide in response to COVID-19 led to a spike in its usage (Rodríguez & Pulido-Montes, 2022).

Despite the post-COVID return to face-to-face teaching and learning, many students have continued to utilise videoconferencing in educational settings due to its numerous benefits (Bashir et al., 2021; Lockee, 2021). Most notably, it enables students to attend lessons from their preferred location, thereby increasing students' accessibility to synchronous learning regardless of geographical boundaries while '[reducing] environmental impact and [lessening] stress and fatigue from travel' (Li & Yee, 2022, p. 797). It also encourages information sharing due to the ease of screensharing and sharing documents digitally, and facilitates the recording of lectures for future reference. Thus, videoconferencing in education is expected to remain in the foreseeable future by complementing face-to-face teaching and learning or 'as part of hybrid teaching … in which students can decide whether to attend class via videoconference or in person' (Gatrell, 2022, p. 269).

VF, sometimes referred to as 'Zoom fatigue' (Elbogen et al., 2022), has been defined as a "non-pathological tiredness arising from videoconferencing which manifests in physical, emotional, cognitive and social ways" (Li & Yee, 2022, p. 813). The phenomenon quickly became a topic of concern and discussion against the backdrop of increased use of videoconferencing during the COVID-19 pandemic. With the urgent need to conceptualize VF and explore its facets, scholars employed preliminary definitions and measures in earlier studies (e.g., Bennett et al., 2021; Li et al., 2022). Later, researchers developed the validated Zoom Exhaustion & Fatigue (ZEF) scale in understanding and measuring VF (Fauville et al., 2021). The instrument comprises 15 items spanning five dimensions of fatigue, namely, general, social, emo-

tional, visual, and motivational fatigue. Studies utilizing the ZEF scale have found higher levels of VF among women (Ratan et al., 2022; Fauville et al., 2023), and individuals who were enrolled as higher education students (Montag et al., 2022). Other populations where the scale have been used as a measure of VF include teenagers (Lee et al., 2023) and nursing students (Oducado et al., 2022). The popularity of the ZEF scale has also led to translations in various languages such as Bahasa Indonesia (Salim et al., 2022), Italian (Simbula et al., 2024), and Thai (Charoenporn & Charernboon, 2023).

2.2 Antecedent factors causing VF

As illustrated above, while videoconferencing provides certain advantages for teaching and learning, educators and students must also grapple with the associated fatigue in which videoconference use can generate. Previous scholars have provided substantive conceptualizations of and validated measures for the phenomenon, as well as discussing the undesirable effects of VF (Fauville et al., 2021). Along these streams of research, researchers have sought to explore the underlying factors that could lead to VF. Disparate pieces of work point towards several crucial factors. Pingkiany et al. (2021) suggested that the long duration and intense frequency of videoconferencing were key causes of VF among students, especially since these students, being 17–21 years old, used the technology more often than those outside that age range. Most notably, a recent and comprehensive synthesis of recent research suggested that the antecedents of VF could be categorized across five different dimensions – chronemic, technical, psychological, social, and productivity-related (for a review, see Li & Yee, 2022). The research was synthesized not only from studies which looked at VF in the workplace, but also from those that looked at VF in higher education. For the sake of convenience, we will call this the CTPSP framework and provide a brief overview of these factors next.

Chronemic factors. The extent of videoconference-platform use in time-related dimensions is a key factor that mediates users' experience of VF. Fauville et al. (2021b) showed that frequency of meetings, duration of meetings, and burstiness (i.e. the time between meetings) are associated with higher levels of VF. Indeed, 51% of videoconference users reported feeling exhausted from the increased frequency of meetings since the pandemic (Virtira, 2021).

As for higher education students, many have noted that the increase in screen time makes it harder to stay engaged as they experience headaches or are simply not used to looking at the screen for such a long duration (Massner, 2021). Bennett et al. (2021) found that the time of day that videoconference-platform use occurs can also affect users' experience of VF.

Technical factors. Videoconference platforms are a highly technology-driven mode of communication, relying primarily on live video and audio feeds supported by a strong and stable internet connection (Shapiro, 2020). While these can create a synchronous communication experience that mimics face-to-face meetings, it often does not simulate it perfectly. In reality, delays between the audio-visual input and corresponding output shown to other users due to lags in the transmission and processing of data, or latency issues, can affect a user's videoconferencing experience

(Coutinho, 2021). Additional mental capacity – which sometimes goes unnoticed – is then required to overcome and rationalize the delay (Wiederhold, 2020).

Other technical issues that can put a mental strain on users include slow internet connections that result in freezing video feeds, choppy audio, disconnection issues, as well as human errors that result in disruptive noise or distracting visuals from other users. These technical difficulties increase the cognitive load for users and exacerbate chronemic factors by often making videoconference calls longer than they need to be, creating frustration and fatigue for users (Meisenzahl, 2020).

Psychological factors. Bailenson (2021) noted the excessive amounts of close-up eye gaze, cognitive load, increased self-evaluation from staring at video of oneself, and constraints on physical mobility as contributors to psychological stress that arises from videoconference platform interfaces. Many videoconference meetings have an unspoken rule where webcams are required to be turned on. Indeed, 61% of all work meetings mandate participants to turn on webcams, and 25% of videoconference users feel the pressure to leave their cameras on (Virtira, 2021).

A screen of talking heads may be counterintuitive, increasing distraction and participation anxiety (Virtira, 2021). Moreover, having the webcam switched on may cause mirror anxiety as a result of the self-view window in videoconference platforms. The increased self-focused attention can have negative implications on one's mental wellbeing as users may tend to worry about how they look to other participants over the call (Rutledge, 2020). They could also feel physically trapped and constrained by the field of vision of the webcam, which may reduce cognitive performance (Fauville et al., 2021). The "hypergaze" effect, which is the constant experience of having other people's eyes in one's field of view, may also negatively affect users. The heightened number of unusually close faces creates arousal and anxiety that may trigger a 'fight or flight' response, impairing concentration (Fauville et al., 2021b).

Social factors. In videoconferences, social norms and rules are violated in several ways which can lead to VF. Users' body language and nonverbal interactions are now limited to closeups in a window that seem to invade personal space and limit their verbal and nonverbal expressiveness to others (Bailenson, 2020). Additionally, Hudson (2021) noted that due to the distortion of space and issues of gaze misalignment over videoconference platforms, users can come across as if they are not paying attention to the meeting. Thus, they feel compelled to overcompensate to send nonverbal cues to prove otherwise (Bailenson, 2020), which can add to the above-mentioned cognitive overload on top of social pressure. An overload of visual cues in a group meeting on top of audio-visual asynchrony due to latency issues can leave users disoriented, resulting in them talking over others, having difficulty in knowing how to interject, or being unsure of how much to participate (Sklar, 2020).

The resulting behaviors may reinforce unintended negative social messages and perceptions of being rude or disrespectful. The fear of being unable to follow social norms or constantly breaking them can heighten discomfort and anxiety (Rutledge, 2020). Some users have also reported feeling like meetings are impersonal when cameras remain switched off (Goodman, 2021), as well as awkwardness due to the distance and lack of chatter that usually occurs on the periphery of in-person meetings (Pickrell, 2020).

Moving from the virtual space to the physical social environment, environmental issues regarding users' space and surroundings also have the potential to correlate with their experience of VF. Notably, pandemic-induced videoconferences often take place at home, which may bring about other 'unplanned yet unavoidable' interruptions from family members or pets that require additional effort to multitask (Ebner & Greenberg, 2020). Cognitive dissonance can also arise from the home environment itself, due to the misalignment between the activities of professional or student life and what would otherwise be considered the space that belongs to personal life. The blurring of the limits of personal space and time creates an odd work-life or study-life imbalance that could cause greater frustration (Massner, 2021), which is exacerbated by the use of videoconference platforms for social purposes as well (Ardill, 2020).

The distinction between private, shared, and public spaces can also affect users' ability to videoconference smoothly (Fosslien & Duffy, 2020), as these physical locations bring about their own disruptions that can be controlled to varying degrees. Users' videoconference set-up and furniture also have a part to play in influencing their focus, effectiveness, and physical wellness (Massner, 2021).

Productivity factors. While using videoconference platforms, users must navigate multiple tools within the videoconference platform and might use other software at the same time. According to Reinecke et al. (2017), increased cognitive exertion is to be expected from having to multitask and manage different computer windows, contributing to VF.

Notably, some higher education students have conversely reported that multitasking on non-class-related activities has helped to alleviate feelings of fatigue (Blanco, 2021), which introduces an interesting dynamic between the pros and cons of multitasking.

2.3 Research gap

While previous research provided useful tentative frameworks to study the conditions and factors driving VF, there remains a gap in which our study aims to fill. Specifically, the CTPSP framework put forth by Li and Yee (2022) was developed by synthesizing studies that looked at VF in the contexts of the workplace and higher education. While the CTPSP framework is a useful one, there is currently no existing measure that builds on the framework.

To provide a comprehensive and empirically validated instrument, we employed a mixed-methods approach which utilizes comprehensive qualitative and quantitative methods (focus group discussions and surveys) to develop the scale, which we term the Antecedents to Videoconference Fatigue Scale in Higher Education (AVFS-HE).

3 Method

To operationalize the CTPSP framework for use within the context of higher education, we employed a three-stage process (Simms, 2008). Stage 1 comprises the substantive validity phase, in which we conducted a series of qualitative focus group discussions to identify the antecedent factors of VF in higher education. We also

utilized these focus groups to operationalize the factors. This led to a pool of items which reflected various manifestations of these factors of VF. Stage 2 consisted of the structural validity phase in which we collected data from higher education students to explore the factor structure that underlies the factors leading to VF. Finally, Stage 3 refers to the external validity phase, where we tested the validity of the scale in relation to the ZEF scale in a separate independent sample of higher education students.

3.1 Item pool development (stage 1)

Based on our initial literature review, we conducted focus group discussions with higher education students to obtain their perceptions and experience with VF and the antecedent factors, and to ensure that other potential dimensions are not overlooked. This is consistent with Carpenter's (2018) guide to scale development, and traditional scaling procedures (Brakus et al., 2009), and is for the purpose of establishing substantive validity.

Five focus group discussions were conducted with a total of 21 undergraduates from a Singapore university. Participants were selected based on the criteria of having past or current(present) experiences with online videoconference lessons, with a minimum of six hours a week. These participants had taken part or were taking part in whole-class teaching activities such as lectures, demonstrations, and video screenings, and they could interact with their educators by asking questions and expressing their opinions via computer audio and chat. The minimum duration cut-off of six months was crucial in ensuring that the participants have experienced significant exposure to this format of education, hence increasing the likelihood that they have experienced VF and the potential antecedents that can be verbalized and analyzed for the purpose of the study. Questions asked during the focus group sessions were developed specifically for this stage (Krueger & Casey, 2009).

Responses from the focus group discussions were coded using a combination of inductive, deductive, and abductive reasoning. We first coded the data line-by-line and inductively generated tentative codes. Next, we grouped these tentative codes to higher-order categories of factors surrounding VF as described by Fauville et al. (2021) and Li and Yee (2022). In the process of coding, we came across tentative codes which did not fit well into the pre-defined categories. For these pieces of data, we used abductive coding to either group them into separate higher-order categories, or fit them into the frameworks after a thorough discussion.

3.2 Scale validation (stage 2)

Building on the literature review, the CTPSP framework, and the findings from our focus group discussions, we generated 58 items for our AVFS-HE scale. These items were measured on a 5-point Likert scale from 1 (Never) to 5 (Always). To eliminate order bias, the order of the questions was randomized. Reverse questions such as 'I am unbothered by the behavior of other students during videoconference lessons' were included to reduce the possibility of agreement bias.

We conducted a survey with a total of 508 undergraduates from a Singapore university for Stages 2 and 3 in Spring 2022. Again, the respondents had taken part or

were taking part in whole-class teaching activities such as lectures, demonstrations, and video screenings, and they could interact with their educators by asking questions and expressing their opinions via computer audio and chat. These respondents provided data for both the initial scale validation (Stage 2) and final scale validation (Stage 3) and were randomly split into two equal subsamples for each of the stages. For Stage 2, the subsample of 254 students had an average age of 22.6 years ($SD = 1.56$) of which 131 were female (51.57%). The sample identified as 90.94% Chinese, 1.57% Malay, 3.54% Indian and 3.58% Others, approximately mirroring the multi-racial demographic of the Singapore population.

To establish structural validity, analysis of the scale items was conducted using the *psych* package in *R* (Revelle, 2023), following procedures outlined by Carpenter (2018). The factorability of the data collected was verified with Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin measure of sampling adequacy. To further aid the reduction of items, principal axis factoring was employed using oblique (Promax) rotation based on the assumption that the factors are correlated. The number of factors used to run factor analysis was determined based on parallel analysis (PA), where items with eigenvalues larger than a randomly ordered data set were accepted (Horn, 1965), as recommended by Carpenter (2018). Next, a pattern matrix was generated.

3.3 Relations between AVFS-HE and ZEF scales (stage 3)

Having developed and validated the AVFS-HE scale, our next step was to explore the external validity of the scale through looking at its convergent validity and predictive validity (Simms, 2008). Prior research shows that VF can manifest through different aspects of fatigue (Fauville et al., 2021, 2023). Hence, we examined the relationships between the AVFS-HE scale and the five dimensions of the Zoom Exhaustion and Fatigue (ZEF) scale (Fauville et al., 2021b), the dimensions being general, social, emotional, visual, and motivational fatigue. The subsample of 254 higher education students in this stage had an average age of 22.5 years ($SD = 1.34$) of which 134 were female (53%). Respondents' ethnicity was as follows: Chinese 89.76%, Malay 2.76%, Indian 4.33% and Others 2.43%.

We first conducted confirmatory factor analysis to test the factor structure of the AVFS-HE scale. Prior to confirmatory factor analysis, we assessed multivariate normality using Mardia's test of multivariate skew and kurtosis (Mardia, 1970). Unfortunately, the data significantly deviated from multivariate normality. Due to the non-normal data, the maximum likelihood procedure with estimator defined as "MLM" was used to estimate unknown parameters in the model. The estimator "MLM" was defined in order to correct for biased estimates among the fit indices, resulting in a mean-adjusted chi-square test statistic that is robust to non-normal data (Satorra & Bentler, 1994). Model fit was assessed with the following benchmarks: comparative fit index (CFI) of 0.95 or greater, non-normed fit index (NNFI) of 0.95 or greater, root mean square error of approximation (RMSEA) less than or equal to 0.05, and standardized root mean square residual (SRMR) being less than or equal to 0.08. These cut-offs were based on established recommendations (Bentler & Bonett, 1980; Hu & Bentler, 1999; Schumacker & Lomax, 2004).

4 Results

4.1 Substantive validity (stage 1)

Through the coding and analysis of the participants' responses, it was evident that participants' descriptions of tiredness and discomfort during and after videoconference lessons corresponded with the phenomenon of VF as described by Bennett et al. (2021). They reported that the experience of videoconference platforms was 'tough' and 'so draining' and this was the case 'more or less after every class'. This resulted in feelings of defeat and overstimulation, among others. For them, VF manifested not just physically or psychologically, but also in their social life and productivity as well. In particular, multiple participants highlighted that their experience of VF was recurrent and could even persist throughout the rest of their day, inhibiting motivation and learning capabilities. Participants' recounts of VF manifestations were valuable for tracing the contributing sources of this phenomenon in higher education, and these factors generally fit well within the CTPSP framework proposed by Li and Yee (2022).

Chronemic factors. Students perceive the duration of videoconference classes having only a minor impact on VF. This is possibly due to students being accustomed to having lessons of such long durations. However, issues with the length and frequency of break times were brought up as bigger contributors to participants' experience of VF. Well-timed and adequate breaks are needed for students to maintain a state of focus without being exhausted, but the way that these were implemented in videoconference lessons may not be as satisfactory as in face-to-face lessons.

Participants recognized their limitations in absorbing content in videoconference classes and expressed the need for optimal pacing of their lessons. A participant said that 'it's a bit tiring to keep staring at my laptop screen or my monitor … that interrupts my momentum especially when you're in the zone and you suddenly need to rest.' Others find that breaks can be better timed: 'For me, it's generally … tough to refocus after you've got a short break online.'

Technical factors. A technical antecedent that is closely tied to productivity and the effectiveness of information conveyance is the educator's ability in using videoconference platforms. Participants felt that their educator's technical shortcomings and failure to properly use the software platforms effectively were amongst the strongest factors impacting their experience of the lessons, leading to increased fatigue. In the discussions, students recall that 'one challenge that I [and others] face … are technical difficulties … less tech-savvy professors might take some time to figure them out, and it's a bit frustrating and helpless that we cannot do anything because he or she is on their own.'

The perceived disconnect on virtual platforms between educator and students also points to an interesting distinction between videoconferencing and the traditional two-way communication model of the classroom. In a physical setting, the sender (educator) communicates with a receiver (mass of students as a collective) in a shared space, thus creating social presence (Short et al., 1976); in a videoconference format, however, the sender and receivers are in separate locations, communicating through a simultaneous multitude of individual two-way communication streams between

one educator and each student in attendance. The strangeness of experiencing this form of communication requires adaptation and management of expectations by both parties. Pre-pandemic, such novel forms of communication were not commonplace, and their newfound ubiquity has both highlighted and amplified the peculiarities of videoconferencing through excessive use. This could explain the participants' burgeoning frustration and VF, which arise from the inescapability of videoconference platforms coupled with the constraints and barriers they pose to effective communication in education.

A number of participants noted that there were additional steps that had to be taken prior to speaking, such as having to unmute oneself, check one's physical surroundings to ensure that there are no other disturbances or having to type questions into a chat box that quickly gets flooded by inputs from other students. These unavoidable inconveniences caused additional strain and fatigue in contrast to physical lessons, for which they perceived fewer constraints and barriers to communication. Beyond these barriers, participants also reported feeling 'very defeated' in relation to other factors such as wireless connectivity lags and other technical issues impacting their learning environment. These issues caused participants to 'stumble on and then lose all track of what the [educator said], and that's when all the lethargy [kicked] in.'

Psychological factors. Contrary to existing literature, psychological antecedents were mentioned the least by participants. While negative outcomes relating to hypergaze or visual claustrophobia were highlighted in past research (Bailenson, 2021; Fauville et al., 2021), some participants reported that these factors had a negligible impact on them as they turned off their webcams, thereby avoiding these feelings of constraint or anxiety.

Social factors. Conversely, students frequently mentioned behavioral norms, defined as one's perceived need to conform to a manner of acting, as a key factor leading to videoconference fatigue. One participant mentioned that she felt the 'need to constantly look in the camera for the best optimum experience for the other person,' which 'leads to a lot of unwanted sort of stress in your mind.' Another said that '[Even if I have to turn on the webcam] I must show extra face, I must properly sit upright … and when given the chance, I will turn [the webcam] off because it's way too much effort to think about how I look on that small little screen.' The expectation for students to have to act in a way that is pleasing to others in the videoconference lesson, but unnatural to the self, is a common complaint amongst the participants which corroborates Rutledge's (2020) insights about user behavior and stressors. This is sometimes worsened by students' need to adhere to authority dynamics in the classroom. In some cases, it is also directly tied to students' grades due to the class participation system that rewards displays of active engagement. According to a participant, 'to get good grades you need to show your face for the professor to know you're speaking.'

While the pressures of student performance can be mitigated by social interactions in the physical classroom setting, especially in the form of social interdependence (Deutsch, 1949; Johnson & Johnson, 1989), the lack thereof in the videoconference format can have significant impacts on students. One participant said: 'I'm more drained after online classes than physical, because when physical … Sometimes you can talk to your friends, interact a bit, there's a good mix of fun and learning at the

same time.' Other participants were impacted more negatively: 'I very much enjoyed [physical] tutorials. Because I have someone to talk to and someone to work with … It's fun. In the switch to online, I pretty much almost lost interest in the work, in trying to do the subject. It was quite devastating. It just doesn't work. You just lose your confidence level.'

Productivity factors. The difference in the way videoconference platforms are used in higher education and in the workplace distinguishes how VF affects higher education students in comparison to professionals. We observed that productivity-related antecedents came up the most frequently during the discussions. As intimated by our participants, this factor is related directly to students' perceptions of how much information is conveyed during videoconference classes. Notably, the overload of content during videoconference lessons and the unengaging delivery of content through the videoconference format resulted in fatigue. This inevitably led the students to learn a less amount of content, decreasing their productiveness from attending lessons.

Multiple participants mentioned that in the context of videoconference lessons, '[modules with heavy content] would be emotionally exhausting' and that 'too much information [is being conveyed] continuously non–stop'. To make matters worse, participations noted how university lessons average three hours in length, which to them is too long for to learn effectively. For many participants, the intensity and pressure of this learning experience contribute to VF, as explained by one who said: 'You're staring at a screen. You're listening to your lecturer droning on in your head [for hours on end] … it means that more likely than not, your head is going to short-circuit halfway [through]'.

According to the participants, this overload of information or unsatisfactory delivery of content often results in them multitasking to take their mind off the online lessons. This was interesting as multitasking often results in exposure to more information and cognitive overload (Blanco, 2021), but participants appear to find it beneficial. During the discussions, participants were quick to highlight that the videoconference medium enabled this attention split: 'If I'm too bored with the lecture then I'm going to tap out and go to some other website and do other stuff … I can't do that in a [physical] lecture.' The way that this multitasking phenomenon – which arises from the videoconference format – seems to affect and mitigate VF is worth exploring in further studies. A summary of the themes and sub-themes derived from the FGDs, along with exemplar quotes are presented in Table 1.

Based on the conversations during the focus groups, we developed a questionnaire item pool by crafting several items that exemplified each of the CTPSP dimensions. During this phase, we also noted that the students' specific experiences tended to reflect to videoconferencing as applied in direct instruction. We conducted a check on the teaching practices present in the participant groups by speaking with instructors in their institutions and noted that, indeed, during the pandemic, videoconference was utilized largely as substitutes for lecture-based classes that primarily relied on direct instruction. We provide a discussion on the implications of this in our limitations section.

Table 1 Themes, sub-themes and exemplar statements

Theme	Sub-theme	Exemplar
Chronemic factors	Duration of videoconference	"It can go up to three or four hours. I feel kind of exhausted because you need to stare at the screen for such a long time. Sometimes the prof will even forget a break time in between."
	Frequency of videoconference	"Last semester there were so many videoconference lessons. This semester also same thing, also so many [videoconference lessons]."
	Burstiness	"Some days my lessons are packed back-to-back, so it's a full 6 hours of non-stop online lessons. It's like 'thanks Prof' and then I have to click another Zoom link."
	Flow	"It is tough to sort of refocus after you've got only a short break online."
	Abuse of time	"It's supposed to be 3 hours but [the instructor] says because of the online formatting it's hard to deliver the content so he usually spends like 5 hours teaching us a 3-hour class. You will be like mentally dead after that."
	Long screen time	" I feel very lethargic as well after attending a lecture. Especially my eyes will be very dry because of constantly watching the screen."
Technical factors	Technical ineptitude	We don't really know how to use these tools and we don't really know how to actually make complete use of this online platform in a way that will really help.
	Audiovisual experience	"It's very bad audio, especially when the professor speaks very fast and then you're trying to catch what he is saying."
	Network connection issues	"People drop out of the lesson because their wifi is weak. And it lags a lot when the videos are playing, the sound and the screen doesn't really match up so it's a bit confusing."
	Medium limitations	"It's so troublesome just to show one equation that I wrote down and check whether is it correct or not, as compared to offline lessons."
	Unsuitability of set-up	"Sometimes I just put my laptop on a low table, and then I sit on the floor. There's no space at home."
	Environmental temperature	"I did it in the hall room for the majority of last semester as well and I had no air conditioning, so it was exceptionally hot. And I could not concentrate while the lesson is ongoing."
Psychological factors	Visual claustrophobia	"When I am given a chance, I will turn off the camera because it's way too much effort to think about how I look on that small little screen."
	Mirror anxiety	"I will remove my camera because if I leave it on it would kind of distract me from listening the class, because I would see the self view and notice how I am presenting myself… it's kind of distracting."
	Hypergaze	"When you see your image and you see your classmates image, it makes me very self-conscious regardless of whether they are actually seeing me"
	Detachment	"You don't see the teacher in front of you teaching and delivering knowledge. So I feel there is lack of engagement."

Table 1 (continued)

Theme	Sub-theme	Exemplar
	Misalignment with personal preferences	"The environment in school [during in-person lessons] is also more conducive and the infrastructure like the tables and chairs are nice whereas for my home I just don't feel like I can study as well."
	Entitlement	"I'm like why am I paying my tuition fees for no discussions on the topic that I could just be reading in my own free time? And thinking of this makes me frustrated and tired."
Social factors	Behavioral norms	"Like when with video on I must show my entire face, I must sit properly and sit upright."
	Lack of social interaction	"I tend to prefer face-to-face because in face-to-face lessons, the social aspect of being able to interact with your fellow students and directly approach them for help or for assistance is important to me."
	Authority dynamics	"The lecturer… he insists we turn on the camera because he said he wants to check our facial expressions to see whether we fully understand the content."
Productivity factors	Distractions via multitasking	"I will just change to YouTube if it's a boring part and I'll just watch YouTube for a while… of course it is hard to do both."
	Disruptions from other participants	"One person keep distracting the live lecture, they keep playing weird sounds [from their laptop] during the lecture, then everyone is spamming the chat box talking about it. So the whole lecture felt like a disaster."
	Distractions from surroundings	"I don't personally have my own room so it's quite noisy sometimes. For example when your parents doing something like cooking or just doing housework, even my Airpods can't block out this kind of noise."
Productivity factors	Readiness to absorb content	"I just feel very lazy and demotivated to videoconference continuously, because we have to catch up with the lessons every week. It's tiring."
	Overload of content	" There are tons of reading materials to read every week, and now all the class is conducted on the screen so, now we have to spend more time sitting in front of the laptop. I can't keep up with all the content."
	Unengaging content and delivery	"[The instructor] should not be so monotonous. Just try to engage more rather reading off from slides, which happens so often online."

4.2 Structural validity (stage 2)

Based on the Kaiser-Meyer-Olkin measure of sampling adequacy (Overall = 0.81) and Bartlett's Test of Sphericity ($\chi^2(1653) = 5760.40$, $p < .001$), the data was suitable for factor analysis. The first PA using 1000 bootstrapped samples revealed that nine factors should be extracted. 27 items were initially removed with low factor loadings of 0.5 and below, or cross-loadings with a difference of less than 0.2. This process was carried out six more times until only five clean factors were left. Based on theoretical reasons, we dropped a total of six items which did not theoretically converge. We chose to retain one item loading at 0.43 (PDI3) in the final factor solution, as it fit the theoretical sub-dimension of distraction to productivity, and removing the factor would lead to only a 2-item scale. This was consistent with Hair et al's (2019) recommendation to rely on theory when making decisions about item deletion. Checking the Productivity (Distraction) sub-scale's Cronbach's Alpha showed that it had a satisfactory alpha of 0.75.

The exploratory factor analysis yielded five factors. Three of the factors corresponded well with the psychological, technical and social aspects of the CTPSP framework. However, the chronemic factor was not present at all, while the remaining two factors corresponded with the productivity factor. Upon closer analysis of the individual items, we decided to classify the two factors as productivity (engagement) and productivity (distraction). Overall, the cumulative variance explained by the factors was 53.2%. Table 2 presents the final factor solution of the 17-item AVFS-HE scale, with all items showing satisfactory loadings above 0.40 (given our sample size of each sample being greater than 150), and acceptable Cronbach Alpha's levels above 0.70 (Hair et al., 2019; Guadagnoli & Velicer, 1988). The Cronbach's Alpha values of each subscale is presented in the final column of Table 2, while the individual factor loadings for each item are presented below it.

4.3 External validity (stage 3)

Results showed that the five-factor model of the ASVR scale provided a good fit for the data ($\chi^2(109) = 166.87$, $p < .01$; CFI = 0.95; NNFI = 0.94; RMSEA = 0.05; SRMR = 0.06). All parameter estimates were significant at $p < .01$. Results of the CFA are presented in Fig. 1.

Descriptive statistics for all key variables are shown in Table 3. Internal consistency reliabilities ranged from 0.60 (fair) to excellent (0.88), and all factor loadings were above 0.50. In line with previous research and theorizing in the CTPSP (Fauville et al., 2021; Li & Yee, 2022), we hypothesize that all antecedent factors specified in the AVFS-HE will be positively correlated to general fatigue in the ZEF scale. Having said that, previous research has not provided substantial evidence for how each antecedent factor is associated with different dimensions of fatigue. Given the possible theoretical insights this may provide for future research, we posit the following research question: "How do the different dimensions of the AVFS-HE scale relate to social, emotional, visual, and motivational fatigue?". Correlations between each predictor and criterion variable are presented in Table 4. By and large, the individual factors of the AVFS-HE scale demonstrated small to medium correlations with the

Table 2 Final 17-item AVFS-HE scale with factor loadings from stage 2

How much do you agree with the following statements?	Alpha / Loading
Technical	$\alpha = 0.76$
TEC1 My educators' cameras do not work well	0.74
TEC2 My educators' video feeds during videoconference lessons are low definition/low quality	0.64
TEC3 My educators have internet connection issues	0.69
TEC4 My educators easily maintain adequate microphone quality (R)	0.59
Psychological	$\alpha = 0.87$
PSY1 Whenever I have my camera on, I am anxious knowing that others are watching me	0.81
PSY2 Whenever I have my camera on, I feel constrained when I see myself on the screen	0.68
PSY3 Whenever I have my camera on, I feel anxious when I see myself on the screen	0.98
Social	$\alpha = 0.76$
SOC1 I am unable to move as I have to stay within the webcam square	0.64
SOC2 I have to maintain a certain posture during videoconference lessons	0.78
SOC3 Whenever my camera is on, I tend to avoid moving out of my camera's view	0.67
SOC4 I have to behave a certain way during videoconference lessons because educators want me to	0.57
Productivity (Engagement)	$\alpha = 0.80$
PEN1 I feel detached from my lecture during videoconference lessons	0.69
PEN2 Videoconference lessons are boring in terms of content	0.83
PEN3 Videoconference lessons are boring in terms of delivery	0.84
Productivity (Distraction)	$\alpha = 0.75$
PDI1 I am distracted by people in my surroundings during videoconference lessons	0.82
PDI2 I am distracted by noises in my surroundings during videoconference lessons	0.80
PDI3 I get distracted by external notifications (not from the videoconference platform) during videoconference lessons	0.43

ZEF scale and its dimensions. All correlations were significant at the $p < .001$ level, suggesting that the AVFS-HE scale has good external validity.

5 Discussion

We conducted a comprehensive study that consisted of qualitative focus group discussions and a quantitative survey with higher education students. Theoretically, the CTPSP provides a framework to understand the antecedent factors of VF. Our study operationalized these factors by identifying and itemizing specific experiences which drive the students' likelihood of experiencing VF, and by creating a validated measure which encapsulates the experiences into a 17-item scale entitled the AVFS-HE. Thus, the AVFS-HE is theoretically grounded in the CTPSP framework. While the CTPSP framework describes the antecedent factors driving VF, the AVFS-HE shows how the factors are operationalized in the context of whole-class direct instruction in higher education.

There are several theoretical and practical implications we can derive from this study. First, by operationalizing and quantifying the CTPSP framework, it provides empirical support for previous work which provides an account of the most impor-

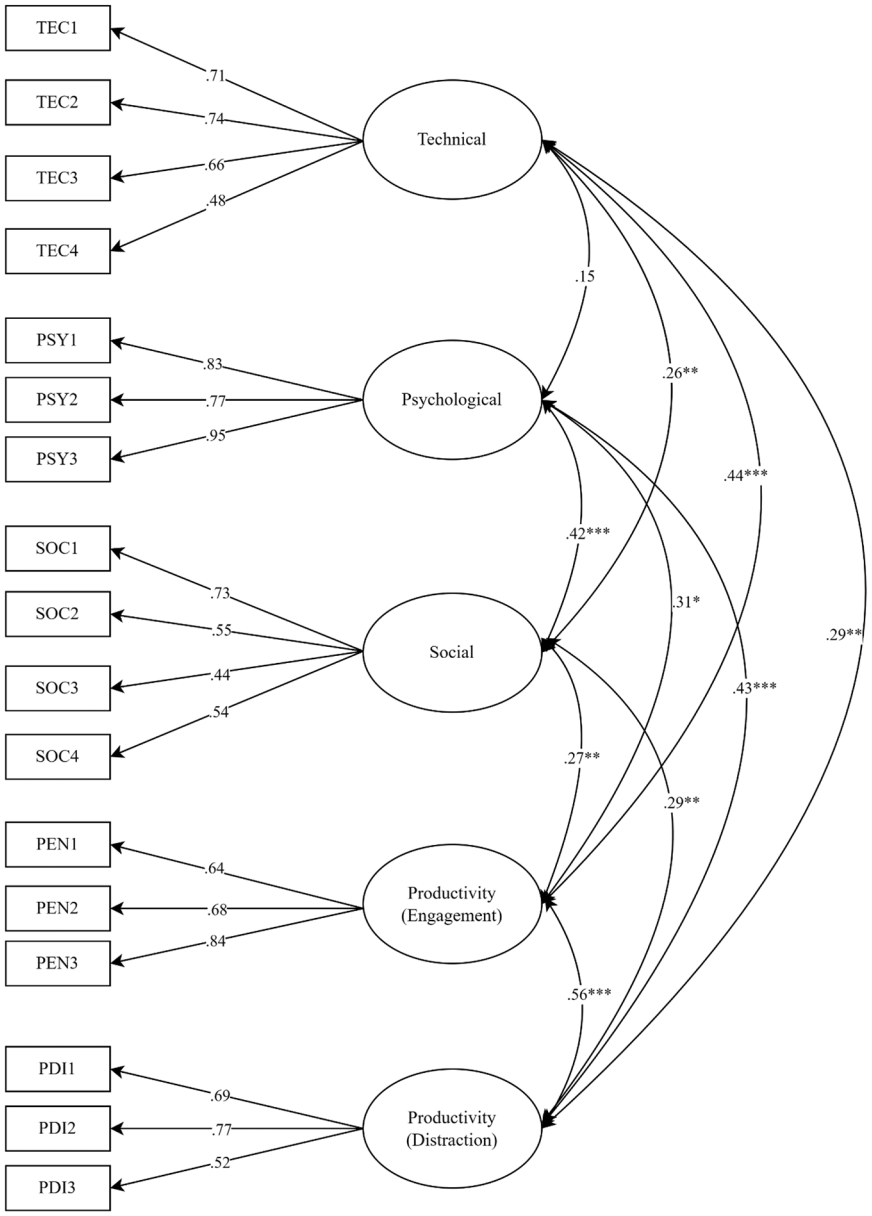

Fig. 1 Confirmatory factor analysis of the 17 item five-factor AVFS-HE scale
Note: *$p<.05$. **$p<.01$. ***$p<.001$

Table 3 Descriptive statistics of key variables for stage 3 ($n=254$)

Scale	M	SD	Cronbach's Alpha
Predictors			
Technical	2.3	0.54	0.76
Psychological	3.2	1.06	0.88
Social	3.06	0.88	0.68
Productivity (Engagement)	3.19	0.75	0.77
Productivity (Distraction)	3.01	0.79	0.60
Criteria			
ZEF	3.25	0.76	0.93
General Fatigue	3.64	0.86	0.93
Visual Fatigue	3.12	1.01	0.91
Social Fatigue	3.13	1.02	0.88
Motivational Fatigue	3.46	0.96	0.91
Emotional Fatigue	2.88	0.99	0.90

Table 4 Predictor-criterion correlations and standardized regression weights for stage 3 ($n=254$)

	Criterion					
Predictor Correlations	ZEF	General Fatigue	Visual Fatigue	Social Fatigue	Motivational Fatigue	Emotional Fatigue
Technical	0.29***	0.18**	0.20**	0.17**	0.24***	0.34***
Psychological	0.39***	0.30***	0.18**	0.34***	0.37***	0.36***
Social	0.33***	0.28***	0.27***	0.19**	0.22***	0.34***
Productivity (Engagement)	0.48***	0.46***	0.23***	0.28***	0.47***	0.44***
Productivity (Distraction)	0.43***	0.42***	0.20**	0.22***	0.47***	0.39***
Standardized Regression Weights						
Technical	0.12*	0.01	0.12	0.07	0.08	0.19***
Psychological	0.18**	0.08	0.04	0.25***	0.19**	0.15*
Social	0.15**	0.13*	0.20**	0.05	0.02	0.17**
Productivity (Engagement)	0.27***	0.31***	0.11	0.16*	0.26***	0.23***
Productivity (Distraction)	0.19**	0.23***	0.07	0.04	0.27***	0.16**
Model Summary						
R^2	0.37	0.30	0.12	0.16	0.34	0.34
Adjusted R^2	0.35	0.29	0.11	0.14	0.33	0.33
F statistic	28.50***	21.30***	6.99***	9.36***	26.00***	25.90***

Note. *$p<.05$. **$p<.01$. ***$p<.001$

tant factors driving VF, especially in education. Surprisingly, chronemic factors such as duration and frequency of videoconference lessons were not found to be a salient contributory condition for VF in our survey. This could be because college students already spend an inordinate amount of time communicating with each other on mediated platforms (e.g., Hanson et al., 2010), and so are used to digitally mediated communication. It suggests that, when considering antecedent factors of VF, it is important to consider individual differences which may cause some factors to be more pertinent for certain groups of people.

Beyond empirically testing the CTPSP framework, our findings are particularly useful in informing pedagogical practice for instructors using videoconferencing for

lectures. Our findings show that effective lectures in videoconferencing must not only include good technical setups (e.g., bandwidth for high-quality video feeds, microphones for good audio quality, etc.), but also environmental and social conditions which reduces anxiety, social pressure, engagement, and distraction. As far as instructors can adopt teaching practices to facilitate a conducive videoconference class – such as in making the turning on of student webcams non-mandatory –, students must also keep their environment free of distractions. This highlights the importance of partnerships between instructors and students in cultivating a good videoconference-mediated learning environment.

Beyond theoretical and practical implications, our study introduces a brief measure that enables researchers and educators to screen the extent of the factors causing VF among higher education students as they take part in whole-class teaching activities. Given that it is a short 17-item questionnaire, administrating after a videoconference class allows instructors to pinpoint main areas in which they can improve the teaching and learning experience. For example, if after getting feedback from the students that the social environment is not conducive, instructors can adapt and reflexively implement practices which enhance a specific aspect of the class.

5.1 Limitations and future directions

The AVFS-HE is a relatively short measure that researchers and educators can use to determine the extent of the factors causing VF among higher students as they participate in whole-class teaching activities. However, there remain some limitations in our study which suggest that some of our findings ought to be interpreted with caution. First, our study was conducted in Singapore, where there is a high level of Internet use and access. While the AVFS-HE included technical factors in its scale, it could be that some fundamental technical factors that would have emerged in studies where Internet access and use is lower were missed. For example, while educator videoconference efficacy emerged as a contributing factor to VF, we did not see the emergence of *student* videoconference efficacy. This is likely due to the efficacy of Singaporean higher education students in navigating technology. Future research ought to test if the framework holds among other populations, by conducting validation studies exploring the relationships between the factors identified and VF, among other variables of interest. With that being said, we do not believe that the items in the AVFS-HE are fixed per se, and that extensions to the questionnaire are not only welcomed but encouraged.

Second, the AVFS-HE is usage-specific, as its use is restricted only to higher education students who take part in whole-class teaching activities. This limits the AVFS-HE's use to other educational settings and learning scenarios, such as secondary school students doing CSCL group work in Zoom breakout rooms. We recommend collecting data on other educational settings and learning scenarios to develop research instruments applicable to those settings and scenarios. In other words, the existing AVFS-HE scale, while valid for direct instruction administered through videoconferencing, may not be applied to other educational contexts and teaching techniques.

In the item generation phase, we conducted interviews with a small sample of students who were affected by the pandemic-related shift to online teaching. This allowed us to quickly explore common experiences students faced when attending direct instruction classes online - these were the most common type of online classes during the pandemic at our university. In so doing, the items generated for the scale may represent very specific experiences related to videoconference fatigue that are limited to their experiences. Indeed, different individuals may have different experiences and needs. For example, scholars have noted that gender non-binary participants may face specific discomforts when interacting with web-based interfaces (Scheuerman et al., 2021). As such, we highlight the importance of future research in augmenting the scale to include other antecedents which may not have been originally captured in our scale. Despite these limitations, we believe that the AVFS-HE provides a modest contribution to research on VF among higher education students.

6 Conclusion

In this study, we developed and validated a 17-item research instrument for the study of the antecedents to VF in the context of whole-class teaching in higher education. We hope findings here would encourage researchers and educators to delve further into this area. Once researchers and educators have screened the extent of the factors causing VF and identified the key causes, the latter could take the relevant steps to address those key causes in order to mitigate its effects. Given the staying power of videoconferencing post-pandemic, and as student mental wellbeing becomes of increasing concern for universities (see Lindsay et al., 2023), this measure is a useful tool for educators and administrators to assess, design, and deliver videoconference lessons which are less fatiguing for these students.

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Data availability The data generated and analyzed for the study is available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no competing interests to declare.

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