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**To cite this article:** Madison C. Chandler, Oksana K. Ellison, Amanda L. McGowan, Kimberly M. Fenn & Matthew B. Pontifex (2024) Physical activity and sleep moderate the relationship between stress and screen time in college-aged adults, *Journal of American College Health*, 72:5, 1401-1411, DOI: [10.1080/07448481.2022.2077110](https://doi.org/10.1080/07448481.2022.2077110)

**To link to this article:** <https://doi.org/10.1080/07448481.2022.2077110>



Published online: 25 May 2022.



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MAJOR ARTICLE



## Physical activity and sleep moderate the relationship between stress and screen time in college-aged adults

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### ABSTRACT

For undergraduate students, excessive screen time is associated with poorer mental health and greater perceived stress. **Objective:** The purpose of the present investigation was to determine the potential moderating influence of physical activity and sleep on the relationship between screen time and stress. **Participants & Methods:** A cross-sectional sample of 513 undergraduate students between Fall 2017 & Spring 2020 were given a questionnaire to assess perceived stress level, physical activity engagement, screen time, and sleep. **Results:** Stepwise hierarchical regression analyses identified that screen time, sleep, and the three-way interaction between screen time, sleep, and physical activity were associated with stress. Post-hoc decomposition revealed that higher levels of physical activity and sleep both mitigated the relationship between screen time and stress. **Conclusions:** Findings suggest that modifiable health behaviors such as physical activity and sleep may be important factors for managing the negative effects of screen time on stress in college-aged adults.

### HIGHLIGHTS

- Excessive screen time is associated with higher levels of stress.
- Cross-sectional sample of 513 college-aged young adults.
- Adiposity and aerobic fitness were unrelated to stress.
- In high active individuals, screen time is unrelated to stress.
- In low active individuals, greater sleep attenuates the screen time-stress relationship.

### ARTICLE HISTORY

Received 31 March 2021  
Revised 11 April 2022  
Accepted 6 May 2022

### KEYWORDS

Health behaviors; interaction;  
mental health; well-being

For undergraduate students, stress is a nearly universal experience whose insidious effects impact a wide range of outcomes spanning both mental and physical health. University counseling centers have seen considerable increases in the number of students making appointments: for example, between Fall 2009 and Spring 2015, campus counseling center utilization increased by an average of 30–40%.<sup>1</sup> Many of these appointments are for stress-related issues: in fact, data from the 2020 Annual Report of the Center for Collegiate Mental Health – comprising 602 college and university counseling centers with 185,440 total unique students – shows that stress was the third-ranking concern overall (behind anxiety and depression) in the 2019–2020 school year, reported by 42% of students.<sup>1</sup> In the Spring 2021 report from the American College Health Association (ACHA) (based on a survey of 70,087 undergraduate students from 137 institutions across the United States), 81.8% of undergraduates reported experiencing either moderate or high levels of stress – and 46.7% reported that stress had negatively impacted their academic performance.<sup>2</sup>

One factor commonly attributed to such high levels of stress is excessive screen time given the ubiquity of phones,

tablets, laptops, computers, and televisions in modern society.<sup>3</sup> Excessive screen time is related to college students' mental health, with greater amounts of screen time being associated with a higher risk of depression, anxiety, and perceived stress.<sup>4–7</sup> Indeed, prospective studies of the relationship between the use of screens and perceived stress have shown that higher levels of mobile phone and computer use at baseline are associated with an increased risk of reporting prolonged stress one year later.<sup>8,9</sup> Beyond concerns regarding the potential addictive nature of screen time,<sup>10</sup> screen time has also become increasingly harder to avoid for most college students, as many assignments, exams, and entire classes have been moved to an online or primarily-online format. Screen time is a predominantly sedentary behavior linked to health problems such as obesity, hypertension, and psychosocial problems.<sup>11</sup> Furthermore, screen time behaviors (e.g., streaming videos, playing video games, Internet use) occur indoors, limiting exposure to the most potent zeitgeber for humans: daylight. Indeed, reduced exposure to daylight in the 9 hours preceding sleep onset has been associated with decreased sleep duration and delayed sleep phases (i.e., going to bed later).<sup>12</sup> Adolescents

with poor sleep may be more susceptible to being exposed to an obesogenic environment (increased time spent sedentary performing screen time activities and less time spent physically active).<sup>13</sup> Accordingly, it is essential to gain a better understanding of how other modifiable behaviors such as physical activity and sleep may ameliorate the negative impacts of screen time. As such, the aim of the present investigation was to provide insight into the interactive contributions of these health behaviors as they relate to perceptions of stress in college-aged adults.

Physical activity in particular has emerged as a potentially relevant modifiable health behavior for mental health and well-being. Specifically, higher levels of engagement in physical activity have been associated with lower levels of anxiety, depression, and perceived stress.<sup>14–19</sup> An investigation of 14,804 students from 94 colleges in the United States showed that those who met guidelines for engagement in vigorous physical activity had lower levels of perceived stress than those who did not<sup>19</sup> – and intervention work has shown that engagement in a 16-week physical activity program over the course of a semester significantly reduces levels of perceived stress in college students.<sup>14</sup> Furthermore, physical activity may serve to negate the increased risk of poorer mental health that is associated with elevated screen time. In a sample of 4,747 college students separated into groups based upon screen time, higher screen time (>2 hours per day) was associated with an increased incidence of anxiety, depression, and psychopathological symptoms (odds ratio confidence intervals ranging from 1.38 to 2.09).<sup>7</sup> Additionally, low levels of physical activity (<3 days of exercise per week) and high levels of screen time were independently and interactively associated with increased risks of these mental health problems.<sup>7</sup> Similarly, Ge and colleagues<sup>6</sup> assessed these relationships using a sample of 756 female college students separated into groups based upon screen time and physical activity. Overall, higher screen time was associated with an increased perception of stress (odds ratio confidence interval ranging from 1.2 to 2.3) – however, in students with greater physical activity participation, higher screen time made no difference in stress perception (odds ratio confidence interval ranging from 0.9 to 2.0).<sup>6</sup> A critical limitation of the present literature in regards to the potential moderating influence of physical activity on the relationship between screen time and stress has been the reliance upon binary cut-points reflecting either public health-related recommended behavioral thresholds or median-split approaches. As such, we have little understanding of the extent to which this relationship exists along a continuum or if there is some threshold level of behavior necessary to incur potential benefits. In addition, existing work examining the relationship between physical activity and stress does not account for health-related attributes such as aerobic fitness and body composition – both of which have been associated with engagement in physical activity<sup>20</sup> – and could be a potential confound. Some evidence also exists to suggest that those who are more-aerobically-fit show a reduced stress response compared to those who are less-aerobically-

fit<sup>21,22</sup> – and so accounting for this physiological variable is essential to provide a fuller understanding of these variables in the context of their relationship to perceived stress.

To date, much of the literature in this area has also investigated sleep duration as a variable associated with both screen time and stress. Higher levels of screen time have consistently been associated with shorter sleep duration<sup>23,24</sup> – in essence, more engagement in screen-based activities is related to less hours of sleep on average each night. To illustrate: a systematic review of the relationship between screen time and sleep in children and adolescents found that out of nine articles examining sleep duration as an outcome variable, eight of the nine (89%) reported a negative association with an aggregate measure of total screen time.<sup>24</sup> Similarly, a study of 653 adult participants found that higher-than-average objectively-measured screen time was associated with shorter self-reported sleep duration.<sup>23</sup> Therefore, it is important to consider that sleep may also be a valuable health behavior to consider in the context of a negative relationship with screen time and stress. Indeed, short sleep duration has been linked to poorer mental health outcomes, including stress. For example, one study of 31,596 Korean adults showed that short sleep duration (ie, ≤6 hours per night) was associated with higher levels of stress in both men and women.<sup>25</sup> Concerningly, nearly half (40.2%) of undergraduate students report getting less than 7 hours of sleep per weeknight.<sup>2</sup>

Furthermore, although sleep may be independently associated with stress, it is also important to note that greater physical activity engagement has also been associated with improved sleep;<sup>26</sup> and the nature of collegiate life – added responsibilities, academic pressures, and time constraints – makes it difficult to balance screen time, adequate levels of sleep, and/or regular physical activity. In the same way that we would not examine the effects of a diet by considering only what someone ate for dinner, the impact of health behaviors on stress involves not just one singular variable (e.g., physical activity) but instead a complex and nuanced interplay between multiple lifestyle factors (e.g., the previous night's sleep, duration of extended sitting performing screen-based activities throughout the day). Although the separate effects of physical activity, sleep, and screen time on stress have been demonstrated in the literature,<sup>4–7,27–29</sup> the generalizability of these findings are tempered as little insight is given to the independent and combined contributions of these health behaviors to stress. However, evidence from large population health studies and animal models offer promising support for the synergistic influence of physical activity and sleep in areas of mental health adjacent to stress. For example, regular physical activity at or above weekly recommended levels (600 MET minutes/week) mitigates the detrimental effects of poor sleep on mental well-being,<sup>30</sup> and exercise via wheel running prevents anxiety-like behavior in rats induced by sleep deprivation.<sup>31</sup>

Accordingly, the purpose of the present investigation was to examine the independent and potentially interactive contributions of physical activity and sleep for moderating the

relationship between screen time and stress in college-aged adults while accounting for the potential influences of demographic factors and health-related attributes (ie, adiposity and aerobic fitness). As these constructs are inherently related within the broader framework of 24-hour movement guidelines, we hypothesized that both physical activity and sleep would independently moderate the association between screen time and stress. However, as the extant literature has largely examined these constructs independently, such hypothesis is conjecture, and as such, the present investigation is well-positioned to advance our understanding in this area and consider potential interactions between physical activity and sleep. In particular, understanding how these variables interact in the context of stress will provide valuable and practical insights for application to the lives of contemporary college students.

## Method

### Participants

A sample of 513 college-aged young adults ( $N=348$  female;  $M_{\text{age}} = 19.1 \pm 1.2$  years; 24.4% nonwhite) participated in this investigation at Michigan State University prior to the COVID-19 pandemic. Participants were recruited from an introductory Kinesiology class between the Fall 2017 and Spring 2020 semesters, and students were offered extra credit for their participation in the study. All participants reported being free of neurological disorders or physical impairments, indicated normal or corrected-to-normal vision, and provided written informed consent. This investigation was approved by the Human Research Protection Program at Michigan State University. Demographic data for all participants are provided in Table 1.

### Procedure

Using a cross-sectional design, participants visited the laboratory on a single day. Upon arrival, participants provided written informed consent and were screened for any existing health issues that might be exacerbated by the aerobic fitness assessment using the Physical Activity Readiness Questionnaire (PAR-Q).<sup>32</sup> Participants also were asked to complete a health history and demographic questionnaire. Included in this questionnaire were measures of perceived stress levels, physical activity engagement, screen time, and sleep.

### Perceived stress levels

Participants were asked “How often would you rate your stress level as HIGH?” and given five response options, which were numerically coded for analysis as follows: “Never” = 0, “Rarely” = 1, “Sometimes” = 2, “Most of the Time” = 3, “Always” = 4. This single-item measure was adapted from two other single-item measures of stress: one taken from the Korean National Health and Nutrition Examination Survey that was used in a large-scale study ( $N=17,638$  adults) of sleep duration and mental health,<sup>25</sup> and the other from the 2021 ACHA’s National College Health Assessment, which asked “Within the last 30 days, how would you rate the overall level of stress experienced?” with answer choices of “No stress,” “Low,” “Moderate,” and “High.”<sup>2</sup>

### Physical activity engagement

Similar to previous studies of health behaviors in college students,<sup>33</sup> physical activity engagement was measured using two simple self-reported items. Because we were interested in hours per day (as opposed to days per week) of physical

**Table 1.** Participant demographic and health-behavior-related characteristics (mean  $\pm$  SD).

Measure	All participants	[Range]
<i>N</i>	513 (348 female)	
Age (years)	19.1 $\pm$ 1.2	[18–26]
Race/Ethnicity (%)	Black or African American = 11.1% American Indian or Alaska Native = 0.6% Asian = 5.3% Native Hawaiian or Pacific Islander = 0.2% Two or More Races = 4.3% White or Caucasian = 77.8% Hispanic/Latinx = 4.9% Missing or Unreported = 0.8%	
Nonwhite (%)	24.4%	
Education (years)	13.0 $\pm$ 1.3	[12–18]
Percent Body Fat (%) <sup>a</sup>	Males: 20.4 $\pm$ 6.2 Females: 32.1 $\pm$ 6.6	[5.7–41.7] [8.5–52.0]
Aerobic Fitness Percentile <sup>b</sup>	46.8 $\pm$ 33.1	[3–97]
Total Weekly Physical Activity (hours)	9.1 $\pm$ 5.7	[0–25]
Total Weekly Sleep (hours) <sup>c</sup>	45.7 $\pm$ 5.9	[30–65]
Total Weekly Screen Time (hours)	23.4 $\pm$ 12.3	[0–60]
Stress	1.9 $\pm$ 0.7	[0–4]
Frequency of High Stress – Never	0.8%	
Frequency of High Stress – Rarely	21.1%	
Frequency of High Stress – Sometimes	57.3%	
Frequency of High Stress – Most of the time	19.7%	
Frequency of High Stress – Always	1.2%	

Notes: <sup>a</sup>Ranges for healthy body fat percentage according to the American College of Sports Medicine are 10–22% for males and 20–32% for females.<sup>53</sup> <sup>b</sup>VO<sub>2</sub>max percentile based on normative values for VO<sub>2</sub>max.<sup>44</sup> <sup>c</sup>Percentage of students averaging less than the recommended 7–9 hours of sleep per night = 45.8%.

activity, participants reported the typical amount of time they spend engaging in physical activity both on a typical weekday and a typical weekend day. Total weekly engagement in physical activity was calculated by multiplying participants' weekday activity by 5 and weekend activity by 2 and summing these values. Responses were capped such that the maximum possible number of hours of physical activity engagement for the week was 25 hours.<sup>34</sup>

### Screen time

Screen time was measured using three items adapted from the Sedentary Behavior Questionnaire,<sup>35</sup> which have demonstrated sufficient reliability (ICC's  $\geq 0.80$ ) and criterion validity with the IPAQ sedentary behavior questions ( $r$ 's  $\geq 0.44$ ,  $p$ 's  $< 0.01$ ). Participants reported the typical amount of time they spend watching television, on the computer, and playing video games both on a typical weekday and a typical weekend day. Responses were numerically coded according to the lower number in the self-reported categorical range (e.g., 4–5 hours per day = 4). The amount of time spent watching television, on the computer, and playing video games was added together to obtain a total weekday screen time variable and a total weekend screen time variable (e.g., 2 hours per day of television + 5 hours on the computer + 1 hour playing video games = 8 hours of screen time). Total weekly engagement in screen time was calculated by multiplying participants' weekday screen time by 5 and weekend screen time by 2 and summing these values, with the maximum possible hours of screen time for the week being 84 hours. However, given the distribution of the reported weekly screen time, to reduce the potential for extreme values to confound the results, the maximum possible hours of screen time for the week was capped at no more than 60 hours. The findings remained the same even when this conservative threshold was not utilized.

### Sleep

Sleep duration was measured using two items, adapted from the "sleep duration" item of the Pittsburgh Sleep Quality Index (PSQI).<sup>36</sup> Consistent with measures of sleep duration in previous investigations,<sup>25,37,38</sup> participants reported how much sleep they get on both a typical weeknight and a typical weekend night. Total weekly sleep was calculated by multiplying participants' weeknight sleep by 5 and weekend night sleep by 2 and summing these values, with the maximum possible hours of sleep for the week being 84 hours. Given the distribution of reported weekly sleep, to reduce the potential for extreme values to confound the results, the minimum possible hours of sleep for the week was capped at no less than 30 hours. The findings remained the same even when this conservative threshold was not utilized.

### Assessment of body composition

Following completion of the health history & demographic questionnaire, participants had their height, weight, and percent body fat measured using a wall-mounted stadiometer and a digital Omron HBF-510 Body Composition Monitor

and Scale (Omron Healthcare Inc., Lake Forest, IL). The Omron scale demonstrates both high reliability ( $R_{xx} = .933-.993$ ) and validity ( $r = .942$ ) for the measurement of body composition in college-aged adults.<sup>39</sup>

### Assessment of aerobic fitness

Participants' aerobic fitness level was determined via assessment of maximal oxygen consumption ( $VO_{2max}$ ; measured in ml/kg/min) (see Chandler et al.<sup>40</sup>; McGowan et al.<sup>41</sup> for full procedures). Attainment of maximal effort was evidenced by reaching two of four criteria for reaching  $VO_{2max}$ : 1) a plateau in oxygen consumption (ie, an increase of less than 2 ml/kg/min despite an increase in workload); 2) peak heart rate  $\geq 190$  bpm; 3) respiratory exchange ratio (RER)  $\geq 1.1$ ; and/or 4) ratings on the OMNI scale of perceived exertion<sup>42</sup>  $> 7$ .<sup>40,41,43</sup> Aerobic fitness percentiles were extracted from normative data from Shvartz and Reibold<sup>44</sup> to account for differences in oxygen consumption based on participants' age and biological sex.

### Statistical analysis

All variables and analysis residuals were screened for normality and homoscedasticity using histograms, Q-Q plots, Shapiro-Wilk tests,<sup>45</sup> and Studentized Breusch-Pagan tests.<sup>46</sup> Although none of the health-related variables except for percent body fat were normally distributed, the analysis residuals were normally distributed and homoscedastic. Of note, all findings remained the same even when using a logarithmic transformation. As such, the results presented below reflect the use of the raw data.

All analyses were conducted in R Version 4.0<sup>47</sup> using an alpha level of  $p = .05$ . Bivariate correlation analyses were conducted using Spearman's Rank-Order correlation coefficients to examine the relationship(s) between Stress, demographic factors (Age, Biological Sex [0 = Female, 1 = Male], Years of Education, and Race [0 = White, 1 = Nonwhite]), physical-health-related attributes (Aerobic Fitness Percentile and Body Fat Percentage), and health behaviors (Total Weekly Physical Activity, Screen Time, and Sleep). Of note, the "Nonwhite" variable used in our analyses was a composite measure including both race (ie, indication of anything other than "Caucasian") and ethnicity (ie, Hispanic/Latinx). Statistical summaries of the correlational analysis are provided in Table 2.

To examine the relationship of individual factors and interactions as they related to Stress, a hierarchical approach using stepwise model selection based upon Akaike Information Criterion was performed using the *fmsb*,<sup>48</sup> *psychometric*,<sup>49</sup> *interactions*,<sup>50</sup> *MASS*,<sup>51</sup> and *Rmimic*,<sup>52</sup> packages in R version 4.0. In the first step, Age, Biological Sex (0 = Female, 1 = Male), Years of Education, and Race (0 = White, 1 = Nonwhite) were bidirectionally introduced/removed in a stepwise fashion for the model to determine which demographic factors were significant predictors of Stress Level. In the second step, physical-health-related attributes (Aerobic Fitness Percentile, Percent Body Fat, and the interaction of Aerobic Fitness Percentile and Percent Body



**Table 2.** Bivariate correlations between stress, demographic factors, physical-health-related attributes, and health behaviors.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Stress	–								
2. Age	–0.018	–							
3. Biological Sex (0 female, 1 male)	–0.198*	0.094*	–						
4. Education	0.018	0.745*	–0.041	–					
5. Nonwhite (0 white, 1 nonwhite)	–0.045	–0.036	0.086*	–0.01	–				
6. Percent Body Fat	0.114*	–0.038	–0.657*	0.116*	0.005	–			
7. Aerobic Fitness Percentile	–0.038	0.078	0.257*	–0.056	–0.24*	–0.462*	–		
8. Total Weekly Physical Activity	–0.05	–0.102*	0.121*	–0.042	–0.024	–0.131*	0.206*	–	
9. Total Weekly Screen Time	0.168*	0.062	0.019	0.067	0.083	0.065	–0.178*	0.01	–
10. Total Weekly Sleep	–0.154*	–0.014	0.076	–0.058	–0.138*	–0.053	0.049	0.083	0.003

Note. \* denotes correlation was significant at  $p \leq .05$ .

Fat) were bidirectionally introduced/removed in a stepwise fashion for the model to determine those factors that improved the model fit over and above that of demographic factors alone. In the third step, health behaviors (Total Weekly Physical Activity, Total Weekly Screen Time, and Total Weekly Sleep) were bidirectionally introduced/removed in a stepwise fashion – first as independent predictors and then as interactions – to determine those factors that improved the model fit over and above that of factors added to the model in Steps 1 (demographics) and 2 (physical-health-related attributes). Finally, following selection of all factors for the model, interactions between model terms and demographic factors were assessed. However, no interactions between model terms and demographic factors were observed. Statistical summaries of the hierarchical regression analysis are provided in Table 3.

## Results

### Descriptive statistics

Analyses were conducted on only those participants with complete data for all relevant health-related attribute (aerobic fitness level, body composition) and health behavior (physical activity, sleep, screen time) data ( $N=513$ ). See Table 1 for a full breakdown of the demographic and health-behavior variables for this sample. Individuals were, on average, in the low-to-moderate range of aerobic fitness ( $M_{\text{FitnessPercentile}} = 46.8 \pm 33.2$ , range = 3–97) and the mean percent body fat percentages for both males and females were toward the upper end of the “healthy” range, which for males aged 20–29 is 10–22% and for females is 20–32% (males:  $M_{\text{PercentFat}} = 20.4 \pm 6.2$ , range = 5.7–41.7; females:  $M_{\text{PercentFat}} = 32.1 \pm 6.6$ , range = 8.5–52.0).<sup>53</sup> Participants reported engaging in about 1.3 hours of physical activity per day ( $M_{\text{PhysicalActivity}} = 9.1 \pm 5.7$  hours per week, range = 0–25), sleeping slightly less than the recommended amount for college students ( $M_{\text{Sleep}} = 45.7 \pm 5.9$  hour per week, range = 30–65; corresponding to approximately 6.5 hours of sleep each night), and spending approximately 3.3 hours per day engaged in screen time ( $M_{\text{ScreenTime}} = 23.4 \pm 12.3$  hours per week, range = 0–60).

### Correlations: Health-related attributes, health behaviors, & stress

See Table 2 for a full breakdown of the correlational analyses. For physical health-related attributes, there was a moderate inverse relationship between Aerobic Fitness Percentile and Percent Body Fat,  $r_s = -0.46$  [95% CI:  $-0.53$  to  $-0.39$ ],  $p < 0.001$ . Total Weekly Physical Activity was positively related to Aerobic Fitness Percentile,  $r_s = 0.21$  [95% CI:  $0.12$  to  $0.29$ ],  $p < 0.001$ . Biological Sex and Total Weekly Sleep were negatively related to Stress ( $r_{ss} \leq -0.15$  [95% CIs:  $-0.28$  to  $-0.07$ ],  $p's < 0.001$ ), whereas Percent Body Fat and Total Weekly Screen Time were positively related to it ( $r_{ss} \geq 0.11$  [95% CIs:  $0.03$  to  $0.25$ ],  $p's \leq 0.01$ ).

### Regression: Step 1 – Demographic characteristics and stress level

Initial stepwise model selection identified that of the potential demographic characteristics, only Biological Sex exhibited a relationship with Stress,  $F(1, 511) = 22.2$ ,  $p < 0.001$ ,  $f^2 = 0.04$  [95% CI:  $0.01$  to  $0.08$ ],  $R^2 = 0.04$ ) (See Table 3).

### Regression: Step 2 – Physical-health-related attributes and stress level

Despite the stepwise approach, neither Aerobic Fitness Percentile or Percent Body Fat – nor their interaction – served to improve the model fit ( $F_{\text{change}}(4, 508) = 0.9$ ,  $p = 0.45$ ,  $f^2 = 0.01$  [95% CI:  $0.0$  to  $0.02$ ]), over and above the predictive capacity of Biological Sex for Stress ( $R^2_{\text{change}} = 0.005$ ) (See Table 3).

### Regression: Step 3a – Health behaviors and stress level

The stepwise model selection identified Total Weekly Screen Time ( $B = 0.01$  [95% CI:  $0.01$  to  $0.01$ ],  $SE B = 0.06$ ,  $\beta = 0.17$ ), Total Weekly Sleep, ( $B = -0.02$  [95% CI:  $-0.03$  to  $-0.01$ ],  $SE B = 0.01$ ,  $\beta = -0.13$ ), and the three-way interaction of Total Weekly Screen Time  $\times$  Total Weekly Sleep  $\times$  Total Weekly Physical Activity as improving the capacity to predict Stress ( $F_{\text{change}}(4, 508) = 9.3$ ,  $p < 0.001$ ,  $f^2 = 0.05$  [95% CI:

**Table 3.** Summary of hierarchical regression analysis.

	$R^2$	$R^2_{\text{change}}$	$F^2$ [95% CI]	B [95% CI]	SE B	$\beta$	$t$
<b>Model 1: Demographic factors</b>							
Stress ~ Biological sex	0.042	0.042*	0.04 [0.01 to 0.08]	−0.3 [−0.43 to 0.18]	0.06	−0.2	4.7*
<b>Model 2: Physical health-related attributes (including Model 1: Biological sex)</b>							
Stress ~ Aerobic Fitness Percentile, Percent Body Fat, and Aerobic Fitness Percentile × Percent Body Fat	0.047	0.005	0.01 [0.0 to 0.02]				
Aerobic Fitness Percentile				−0.04 [−0.11 to 0.03]	0.04	−0.06	1.2
Percent Body Fat				−0.01 [−0.08 to 0.05]	0.03	−0.02	0.5
Aerobic Fitness Percentile × Percent Body Fat				−0.05 [−0.12 to 0.01]	0.03	−0.07	1.5
<b>Model 3: Health behaviors (including Model 1: Biological sex)</b>							
Stress ~ Screen Time, Sleep, and Screen Time × Physical Activity × Sleep	0.091	0.05*	0.05 [0.01 to 0.09]				
Screen Time				0.12 [0.06 to 0.18]	0.03	0.17	4.1*
Sleep				−0.09 [−0.15 to −0.03]	0.03	−0.13	3.1*
Screen Time × Physical Activity × Sleep							
When Physical Activity ≥ 10 hours per week							
When Sleep > 49 hours per week							
Screen Time				0.01 [0.0 to 0.02]	<0.01	0.12	1.4
When Sleep is between 44 hours and 49 per week							
Screen Time				<0.01 [0.0 to 0.02]	<0.01	0.1	2.0
When Sleep < 44 hours per week							
Screen Time				<0.01 [0.0 to 0.02]	<0.01	0.08	1.0
When Physical Activity < 10 hours per week							
When Sleep > 49 hours per week							
Screen Time				<0.01 [0.0 to 0.02]	<0.01	0.08	1.3
When Sleep is between 44 hours and 49 per week							
Screen Time				0.01 [0.01 to 0.02]	<0.01	0.13	3.5*
When Sleep < 44 hours per week							
Screen Time				0.015 [0.01 to 0.03]	<0.01	0.19	3.0*

Note. \* denotes was significant at  $p \leq .05$ . Model summaries for the interaction of Screen Time × Physical Activity × Sleep on Stress reflect simple slopes point estimations at different intercept values of Total Weekly Sleep and Total Weekly Physical Activity.

0.01 to 0.09)], over and above that of Biological Sex ( $R^2_{\text{change}} = 0.05$ ) (See Table 3).

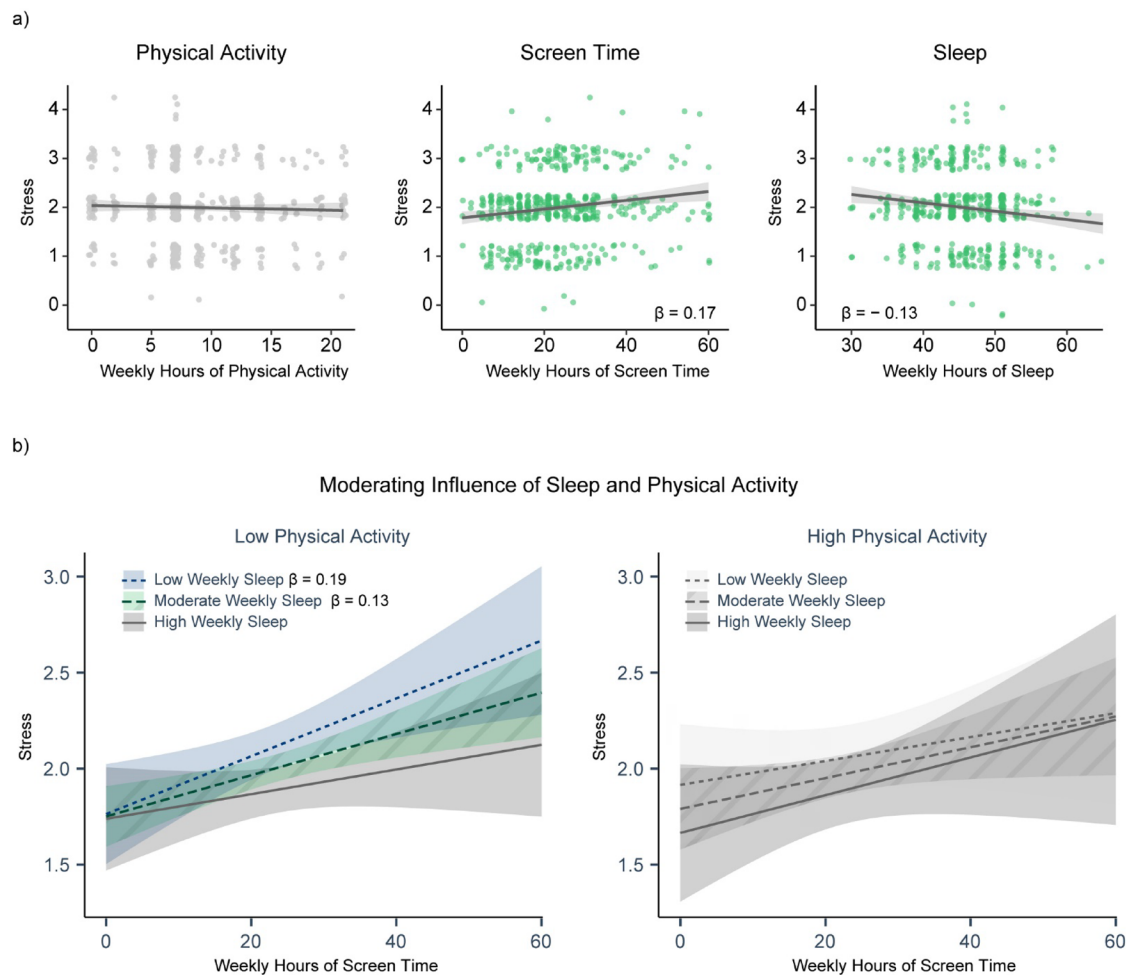
### Regression: Step 3b – Exploration of interaction

The three-way interaction was decomposed using simple slopes analysis,<sup>54</sup> which examined the moderating influence of Total Weekly Sleep and Total Weekly Physical Activity on the relationship between Total Weekly Screen Time and Stress (the dependent variable of interest). This approach allowed for the estimation of the association between these factors at different values by re-centering and re-estimating model parameters. Stated more simply, this approach allows for characterizing how the slope of the relationship between Total Weekly Screen Time and Stress changes at different point estimates of Total Weekly Sleep and Total Weekly Physical Activity while still retaining the underlying continuous relationships.

The normal distribution of Total Weekly Sleep lent itself toward estimating the associations across terciles of sleep behaviors (Low Sleep: accumulating less than 44 total weekly hours of sleep; Moderate Sleep: accumulating between 44

and 49 total weekly hours of sleep; and High Sleep: accumulating more than 49 total weekly hours of sleep). The skew of Total Weekly Physical Activity, however, necessitated estimating at points corresponding to a dichotomous distribution of physical activity behaviors (Low Physical Activity: accumulating less than 10 total weekly hours of physical activity; relative to High Physical Activity: accumulating 10 or more total weekly hours of physical activity). Interpretations of the interaction of Total Weekly Screen Time × Total Weekly Sleep × Total Weekly Physical Activity therefore relied on estimating the relationship between Total Weekly Screen Time and Stress at intercept values of these continuous variables (ie, Total Weekly Sleep and Total Weekly Physical Activity) corresponding to these points (see Figure 1(b)).

When Total Weekly Physical Activity was high, there was no relationship between Total Weekly Screen Time and Stress ( $B's \leq 0.01$  [95% CI: 0.0 to 0.02],  $SE B's \leq 0.01$ ,  $\beta's \leq 0.12$ ,  $p's > 0.05$ ). Similarly, when Total Weekly Physical Activity was low but Total Weekly Sleep was high, there was no relationship between Total Weekly Screen Time and Stress ( $B < 0.01$  [95% CI: 0.0 to 0.02],  $SE B < 0.01$ ,  $\beta = 0.08$ ,  $p = 0.2$ ).



**Figure 1.** a) Greater screen time and less sleep were associated with higher stress, while physical activity appeared unrelated to stress. To prevent overplotting for graphing purposes, a small amount of random jitter was introduced within the scatterplot. Colorized data indicate statistically significant relationships. b) For individuals with low physical activity (left), greater amounts of sleep mitigated the negative relationship between screen time and stress. Whereas no relationship between screen time and stress was observed for individuals with high physical activity (right). Regression fits and 95% confidence intervals are colorized for statistically significant relationships.

The relationship between Total Weekly Screen Time and Stress was only apparent when Total Weekly Physical Activity was low and Total Weekly Sleep was Low to Moderate, ( $B's \geq 0.01$  [95% CI: 0.01 to 0.03], SE  $B's = 0.01$ ,  $\beta's \geq 0.13$ ,  $p's \leq 0.003$ ) (See Table 3).

## Discussion

The aim of the present investigation was to examine the potential independent and interactive contributions of physical activity and sleep for moderating the relationship between screen time and stress in college-aged adults. Consistent with the current literature,<sup>6,27,29</sup> findings from this investigation replicated the well-established observations that greater amounts of screen time and poor sleep (as indexed by shorter sleep duration) were both independently associated with higher reported stress [see Figure 1(a)]. In contrast, however, no independent associations between physical activity and stress were observed. When considered within the broader context of the literature in this area, these findings are perhaps unsurprising given the observation that the

intensity of the physical activity – rather than just the overall quantity of physical activity – is an important attribute related to perceptions of stress. In particular, prior investigations suggest that time spent in vigorous intensity physical activity may be especially relevant for being associated with reductions in stress.<sup>6,19,28</sup> However, it is important to acknowledge that within the present investigation, a large proportion of participants reported participating in a little over 1 hour of activity per day – perhaps due to the fact that they were students on a large campus that requires a considerable amount of walking to get from place to place. As such, there may not have been sufficient variability in physical activity levels for the independent association of physical activity with stress to become apparent.

Nevertheless, a novel finding in the present investigation was the observation of a three-way-interaction between screen time, sleep, and physical activity independent from the effects of biological sex on perceived levels of stress. These findings build upon those of Ge et al,<sup>6</sup> considering the moderating role of not just physical activity but also sleep – and the interaction between the two – in the context of the screen time-stress



relationship. Specifically, the relationship between screen time and perceived stress was moderated by sleep and physical activity such that the relationship between screen time and stress was only apparent under low levels of physical activity and low to moderate levels of sleep (see [Figure 1\(b\)](#)). Thus, accumulating approximately 1.5 or more hours of physical activity each day was associated with a diminishment in the strength of the relationship between screen time and stress. For those individuals who were not as active, the strength of the relationship between screen time and stress was observed to be lower with greater amounts of sleep – such that it was absent in those accumulating more than 7 hours of sleep each night. Also novel to the present investigation was the concurrent consideration of health-related attributes (specifically, body composition and aerobic fitness) as potential covariates relating to perceptions of stress. However, no independent relationships with stress were observed for either body composition or aerobic fitness, nor did body composition or aerobic fitness interact with the assessed health behaviors. Thus, although health behaviors are antecedents to these health-related attributes (e.g., engagement in more aerobic physical activity is usually associated with higher levels of aerobic fitness), stress appears to be more strongly related to the behaviors themselves – not necessarily the more stable, resulting attributes – although this could perhaps reflect differences in self-report vs. objective measures. These findings help provide nuance to meta-analytic evidence from Nokes,<sup>21</sup> who concluded that aerobically fit subjects had a reduced stress response. However, because this review included both acute and chronic exercise interventions as well as cross-sectional fitness studies, it is difficult to parse out how much variance in stress response was due to engagement in exercise itself vs. the attribute of aerobic fitness – and so our data help to shed light on this distinction between dynamic behaviors and more static individual characteristics.

Despite the strength of the present investigation, it is important to note that it was ultimately cross-sectional in nature; thus, no causal relationships can be attributed. Indeed, it may well be that these health behaviors exhibit bidirectional relationships with stress or that greater perceptions of stress lead to reductions in physical activity and sleep as well as greater engagement in screen time (e.g., Mouchacca et al<sup>55</sup>). For example, one study conducted in a sample of police officers found that higher levels of perceived stress were associated with shorter sleep duration.<sup>56</sup> In addition, it may be possible that people suffering from insomnia (ie, short sleep duration) – potentially influenced by stress – could engage in more bedtime screen time, or that screen time could be used as a coping mechanism for mood regulation.<sup>57</sup> Accordingly, future research is necessary to determine the directionality of these relationships, as well as if interventions manipulating physical activity and sleep are effective at reducing stress – and, in particular, stress associated with greater screen time. Alternatively, interventions targeting reductions in screen time could potentially provide students with more time to engage in physical activity and/or sleep.

When it comes to implementation of potential physical activity and/or sleep intervention programs in a university setting, existing literature provides several important key points to consider. A recent meta-analysis of health behavior

interventions in college students found that the most effective programs at improving physical activity outcomes were those embedded within existing university courses – perhaps because of the frequent face-to-face contact with instructors and ample opportunities for feedback and support.<sup>58</sup> Overall, any interventions where students received feedback were more effective than those in which they simply passively received information – and many effective interventions also made use of existing campus fitness facilities such as gyms or tracks, since students already had easy access to these (and in many cases, membership dues were included in their student fees).<sup>58</sup> Regarding sleep duration, a meta-analysis conducted in 2021 showed that interventions employing behavior change techniques resulted in significantly higher sleep duration (by approximately 45 minutes) as compared to control groups or baseline measures.<sup>59</sup> Specifically, those with a direct intervention component (e.g., having participants schedule the times at which they would go to bed and wake up) were more effective than those with indirect intervention (e.g., more passive techniques like educational seminars).<sup>59</sup> Interestingly, intervention programs with more curriculum components had smaller effect sizes than those with fewer – highlighting the importance of not only behaviorally-targeted but also simple programs vs. broader, more complicated ones.<sup>59</sup>

A limitation of the current study was the use of a single-item measure of stress as opposed to a multi-item scale or questionnaire. However, trends of stress prevalence in our data are consistent with trends observed in undergraduate students across the country using similar metrics. To illustrate: 78.2% of students in our sample indicated experiencing high levels of stress sometimes, most of the time, or always, compared to 81.8% of undergraduates in the United States reporting their overall levels of stress as either moderate or high.<sup>2</sup> In addition, most research that has been published on single-item measures suggests that they are comparable in reliability and validity to their multi-item analogues.<sup>60–62</sup> Regarding our measure of sleep, while subjective reports of sleep are prone to over-reporting, they are moderately correlated with actigraphy-measured sleep<sup>63</sup> and the nature of the over-reporting does not appear to systematically be biased by other potential attributes such as body mass index (BMI).<sup>64</sup> Especially because this investigation focused on sleep duration rather than sleep quality, the nature of the self-reported questions were consistent with the majority of existing research on sleep duration, including the sleep duration sub-component of the PSQI (measured via one single question), which is the gold-standard self-reported-sleep tool.<sup>36</sup> Thus, there is little reason to assume that these subjective estimates of health behaviors fail to be representative of the behaviors of interest. In fact, 45.8% of our sample averaged less than the recommended 7 hours of sleep per night, which is consistent with the most recent data from the National College Health Assessment showing that approximately 40.2% of undergraduates reported sleeping less than 7 hours on weeknights.<sup>2</sup> Finally, with technological advancements and societal trends toward greater engagement in social media, the present investigation was limited in not considering the potential stress-related implications of greater phone/mobile device use

or social media time as a specific subdomain of screen time. Given the growing body of evidence on social network stress,<sup>65,66</sup> future research is warranted to better understand if and how health behaviors may help to mitigate mental health-related issues arising specifically from social network use. Indeed, similar to sleep or physical activity interventions, interventions specifically targeting social media use (e.g., Ko et al<sup>67</sup>) could be designed reduce engagement in this specific aspect of screen time, potentially corresponding with changes in various mental health outcomes including stress.

Collectively, findings from this investigation provide compelling evidence to suggest that modifiable health behaviors such as sleep and physical activity – as well as the interaction between the two – play a role in moderating the relationship between screen time and stress in college-aged adults. Given the increasing utilization of screens, an understanding of potential methods of reducing screen-time related stress is of considerable relevance and practical importance – particularly as stress-related visits to university counseling centers continue to increase.<sup>1,3,68</sup> In particular, young adults in America report the highest average stress level relative to other generations, and nearly 60% of young adults indicate that they need more emotional support than they have received in the past year.<sup>69</sup> Realistically, it is challenging for contemporary college students to optimize both physical activity and sleep while also keeping screen time to a minimum – especially if they are engaged in virtual learning, the screen time associated with which is largely unavoidable (e.g., attending online classes or completing online assignments). As such, findings from the present investigation suggest that deficits or challenges in the engagement in sufficient amounts of physical activity could potentially be compensated for by obtaining sufficient sleep, and vice-versa – especially if university administrators seek to employ some of the best-practices intervention strategies mentioned above, based on meta-analytic data. If engagement in these health behaviors does lead to reductions in screen-time-related stress, the bidirectional nature of these relationships may then lead to a greater ability to be physically active and obtain quality sleep. Accordingly, interventions in this area may serve to not only reduce stress in college-aged adults, but also to address issues of sedentary behavior.

## Acknowledgments

The authors wish to thank the many undergraduate research assistants who aided in data collection for this study.

## Conflict of interest disclosure

The authors have no conflicts of interest to report. The authors confirm that the research presented in this article met the ethical guidelines, including adherence to the legal requirements, of the United States of America and received approval from the Institutional Review Board of Michigan State University.

## Funding

No funding was used to support this research and/or the preparation of the manuscript.

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