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ORIGINAL RESEARCH REPORT

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Burnout among high school students is linked to their telomere length and relatedness with peers

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ABSTRACT

School burnout is a serious concern, as it impairs students' health and academic success. According to the Conservation of Resources Theory, burnout results from the depletion of personal coping resources and can be counteracted by supportive social relationships. However, it is not yet clear how students' relatedness with their peers is linked to their burnout. Next to students' self-reported fatigue, biomarkers such as telomere length (TL), which presents an indicator of aging, complement stress research. To identify school-related factors that may prevent students from experiencing burnout and to link TL to students' self-reported burnout, the current study investigated how relatedness with peers as well as TL at the beginning of the school year explained students' burnout at the end of the school year. The sample included 78 students ($M_{age} = 13.7 \pm 0.7$ years; 48% girls). Results of multilevel analysis in Mplus indicate that, over the school year, students with higher TL and those who experienced relatedness with their peers reported lower levels of burnout. Moreover, students who felt related to their peers exhibited a longer TL. The study implies that students' relatedness with their peers may be a promising setscrew to prevent students' burnout and support their physical health. This is one of the first studies to link TL with school-related variables such as burnout and relatedness to peers in a non-clinical student sample, providing a baseline for interventions and future interdisciplinary studies in the field of education and stress.

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Burnout; relatedness with peers; telomere length; high school students; multilevel analyses

1. Introduction

Burnout among high school students has become a serious health concern (Ottová-Jordan et al., 2016; Torsheim et al., 2003), placing students' well-being and academic development at risk (OECD, 2017; Pascoe et al., 2020). School burnout is defined along three dimensions – exhaustion from school demands, a cynical and detached attitude toward school and a feeling of inadequacy at school (Salmela-Aro et al., 2009) and is a consequence of chronic school-related stress, which occurs if academic demands regularly exceed students' resources (Salmela-Aro & Upadyaya, 2014). School burnout presents a risk factor for students' academic development and well-being (OECD, 2017; Pascoe et al., 2020), as students who feel exhausted are more likely to exhibit low educational aspirations, low school motivation (Salmela-Aro et al., 2008; Vasalampi et al., 2009) and high absenteeism. Additionally, they tend to drop out of school earlier than their peers (Fiorilli et al., 2017; Korhonen et al., 2014).

According to the Conservation of Resources Theory (COR; Hobfoll & Shirom, 2001), burnout is described as a psychosocial strain resulting from the depletion of personal coping resources; it can be counteracted by supportive social relationships (Hobfoll et al., 1990). Within the school context, students' relationships with their peers become increasingly important for their psychosocial development (Bokhorst et al., 2010). Relatedness represents one basic psychological need within the self-determination theory, which describes the need to feel connected to others (Ryan & Deci, 2017). If this need is met and students feel related to their peers, they experience mutual trust, support and belonging with a social peer group, which, in turn, is related to positive affect and mental health (Schutte & Malouff, 2021).

Empirical evidence suggests that students who receive peer support and feel related to their peers – in other words, they feel they belong to the peer group and experience mutual trust – suffer less stress than others their age and exhibit better coping strategies (Hoferichter et al., 2022a; Weinstein & Ryan, 2011). Particularly among 15-year-olds, compared to 11- to 13-year-old students, peer support buffered their stress-related health complaints (Sonmark & Modin, 2017). However, how students' relatedness to their peers is linked to burnout is not yet clear but could be essential to preventing this fatigue.

In addition to students' self-reported data on burnout, biophysiological markers – whose investigation is still rare within

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the educational context (Hoferichter & Raufelder, 2023; Tomczyk & Hoferichter, 2022) – such as telomeres, are promising indicators to complement stress research in non-clinical samples of students. Telomeres are composed of repetitive DNA that stabilizes the chromosomal ends and naturally reduces in length over time due to cell division (Blackburn, 2005). However, the telomere sequence and the length of telomeres are maintained and recovered by telomerase (Blackburn, 2000; Verhoeven et al., 2015).

Psychosocial stressors have been linked to accelerating biological aging, as chronic stress directly affects cellular processes that are related to the onset of various diseases and that shorten TL (Pepper et al., 2018; Rentscher et al., 2020). As such, TL is related to psychosocial stressors, for example, in individuals who experienced extreme early stressful life events (SLEs) such as poverty, maltreatment and institutionalization (Coimbra et al., 2017). In recent decades, a growing body of literature has consistently found that shorter TL is associated with psychosocial stressors (Rentscher et al., 2020; Shalev et al., 2013; Woody et al., 2017), for example, among adults who report high perceived stress levels (Puterman et al., 2010), work exhaustion (Ahola et al., 2012) and SLEs over a one- to six-year period (Puterman et al., 2015; Van Ockenburg et al., 2015).

However, some studies did not find significant stress–TL associations in different study cohorts. Rej et al. (2019) investigated Philippine caregivers who took care of an adult household member with a chronic illness or disability, but they could not find an association with TL. Similarly, Chang et al. (2018) did not detect significant stress–TL relationships among older caregiving women ages 60–81.

Investigating stress–TL associations, a variety of studies applied a causal approach by assuming that behavior causes telomere attrition. However, shorter TL has also been demonstrated to predict behavioral outcomes, as individuals with shorter TL may adopt different behavioral patterns compared to those with longer TL, as proposed in the selective adoption hypothesis (Bateson & Nettle, 2018). For instance, Costa et al. (2015) found that TL predicted the hyperactive–impulsive dimension of attention deficit hyperactivity disorder. In an experimental study, Yim and colleagues (2026) found that shorter TL predicted individuals' impatience, measured by a delay discounting task.

Following the selective adoption hypothesis (Bateson & Nettle, 2018) in this study, we investigate how TL is associated with burnout among healthy secondary school students. Research into young, healthy adults' association between TL and burnout is scarce; the only such study was conducted by Zou et al. (2017), who found no significant association between TL and academic stress (Zou et al., 2017). That cross-sectional study investigated three groups of students with mild, moderate and severe anxiety but not burnout.

Building on the COR (Hobfoll et al., 1990), the selective adoption hypothesis (Bateson & Nettle, 2018) and previous studies on telomere research (Rentscher et al., 2020; Shalev et al., 2013), we expect that (1) students who exhibit higher TL at the beginning of the school year report lower levels of school burnout at the end of the school year and that (2) students who feel related to their peers at the beginning of the school year report lower levels of burnout at the end of the school year. As control variables, we included gender, body mass index (BMI), SLEs and age, as previous studies found that girls were more likely to experience burnout (Salmela-Aro et al., 2009) than boys. BMI was also identified as a confounder for TL (Gielen et al., 2018), as were SLEs (McFarland et al., 2018) and age (Blasco, 2007). In addition, burnout has been linked to SLEs (Mather et al., 2014; Plieger et al., 2015).

2. Materials and methods

2.1. Sample and procedure

A total of 733 students in grades seven and eight at 11 randomly selected schools in northeast Germany participated in the questionnaire study. Additionally, a randomly selected subsample of 83 students participated in biomarker testing, of whom 78 were considered for the current analyses ($M_{age} = 13.7 \pm 0.7$ years; 48% girls), as one student had to be excluded due to extreme values. The first data collection (questionnaire study, biomarker testing at t1) took place at the beginning of the 2018–19 school year, and the second collection (questionnaire study at t2) was done at the end of the academic year.

To describe the student cohort in more detail, students were asked to report their hours of sleep before data collection, their regular use of medication, and their height, weight and abdominal girth to calculate their BMI. On average, the students' height was 169 ± 8 cm, their weight was 62.2 ± 15.1 kg and their abdominal girth was 72.3 ± 11.2 cm. Students had slept, on average, 8.4 ± 1.3 hours prior to the collection of their biomarkers and awoke at approximately 7:53 a.m. Approximately 6% of students reported taking painkillers every week, but 74.7% reported not taking the medication regularly. Daily, 4.8% of the student sample took medication for allergies, 1.2% took Ritalin and 2.4% used asthma inhalers. Due to missing data, particularly at the second measurement point, the current study sample includes 142 observations (i.e. 78 obs. at t1 and 64 obs. at t2, see Table 1).

To conduct the study, approval was obtained by the ethics committee of the university medical center and the Ministry of Education, Science and Culture of Mecklenburg-Western Pomerania. Written informed consent – including information on data handling, the voluntary nature of participation, the free choice to drop out, et cetera – was collected from students and their parents. The questionnaire was administered in the classrooms, and the biophysiological testing took place at the university.

2.2. Measures

2.2.1. Telomere length (predictor variable)

Salivary cells and the subsequent analytical approach have been proven as reliable measures for TL compared to other major methods, e.g. buccal and leukocyte TL (Montpetit et al., 2014; Zizza et al., 2022) and up to now are the most commonly used method, also due to ease of adaptation, low cost, and requirement of low DNA quantity (Lai et al., 2018).

Table 1. Descriptive statistics ($n = 82$) and bivariate correlations ($n = 64$, listwise deletion).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. School burnout-t1	--						
2. School burnout-t2	0.778	--					
3. Telomere length	−0.254	−0.278	--				
4. Body mass index	0.234	0.059	0.143	--			
5. Stressful life events	−0.357	−0.366	0.353	0.035	--		
6. Relatedness with peers -t1	−0.559	−0.404	0.304	−0.334	0.223	--	
7. Relatedness with peers -t2	−0.382	−0.411	0.247	−0.206	0.145	0.754	--
M	3.04	3.00	2.47	21.40	−1.05	3.24	3.32
SD	0.96	1.02	0.19	4.34	0.80	0.83	0.70
min	1.11	1.00	2.13	12.84	−2.00	1.00	1.00
max	5.11	5.00	3.03	33.51	0.60	4.00	4.00
% Missing	0.0	17.1	3.7	1.2	0.0	0.0	17.1

XX-t1: first measurement point (baseline), XX-t2: second measurement point; SD: standard deviation. Bivariate associations were calculated with Pearson's R.

Saliva samples were collected by means of Oragene•DNA (OG-500) collection kits and processed by means of prepI-T•L2P | PT-L2P (DNA Genotek, Steinbrenner Laborsysteme GmbH, Wiesenbach Germany) according to the instructions of the manufacturer. By using a NanoDrop spectrophotometer (Isogen Life Science, Belgium), the quality and concentration of the extracted DNA were determined. The quality of DNA was determined as A260/280 and ranged between 1.7 and 2.1. DNA was stored at −20 °C until telomere length measurement. Following Gielen et al., 2014, we used the method of monochrome multiplex quantitative PCR (q-PCR) (Cawthon, 2009), using 384-multiwells plates (Roche, Switzerland) that were run on a LightCycler 480 machine (Roche). All samples were measured in triplicate on a single plate. The outer wells of the plate were not used since we found that PCR results of these wells deviated from those of the more central wells. After thawing, DNA was diluted in nuclease-free water to a concentration of 4 ng/µl. For q-PCR the following primers were used (Cawthon, 2009): telg (ACACTAAGGTTTGGGTTTGGGTTTGGGTTTGGGTTAGTGT); telc (TGTTAGGTATCCCTATCCCTATCCCTATCCCTATCCCTAACA); hbgu (CGGCGGCGGGCGGCGCGGGCTGGGCGGcttcatccacgttcaccttg); and hbgd (GCCCGGCCCGCCGCGCCCGTCCCGCCGgaggagaagtctgccgtt). The wells were filled with 4.6 µL DNA solution and 5.4 µL master mix which for each well consisted of 5 µL SyBr-green q-PCR master mix (Sensimix SYBR & Fluorescein, GC Biotech) and 0.1 µL of each primer (final concentration telg and telc primers was 300 nM, final concentration hbgu and hbgd primers was 350 nM), making a total volume of 10 µL. The PCR program was as follows: 15′ 95 °C enzyme activation; 2 cycles of 15″ 94 °C, 15″ 49 °C; 32 cycles of 15″ 94 °C, 10″ 62 °C, 15″ 73 °C (Ct telomere), 10″84 °C, 15″ 87 °C (Ct b-globulin); 60→95 °C 0.11 °C/s, 5 acquisitions/s (melting curve); 0.05″ 65 °C; 95→40 °C (cooling). Q-PCR signals were processed using the LC480 Conversion program and LinRegPCR (Roche).

DNA of two reference samples with known telomere lengths was included in each run, a Hela S3 cell line and a Hela 229 cell line, with known telomere lengths of 5.5 kB and 14.5 kB, respectively. Hela cell lines were kindly provided by Prof. Alexander Bürkle, University of Konstanz, Germany. The HelaS3 DNA was included in 5 dilutions (4.0–0.25 ng/µl). PCR efficiency of the telomere primers was 110%, and PCR efficiency of the b-globulin primers was 97%, which was within an acceptable range. Telomere length was estimated using a regression line based on the references. The Hela S3 was used as a reference to calculate T/S values and by definition has a T/S value of 1.0, and the T/S value of the Hela 229 was 3.3.

The current study includes averaged telomere length from samples that were measured in triplicate. None of the samples was excluded and 4 randomly selected samples (5%) were repeated in triplicate on a separate plate, resulting in values that were within 1 SD of the value of the same sample measured in the first run. The intra-class correlation coefficient for telomere length estimated in kB was 0.74 (95% CI: 0.65–0.81). Average ± SD TL found for the complete study population was 12.05 ± 2.42. The telomere lengths in kB were further transformed by natural log to obtain a distribution closer to normal. The measurement of telomere length is also described in Jentsch et al., 2022.

2.2.2. School burnout (outcome variable)

School-related burnout was measured with the School Burnout Inventory (SBI, Hoferichter et al., 2022b) at baseline (t1) and the second measurement point (t2). The SBI consists of nine items (e.g. "I often sleep badly because of matters related to my schoolwork"; "I keep wondering if my schoolwork is good for anything") which are answered on a six-point scale ranging from 1 (completely disagree) to 6 (strongly agree). Salmela-Aro et al. (2009) showed that the SBI correlated with depression, academic achievement, as well as school engagement, and is best represented by a three-factor model comprising the sub-scales exhaustion, cynicism, and inadequacy. However, in light of a small sample size and strong intercorrelations among the subscales ($r > 0.58$), we used a single-factor model (mean scores) that resulted in good reliabilities (Cronbach's $\alpha = 0.83/0.86$). We validated our approach by performing confirmatory factor analysis for a single-factor model to ensure measurement invariance over time. A model with factor loadings fixed to one and intercepts constrained over time had a good fit to the data (CFI = 1.00, TLI = 1.02, RSMEA = 0.00, SRMR = 0.06).

2.2.3. Relatedness (predictor variable)

Students' perceived relatedness was measured with four items of an instrument that was constructed in accordance with self-determination theory (Deci & Ryan, 1985). Students were asked how often they felt related in class (e.g. "I feel comfortable in the class community"; "I feel like I belong in the class")

and answered on a four-point scale ranging from 1 (never) to 4 (very often), both at baseline and t2. The instrument also included twelve items on perceived autonomy and competence which are not under study in this paper and therefore not further analyzed (Rakoczy, 2006; see also Prenzel et al., 1996). Reliability for relatedness mean scores was very good (Cronbach's $\alpha = 0.94/0.88$), and we also found no violation of measurement invariance over time (i.e., factor loadings fixed to one and constrained intercepts, CFI = 0.99, TLI = 0.99, RSMEA = 0.04, SRMR = 0.07).

2.2.4. Control variables

In our analysis, we controlled for sex, age, and BMI at baseline. Students' BMI was constructed from their respective height and weight. We also used established BMI categories (underweight/normal weight/overweight or obese, e.g. Nuttal, 2015) for additional exploratory analysis. The resulting categorical BMI showed that 18 students were underweight (BMI <18 kg/m^2), 48 had normal weight (BMI = 18–24.9 kg/m^2), and 15 were overweight (BMI = 25–30kg/m^2) or obese (BMI > 30 kg/m^2), neglecting one missing value. In addition, we asked students how much they had to struggle with stressful life events (SLE, Steinhausen & Winkler Metzke, 2001), which is considered an important covariate of telomere length and perceived stress in a recent literature review (Rentscher et al., 2020). The SLE list included eleven events such as parents' divorce or the loss of a relative, and students responded on a five-point scale ranging from −2 (very stressful) to 2 (not stressful at all) by answering "Have you ever experienced any of the following situations and how did you feel about the event?". The scale was recorded to increase the interpretation of results such as a high value indicates that life events have been stressful. As about 75% of students reported having experienced all events, an indication of "0" can be interpreted as "did not affect me" rather than "did not experience the life event". The outcome variable school burnout was regressed on all control variables.

2.3. Statistical analysis

Using Mplus Version 8.1 (Muthén & Muthén, 1998-2017), we performed multilevel regression analysis to answer our research questions (Goldstein, 2011). All models included school burnout as an outcome, potentially varying both within and between individuals, with time as a level-1 predictor (within) and TL as a level-2 predictor (between). Model finding with regard to control variables was performed by using a backwards selection process, such that we included all variables first and then removed those that did not explain a statistically significant amount of variance in the outcomes at a type-1 error of 10%. We estimated a model with random intercepts for school burnout and successively increased model complexity by including random slopes for burnout trajectories over time and adding relatedness as another predictor (i.e., relatedness and telomere length are mutually adjusted for the other exposure). Models were compared with regard to the amount of explained variance on both levels and information criteria, which penalize models with a greater number of parameters.

In this paper, statistical inference relies on Bayesian estimation techniques (Gelman et al., 2013) in the sense that unknown parameters are considered randomly distributed (i.e., in contrast to the fixed value of a point estimate). This means that we must explicitly state our prior knowledge by formulating the corresponding distributions for the unknown parameters. In light of the data, this prior knowledge is updated and yields a posterior distribution which contains all of the necessary information on the parameters. Because there is still limited evidence on the association between TL and school burnout in adolescents, we apply vague priors that are implemented in Mplus as a default (e.g. broad normal priors centered at zero for regression coefficients and inverse Gamma or Wishart distributions for variance and covariance parameters, respectively). However, recent critiques have stated that default priors for variance parameters should be used with care, particularly in a multilevel context (e.g. Zitzmann et al., 2020). Therefore, we conducted a small sensitivity analysis in which we also applied more informative priors (for details, see the electronic supplemental material, Appendix A). Because the results across different distributions were similar and, in our opinion, vague priors better reflect the state of research, we report the latter.

Direct Bayes estimation produces unbiased estimates with missing data under the missing at random (MAR) assumption (Gelman et al., 2013; Little & Rubin, 1987), similar to established frequentist procedures such as maximum likelihood. However, we have re-estimated all reported models with complete cases only ($n = 64$) and also performed a sensitivity analysis under the missing not at random (MNAR) assumption, as suggested in the literature (e.g. Leurent et al., 2018; for more information, see the electronic supplemental material, Appendix B). In doing so, we acknowledge that unobserved burnout outcomes could be associated with dropout from the study, such that adolescents with severe burnout were unable to participate in the second measurement, for instance. Because both alternative methods yielded negligible differences, we refrain from presenting them in the main article.

3. Results

Table 1 depicts descriptive statistics and bivariate correlations for all variables used in the presented models. Approximately 75% of the total variability in school burnout outcomes was due to differences between students (i.e., share of level-2 variance). Model findings resulted in the removal of sex and age predictors from further analysis. However, we retained the BMI and SLEs during the remaining statistical procedures. Table 2 presents the findings from the four models that were estimated to answer our research questions.

3.1. Model 1: random intercepts for school burnout in adolescents

Results from model 1 suggest that there was no overall difference in school burnout over time ($\beta = -0.03$). Higher

Table 2. Standardized regression coefficients and confidence intervals for three multilevel models on the relations between telomere length (TL), relatedness, and school burnout ($n = 142$ obs. on level 1).

	Model 1: random intercepts (RIs)		Model 2: RIs and random time slopes		Model 3: RIs, random time slopes and relatedness as predictor		Model 4: RIs and relatedness as predictor	
	β	90%-CI	β	90%-CI	β	90%-CI	β	90% CI
Level 1: 24.9% of the total SBI variance within students								
Time	−0.025	[−0.171, 0.119]	−0.014	[−0.111, 0.096]	.020	[−0.049, 0.119]	0.021	[−0.128, 0.137]
Relatedness					−0.396	[−0.708, −0.107]	−0.357	[−0.524, −0.152]
R^2	0.4%		21.1%		34.0%		13.5%	
Level 2: 75.1% of the total SBI variance between students								
TL	−0.190	[−.374, −.028]	−0.110	[−0.216, −0.002]	−0.070	[−0.183, −.038]	−0.122	[−0.290, 0.060]
BMI	0.161	[0.004, 0.334]	0.222	[.056, 0.387]	0.158	[−0.002, 0.330]	0.093	[0.074, 0.252]
SLE	−0.269	[−0.093, −0.462]	−0.150	[−0.039, −0.270]	−0.141	[−0.028, −0.264]	−0.246	[−0.063, −0.425]
Relatedness					−0.301	[−.509, −0.113]	−0.357	[−0.556, −0.149]
BMI → SBI slopes			−0.231	[−0.545, 0.034]	−0.184	[−0.485, 0.073]		
SBI intercepts ←→ slopes			−0.698	[−0.871, −0.335]	−0.672	[-0.881, −0.148]		
R^2	38.7%		15.1%		21.1%		42.5%	
DIC	259.3		90.2		326.2		458.7	

Regression coefficients for time in models 2 and 3 are averaged over clusters. SBI: school burnout inventory; TL : telomere length; BMI : body mass index; SLE: stressful life events. "BMI → SBI slopes" refers to the effect of BMI on SBI random slopes; and "SBI intercepts ←→ slopes" refers to the correlation between SBI random intercepts and slopes; R^2 : proportion of variance explained; DIC: Deviance information criterion.

telomere length was weakly associated with a decrease in burnout (β = −0.19). Surprisingly, stressful life events (SLE) were negatively correlated with school burnout (β = −0.27). This means that the more students struggled with stressful events earlier in their lives, the less school burnout they reported. The BMI was positively associated with school burnout ($\beta = 0.16$). Overall, model 1 explained no variance at level 1 because time as the only predictor was not related to school burnout. However, on level 2 the model explained 38.7% of the variability between students, which is about 29% of the total variance.

3.2. Model 2: random intercepts and random time slopes

In general, the results from model 2 were consistent with those of model 1. There was still no indication of an increase in burnout over time on average. Including the BMI as a predictor for the random slopes resulted in a weakly negative effect (β = −0.23), indicating that higher BMI is associated with decreasing burnout perceptions. The effects of telomere length and stressful life events on school burnout dropped slightly but remained significant (β = −0.11 and β = −0.15, respectively). As in model 1, students with higher BMI had slightly higher burnout outcomes on average ($\beta = 0.22$). Random intercepts and slopes were highly negatively correlated ($r = -0.70$), which means that students with high burnout outcomes on average were much more likely to report a decrease in burnout over time. Including random slopes resulted in more explained variance on level 1 (21.1%), but a lower amount on level 2 (burnout: 15.1%, slopes: 5.4%). Regarding deviance information criteria (DIC), model 2 had a better fit than model 1 (90.2 vs. 259.3).

To better understand the implications of the associations between BMI, burnout intercepts and slopes, we conducted a simple exploratory analysis to illustrate the multilevel model findings. We compared the individual burnout means and the individual mean differences in school burnout over time across BMI categories (underweight/normal weight/overweight or obese). Indeed, underweight adolescents had slightly lower burnout means ($M = 2.83 \pm 0.87$, averaged over time) than their normal weight (3.08 ± 1.00) or overweight peers (3.10 ± 0.65). On the contrary, burnout values slightly increased over time in underweight (M difference = 0.19 ± 0.62), severely decreased in overweight individuals (-0.40 ± 0.53) and stagnated in students with normal weight (-0.04 ± 0.75).

3.3. Model 3: random intercepts, random slopes, and relatedness as predictor

Relatedness was moderately and negatively associated with student burnout on both levels (within: β = −0.40, between: β = −0.30). Telomere length was no longer related to students' burnout (β = −0.07), and the effect size dropped by about a third compared to model 2 (or sixty per cent compared to model 1, respectively). Regarding control variables, the results of model 3 were mostly consistent with those from models 1 and 2. As such, there were weakly negative effects of SLE (β = −0.14) and a positive effect of students' BMI on burnout random intercepts ($\beta = 0.16$). However, the relation between students' BMI and burnout random slopes was no longer significant, though the effect size was similar (β = −0.18). Random intercepts and slopes were still highly correlated ($r = -0.67$). Although model 3 explained a great amount of variance in student burnout (within: 34.0%, between: 21.1%, slopes: 3.5%) by adding another predictor, it had a worse fit than model 2 with regards to the DIC (326.2 vs. 90.2).

3.4. Model 4: random intercepts and relatedness as predictor (no random time slopes)

A model with less complexity including only random intercepts for school burnout but no random slopes, and relatedness as a predictor was also estimated but resulted in a worse fit to the data (DIC = 458.7, see Table 2). Note, however, that the estimated regression coefficients for this model were very

similar to those of model 3 and the model explained the greatest amount of level-2 variability in school burnout (approx.. 43%).

4. Discussion

The current study investigated how students' relatedness with peers as well as their TL are related to their burnout over one school year, considering their age, gender, SLEs and BMI. By means of multilevel regression analysis, two hypotheses were tested: (1) that students with higher TL at the beginning of the school year report lower levels of burnout at the end of the school year and (2) that those students who experience relatedness with their peers tend to report lower levels of burnout across the school year. Time was tested as a level-1 predictor (within), and TL and relatedness were tested as level-2 predictors (between), successively. Accordingly, a stepwise statistical approach was applied in which model complexity was increased.

First, the results indicate that, on average, students' fatigue levels did not change over the school year. However, there was a large amount of variability in burnout development over time across individuals, indicating that there might be different groups of students (a) reporting an increase, (b) reporting a decrease or (c) reporting no change in burnout over the school year. However, to identify specific student groups regarding their level of burnout, future studies should apply a person-oriented approach (cf. Salmela-Aro & Upadyaya, 2014) and link profiles to students' TL and relatedness to understand the variety of student groups. This, then, would suggest prevention and intervention aspects that would address the needs of different student groups.

In line with hypothesis 1, this study indicates that students with longer telomeres reported slightly lower levels of burnout across the school year. This relationship was also found when examining the link between TL and burnout cross-sectionally, resulting in a moderate effect size. The results indicate that students' biological aging induced by stress is linked to their feelings of exhaustion, cynicism and inadequacy at school. The results add empirical evidence regarding the selective adoption hypothesis (Bateson & Nettle, 2018), as high school students with shorter telomeres may have adjusted their stress-related behavior by changing gene expression involved in behavior.

Thus far, studies that have investigated the stress–TL association have yielded different results. The heterogeneity of results may be caused by (a) various stress measures applied to detect chronic, general, recent or early experiences of stress; (b) the cohort studied (e.g. caregivers, patients with impaired physical or/and mental health); and (c) the tissue analyzed to measure TL. This variety presents a challenge in comparing the results. While some studies have found significant stress–TL associations in blood samples (Ahola et al., 2012; Puterman et al., 2015; Van Ockenburg et al., 2015; Yim et al., 2016) and salivary samples (Chen et al., 2015; Willis et al., 2019), other studies using blood samples have not identified stress–TL association (Chang et al., 2018; Rej et al., 2019).

In summary, this is one of the first studies that seek to answer the question of whether the link between TL and psychosocial stressors, which has been found frequently in clinical trials (Blackburn, 2005; Rentscher et al., 2020; Shalev et al., 2013), can be identified in non-clinical cohorts, such as high school students. However, further research is needed to verify this study's results. Although this research identifies a link between TL – which presents a bio-physiological indicator of aging – and burnout – presenting self-reported stress – it is not clear which factors affect the length of telomeres in the first place, although this study controlled for SLEs and BMI. Future longitudinal and cross-lagged studies may provide insight into the causal relationship between TL and burnout, including, for example, epidemiological data (cf. Wang et al., 2018), personality traits and school contextual variables, measuring school and class climate.

As for hypothesis 2, it was found that students who reported feeling related to their classmates exhibited lower levels of burnout over the academic year. This finding is in line with other studies concluding that students' supportive peer relationships have a positive impact on their stress levels (Hoferichter et al., 2022a), stress-related health concerns (Sonmark & Modin, 2017) and psychological well-being (Hoferichter et al., 2021). Relatedness to peers seems relevant not only to mitigate students' feelings of burnout but also is moderately linked to their TL. That is, students who believe they belong with their classmates were more likely to exhibit longer telomeres. However, as this finding is based on the cross-sectional relationship between relatedness to peers and students' TL, no causal conclusions can be drawn from the results. Thus far, findings on social support and TL are mixed, mostly having been conducted with clinical samples and/or adults, finding either no significant relationship (Montoya & Uchino, 2023) or a positive significant relationship (Lincoln et al., 2019). Hence, future studies with students are advised to investigate the longitudinal and causal relationship between supportive social relationships within the classroom and students' TL. In general, it is well-researched that the feeling of belonging with others alongside the experience of social acceptance and affiliation constitutes basic human psychological needs related to overall well-being (Baumeister & Leary, 1995; Osterman, 2000). As such, if these needs are met within the school context, students tend to exhibit less burnout and longer telomeres, leading to the conclusion that positive relationships with peers present a setscrew for school-based interventions to minimize students' stress.

In accordance with the COR (Hobfoll et al., 1990; Hobfoll & Shirom, 2001) and self-determination theory (Ryan & Deci, 2017), this study provides empirical evidence that social support, measured by relatedness to peers, may function as a resource to overcome stressors that would lead to burnout and accelerated aging processes. The importance of peer relationships, not only for students' psychosocial development (Bokhorst et al., 2010) but also for their physical health, is underlined by the study results.

Next to testing our hypotheses, the results indicate that students who have experienced SLEs reported lower levels of burnout. Although this finding may be counterintuitive and may conflict with previous findings that have indicated an association between stressful and traumatic life events and burnout (Mather et al., 2014; Plieger et al., 2015), students

who have previously struggled with SLEs may have learned how to cope with these events and, therefore, are less susceptible to experiencing school-related stressors linked to school burnout. Additionally, this "learning effect" for how to cope with stressors may explain why several studies found that only recent SLEs – for example, within the last 12 months – predicted stress and burnout but not stressful events that had occurred more than a year ago (Dyrbye et al., 2006; Tiwari & Deshpande, 2020). Interestingly, when examining the correlation between SLEs and TL, we found a moderate positive relationship between the variables, indicating that students who reported having experienced SLEs were likely to exhibit longer TL. Again, coping plays a major role in mastering SLEs, as effective coping styles may compensate for the impact of experiencing multiple stressful events (Suzuki et al., 2018) and reduce the risk of physical and mental health problems (Veisani et al., 2021).

In summary, while previous studies generally found that particularly traumatic SLEs – experienced during childhood or recently during adulthood – are related to accelerated aging, as estimated by the length of telomeres, these events also may trigger coping mechanisms which, in turn, lead to low levels of self-reported burnout and longer telomeres among high school students. Therefore, it is advised to include coping styles as moderating or mediating variables in further analyses investigating the link between SLE burnout and TL.

In addition, the current study found that students with high BMI scores were more likely to experience school burnout in general. Although perceived stress has been linked to less awareness of healthy eating habits, less physical activity and more consumption of fast-food meals (Barrington et al., 2012), few studies have investigated the complex relationship between burnout and BMI among high school students. In this study, detailed analyses uncovered a more complex picture: Although underweight students reported slightly lower burnout compared to their normal and overweight peers, over the school year, underweight students exhibited a slight increase in their fatigue. Interestingly, burnout decreased among overweight individuals and stagnated among normal-weight students. Further studies that consider the link between periodic stressors, such as exam periods or school transitions, and BMI changes may provide insight into this complex mechanism. For example, Roberts et al. (2007) investigated female university students during exam periods and identified student groups that had gained weight (56%), lost weight (27%) and maintained stable weight (17%).

5. Conclusion

In this study we find a link between the length of high school students' telomeres and their self-reported burnout, suggesting that school-related burnout is connected to increased aging in a non-clinical sample of high school students. Although the finding cannot be interpreted in causal order, this is one of the first studies that investigate how stress-related physiological aging processes are linked to students' exhaustion, cynicism and feelings of inadequacy at school. However, if students believe they belong with their classmates and experience positive peer relationships, their burnout levels are much lower over the school year, and these students also exhibit longer telomeres. This, in turn, suggests that positive peer relationships supporting students' health are linked to slower aging.

However, as in all studies, there are limitations when interpreting the results. This study focuses on 82 high school students from urban areas in northeast Germany who participated in the study during one school year. Future researchers may wish to establish various measurement points to investigate causal relationships between biophysiological and self-reported data related to stress processes and include epidemiological variables, contextual variables such as class climate and school climate, the experience of traumatic events, et cetera, to consider confounders that may explain the process of telomerase/telomere shortening over time in more detail. Person-oriented analyses may provide insight into different student groups experiencing high and low burnout linked to their TL and relatedness with peers. Additionally, future studies may consider class and school contextual effects that allow for an investigation of burnout and relatedness to peers on the class or school level to design preventions and interventions on these levels.

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, upon a serious request.

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