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Maturation-dependent vulnerability of emotion regulation as a response to COVID-19 related stress in adolescents

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ABSTRACT

Background: The COVID-19 pandemic created unpredictable circumstances resulting in increased psychological strain. Here we investigate pandemic-related alterations in emotion regulation in adolescents assessed before and during the pandemic. We also take biological age into account in the response to the pandemic.
Methods: Mann-Whitney *U* tests were conducted to compare baseline data on the Difficulties in Emotion Regulation Scale (DERS) total scores of a pre-pandemic adolescent cohort ($n = 241$) with those obtained during the second wave of the pandemic ($n = 266$). We estimated biological age based on an ultrasonic boneage assessment procedure in a subgroup of males, including grammar school and vocational school students in the 9th and 10th grades, and analyzed their data independently.
Findings: There is a gender difference in the timing of vulnerability for pandemic-related stress in grammar school students: females are affected a year earlier than males. Vocational school male students mature faster than grammar school male students, and the timing of emotional vulnerability also precedes that of the grammar school students'.
Discussion: We interpret our findings within a developmental model suggesting that there might be a window of highest vulnerability in adolescent emotion regulation. The timing of the window is determined by both chronological and biological age, and it is different for females and males.
Application to practice: Defining the exact temporal windows of vulnerability for different adolescent cohorts allows for the timely integration of preventive actions into adolescent care to protect mental health during future chronic stressful situations.

Introduction

Besides the health and life threatening consequences, Covid-19 pandemic resulted in psychological distress and disturbance in the population, including children and adolescents. Studies on the psychological consequences of COVID-19 revealed an elevation in the perceived stress by adolescents (Mohler-Kuo et al., 2021; Nocentini et al., 2021; Zhang et al., 2020). Adolescents have been facing multiple adversaries since the start of the pandemic: with schools closed, their daily routines are disrupted; lack of personal contact with peers and other containment measures increase the prevalence of depressive and anxiety symptoms (Ellis et al., 2020; Zhou et al., 2020); attending school in-person once the lockdown is lifted is a challenge for some students, especially for those with mental health problems, such as depression (Lee, 2020). Effectively managing and attenuating emotions helps prevent being overwhelmed by negative emotions and promotes daily functioning of adolescents in challenging life situations (Bunford et al., 2015; Compas et al., 2017). Accordingly, under these extreme circumstances, the acquisition of age-appropriate emotion regulatory skills becomes one of the most important developmental tasks, and the maturity of the

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emotion processing brain circuitry in the background seems to be a particularly relevant aspect of healthy functioning (Ely et al., 2021; Zubovics et al., 2021).

Under regular circumstances, by the time youth reach adolescence, they have acquired differentiated and diversified emotion expression and regulation skills and are able to incorporate environmental feedback and accordingly modify their emotional expressions and regulatory responses (Bunford & Evans, 2017). On the other hand, completely adult-like emotion regulation cannot be expected since the biological changes of adolescence involve brain structures and systems implicated in emotion expression and regulation as well. There is, for example, a second surge of synaptogenesis (dendritic pruning and myelinogenesis), making the teenage years one of the most dynamic periods of human development (Arain et al., 2013; Lynch et al., 2020). Due to the considerable increases in sex hormones, neurocircuitry is still functionally and structurally unstable resulting in marked vulnerability (Patel et al., 2021). Extensive maturation of the basal ganglia and frontal lobe occurs during adolescence (Larsen & Luna, 2015; Sowell et al., 2004), with both the basal ganglia (Johnson et al., 2003) and the frontolimbic system (Banks et al., 2007) implicated in emotion generation and regulation. The prefrontal cortex remains under construction and there is a decrease in dopamine and serotonin levels ((Chugani et al., 1999; Wahlstrom et al., 2010), with these neurotransmitters also involved in emotion regulation (GABA: Thayer & Lane, 2000; dopamine: Laviolette, 2007; serotonin transporter gene: Canli & Lesch, 2007).

Moderated by age and context, there are gender differences in emotion regulation. Females employ both more adaptive (e.g., active coping and re-evaluation) and maladaptive (e.g., rumination and suppression) emotion regulatory strategies relative to males (Chaplin & Aldao, 2013), with this difference potentially reflecting the more general tendency of women being more aware of their emotions and more open to engaging with their emotions (Nolen-Hoeksema et al., 1999). Females tend to show better emotion regulation in young adolescence (age 9–12 years) but worse emotion regulation than males in middle adolescence (age 13–16 years, Zimmer-Gembeck & Skinner, 2011), highlighting a stage of increased emotional vulnerability for females during the middle adolescent years as also reflected in the frequency of anxiety-depressive problems during this developmental period (Muris et al., 2000).

There is a relative paucity of empirical research on the direct effect of acute, laboratory-induced stress on emotion regulation in children and adolescents (Langer et al., 2020), and the available data are mixed, with some evidence indicating that acute stress impairs emotion regulation (Raio et al., 2013; Raio & Phelps, 2015) and other findings suggesting improvements in emotion regulation (Kinner et al., 2014; Langer et al., 2020). Regarding the effects of acute, non-laboratory induced stress, findings on child and adolescent survivors of disasters, wars, and other acute events are also inconsistent regarding behavioral and emotional outcomes. Some data indicate an increase in behavioral (e.g., aggression) and emotional (e.g., anxiety, depression) problems (Marsee, 2008; Scott, Lapré, Marsee, & Weems, 2014) whereas others show no adverse effects on these outcomes (Durkin et al., 1993).

We would like to investigate the impact of Covid-19 pandemic events on emotion regulation, and to determine the modulatory effects of gender and/or maturational status on the timing and magnitude of the pandemic impact. In addition to assuming a gender difference in the timing of the strongest impact, we were also interested in those potential windows of vulnerability that are suggested by the abovementioned brain maturational processes (e.g., pruning, late frontolimbic maturation, neurotransmitter imbalance). We applying a chronological definition of adolescence which refers to the time between the beginning of puberty and adulthood. Considering the large individual differences in the onset of puberty, to ensure that most of our participants reach adolescence and be above 14 years of age (Farello et al., 2019), we focused on a cohort of students in the 9th and 10th grades We relied on grades instead of chronological age to assure that their previous cognitive and social experience was similar. In addition to age, we were also interested in contextual effects that might have an impact on maturation, therefore, we included both grammar school and vocational school students. On a subgroup of students, we also employed bone age measurements to assess their biological maturity levels and to see how biological age might be associated with emotion regulation development. A unique characteristic of our study is that we compare pre-pandemic and pandemic emotion regulation results within age-groups and genders.

Methods

Participants

To study the impact of the COVID-19 pandemic on emotion regulation of adolescents, we compared a Pre-Pandemic and a Pandemic cohort. Both cohorts included students from different grammar schools (GS) attending 9th or 10th grade and a vocational school (VS) attending 9th grade. In Hungary, secondary education includes three traditional types of schools focused on different academic levels: grammar schools, secondary vocational schools, and technical schools. Grammar schools offer general academic education and provides the students with a general qualification for higher education. Vocational schools offer vocational education as well as practical training and students acquire a qualification at the end of their studies. Descriptive statistics of the Pre-Pandemic and Pandemic cohorts are summarized in Table 1. in the Results section.

We involved 170 participants in the Pre-Pandemic GS groups, and 208 participants in the Pandemic GS groups, 71 participants in the Pre-Pandemic VS group, and 58 participants in the Pandemic VS group (see details in Table 1.). (The grammar school participants were from six different institutions. The average number of pupils in these schools is 675, and an average of 107 pupils attend 9th, and 86 pupils attend 10th grade.)

VS participants are from BGSZC Bánki Donát Vocational High School of Transport Engineering (total number of pupils is 840, 124 and 107 students attend 9th and 10th grades, respectively). The proportion of female students is <1% in this school. Due to the low proportion of females all our VS participants are males. It is important to note that VS and GS students have significant differences in economic, social and cultural background. VS students have a typically lower socio-economic background.

127 9th grader male students took part in bone age assessments (see details in Table 2.).

All of our subjects were Caucasian.

Tools

Questionnaire

Emotion regulation processes were measured by the validated Hungarian version (Kökönyei et al., 2014; Cronbach's alpha = 0.80) of the Difficulties in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004; Cronbach's alphas>0.80). The DERS is a comprehensive, 36-item, self-report measure that assesses the typical levels of emotion dysregulation overall and across the following dimensions: (1) nonacceptance of emotional responses, (2) difficulties engaging in goal-directed behaviors when distressed, (3) difficulties controlling impulsive behaviors, (4) lack of emotional awareness, (5) limited access to emotion regulation strategies perceived as effective, (6) lack of emotional clarity. The dimensions of DERS seem to correlate with psychological problems reflecting emotion dysregulation, specifically depression, anxiety, suicidal ideation, eating disorders, alcohol and drug use, ADHD, and social impairment (Bunford et al., 2015, 2018; Weinberg & Klonsky, 2009). It has been validated on adolescents (11–17 years of age) and had a good internal consistency (Bunford et al., 2015; Neumann et al., 2010).

Table 1
Mean ages and DERS results of the subgroups. Mann-Whitney *U* test results of DERS total scores for Pre-pandemic and Pandemic subgroups. Gr = Grade, Mdn = median, GS = Grammar School, VS=Vocational School (*$p < 0.05 >$ **$p < 0.01$).

Group	Gr	Subgroup	N	Mean age (in years)	SD	Mean DERS total	SD	Mdn DERS total	Mean Rank	Sum of Ranks	U	P
GS *female*	9th	Pre-Pandemic	63	14.82	0.49	80.39	19.48	78	53.98	3401	1385	**0.01***
		Pandemic	59	15.16	0.35	90.76	24.18	85	69.53	4102		
	10th	Pre-Pandemic	58	15.76	0.43	83.58	22.12	81.5	56.54	3279	1505	0.85
		Pandemic	53	16.16	0.44	83.54	24.88	80	55.41	2936		
GS *male*	9th	Pre-Pandemic	22	14.94	0.65	80.00	14.61	80.5	39.00	858	561	0.79
		Pandemic	53	15.39	0.42	79.35	16.52	76	37.58	1992		
	10th	Pre-Pandemic	27	15.96	0.43	72.96	17.50	70	28.83	778	400	**0.03***
		Pandemic	43	16.55	0.45	84.41	23.07	80	39.69	1706		
VS *male*	9th	Pre-Pandemic	71	15.49	0.55	67.40	17.10	64	49.40	3507	951	**0.00****
		Pandemic	58	15.47	0.45	89.41	25.50	84.5	84.09	4877		

Bone age assessment

Skeletal maturity (bone age) was assessed with an ultrasonic device (Sunlight BonAge, Sunlight Medical Ltd., Tel Aviv, Israel). Bone age measurements were performed on the left hand and wrist region of the subjects. The same experimenter performed all the bone age assessments with the same device. The device estimates bone age (in years and months) by measuring the speed of sound and the distance between the transducers, using algorithms based on gender and ethnicity (see the detailed description of the method in Kovács et al., 2022).

Procedure

Administering the DERS: Pre-pandemic dataset

The Pre-pandemic GS dataset, which includes both female and male participants, was derived from two databases of different Hungarian adolescent research projects. The first database was completed in 2016 (a previous analysis on these data, not related to the current manuscript, has been published in Kriston & Pikó, 2018). The questionnaires were administered in a paper-and-pencil format in schools.

The other database, provided by the Adolescent Developmental and Translational Neuroscience Research Group, contains data from 2019 and early 2020 (January and February), from both male and female participants. Data collection was administered in the research center via the Qualtrics software, Version 2020 (Qualtrics, Provo, UT).

VS males have been participating in a longitudinal investigation of the Adolescent Development Research Group supported by the Hungarian Academy of Sciences and Pázmány Péter Catholic University. We recruited participants in collaboration with the school management, and participants were given credits in their school for the participation. The Pre-Pandemic assessment took place in November 2019. Students completed the questionnaire in the computer lab of their school using the PsyToolkit software (Stoet, 2010, 2017).

Administering the DERS: Pandemic dataset

Data collection for the Pandemic GS cohort was carried out between November 2020 and February 2021, during the second wave of COVID-19 in Hungary, when the levels of new cases and COVID-related deaths were among the highest in Europe. During this time, Hungary implemented strict pandemic-related restrictions, which included national quarantine with the closure of schools and shops (except for daily essentials), movie theatres, restaurants, and a curfew after 8 p.m. All gatherings were forbidden, private and family events could be held for up to 10 people. In a convenience sampling procedure, GS students were invited to join the study via an invitation e-mail sent out by either the school psychologist or the teachers. We asked 9th and 10th grade students) to simply fill out the online questionnaire, and we did not apply any exclusion criteria.

GS students were offered extra accountable hours in their volunteer work projects, which are mandatory in Hungarian secondary schools, for participating in the research. Due to the epidemiological situation and the lockdown, the data were gathered online via the Qualtrics software.

The VS male students in the Pandemic subgroup participated between November 2020 and February 2021. Similarly to the GS subjects, the data were gathered online using Qualtrics.

Table 2
Means and standard deviations of chronological and bone age for the two male cohorts.

Group	N	Chron. age (mean in y)	SD	Bone age (mean in y)	SD
GS *male* 9th Grade	31	15.33	0.46	15.50	1.49
VS *male* 9th Grade	96	15.40	0.57	16.08	1.19

Assessing skeletal maturation

Ultrasonic bone age estimations were carried out before (November 2020) and after the lockdowns (April 2021). The procedure took place either at the respective schools of the participants or at the Research Center for Sport Physiology at the University of Physical Education, Budapest.

Ethics

The PPCU Institute of Psychology Committee for Research in Psychology (reference number 2020_30) and the Hungarian United Ethical Review Committee for Research in Psychology (reference number 2017/84) approved the study. The pre-pandemic grammar school data collection by the Adolescent Developmental and Translational Neuroscience Research Group was approved by the National Institute of Pharmacy and Nutrition (OGYÉI/17089–8/2019).

Written informed consent was obtained from all subjects and their parents.

Results

Pre-Pandemic vs. Pandemic DERS scores

Mean DERS total score of subgroups is shown in Fig. 1. We compared Pre-pandemic and Pandemic DERS total scores in the groups of 9th and 10th graders. The distribution of total DERS scores was abnormal (Shapiro–Wilk normality test >0.00). Mann-Whitney *U* tests were conducted to determine if the differences between the Pre-Pandemic and Pandemic subgroups regarding the DERS total score were significant. DERS results are summarized in Table 1.

We found a significantly higher DERS median score in the subgroup of 9th grader Pandemic GS females than in the Pre-Pandemic subgroup. In contrast, we did not find a significant difference between the Pandemic and Pre-Pandemic subgroups of GS males. In the 9th grader VS male group, the median of the Pandemic subgroup was higher as

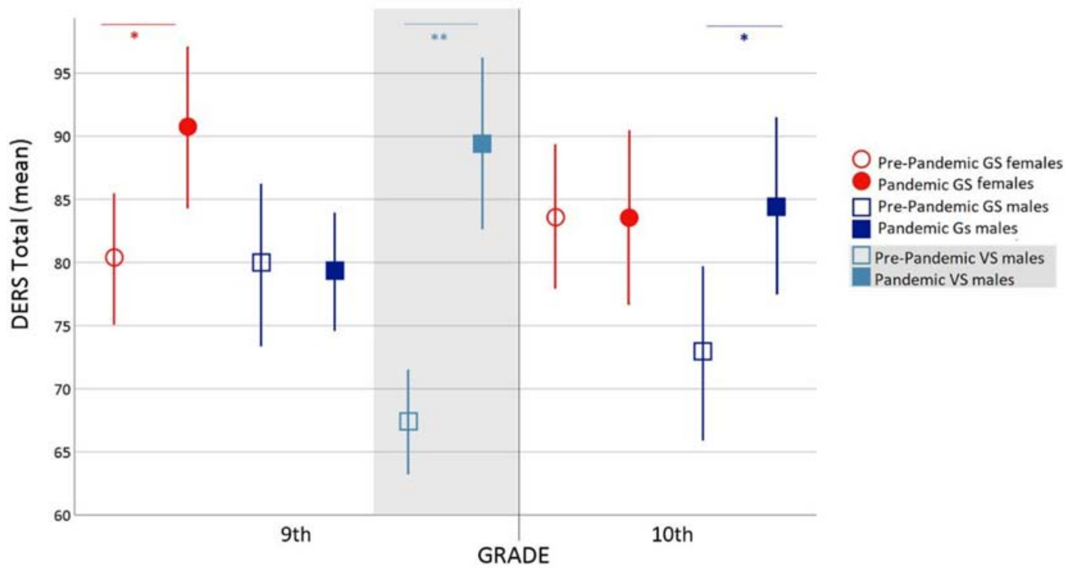

Fig. 1. DERS total score means of the Pre-Pandemic (empty symbols) and Pandemic (solid symbols) subgroups. Error bars indicate 2SE. Asterisks indicate significant difference in the Mann-Whitney U test (*p < 0.05; **p < 0.01). In the Grammar School (GS) female population, the 9th grader Pandemic subgroup has higher DERS total scores as compared to Pre-Pandemic, while there is no difference between the two subgroups in 10th grade. This pattern of difference was the reverse in the GS male population: there is no significant difference between the Pre-Pandemic and Pandemic subgroups in 9th grade, whereas a significant difference occurred between the 10th grader subgroups. The difference between the subgroups of the 9th grader Vocational School (VS) males was similar to the 9th grader GS female pattern: the Pandemic subgroup showed significantly higher DERS total scores than the Pre-Pandemic.

compared to that of the Pre-Pandemic subgroup (similarly to the 9th grader GS female group).

The reverse of the above-described pattern occurred in the groups of 10th graders. The Pandemic subgroup of GS females did not show a significant change in the medians of the total DERS scores as compared to that of the Pre-pandemic subgroup. In contrast, the 10th grader GS male Pandemic subgroup showed a significant increase in the total DERS score median as compared to that of the Pre-Pandemic subgroup.

To compare the GS and VS males on chronological and bone age variables, a univariate analysis of variance (ANOVA) was carried out. ANOVA revealed no difference between samples on chronological age ($F(1,125) = 0.38$, $p = 0.54$). Conversely, bone age of VS males was significantly higher than that of GS males ($F(1,125) = 4.81$, $p = 0.03$). We ran paired sample *t*-tests to determine whether chronological age and bone age is dissociated within these two groups of males. We did not find a significant difference in these variables in GS males ($t(30) = -0.675, p = 0.505$). In contrast, there was a substantial difference in the VS male group between chronological and bone age ($t(95) = -5.29$ $p < 0.00$), bone age being higher by an average of 0.67 years (cc. 8 months) than chronological age.

Discussion

Interestingly, while emotion regulation (as assessed by the total score on DERS) in 9th grader GS females of the Pandemic cohort seemed to be significantly above that of the Pre-Pandemic subgroup (indicating more regulation problems), 10th grader Pre-Pandemic females provided very similar scores as those in the Pandemic group. Males going to GS had the opposite pattern: 9th graders were not affected by the Pandemic in emotion regulation according to their DERS scores, while those in the 10th grade Pandemic group scored significantly above (indicating more emotion regulation problems) the Pre-Pandemic group. Gender difference in the timing of puberty is an acknowledged fact, females typically outstrip males by one and a half years (Farello et al., 2019; Hoyt et al., 2020). This pattern of results, therefore, not only points to a gender difference in the timing of vulnerability but indicates a "window" of vulnerability in both genders: females being very sensitive to the stress due to the pandemic circumstances in the 9th grade, and more stable after that; males being unaffected in the 9th grade, and vulnerable a year later.

We were also particularly interested in those potential windows of vulnerability that are suggested by the earlier mentioned brain maturational processes, e.g., cortical pruning, late frontolimbic maturation (Hwang et al., 2016; Marek et al., 2018; Yang & Tseng, 2021) and neurotransmitter imbalance (for a review see Pitzer, 2019). To this end, we assessed the biological age of both GS and VS adolescent males assuming that biological age as assessed by bone age will be in correlation with brain maturation (Kovács et al., 2022). We found that VS males are significantly more mature than GS males. This is in good agreement with a recent finding by Oelkers et al. (2020) who demonstrated that earlier pubertal onset is more likely in the group of lower socioeconomic status schoolboys as compared to peers with higher socioeconomic status.

9th grader VS males showed a decline in emotional regulation during the pandemic similarly to GS females, therefore, these earlier maturing males show an earlier window of vulnerability as compared to GS males.

As in the case of any developmental event, changes of emotion regulation skills will reach the point of fastest change in between the levels of childlike and adultlike emotion regulation. Since we are not assuming stepwise development, a sigmoid function is a good approximation of that, and the inflection point of this curve characterizes the point of fastest change (Burchinal & Appelbaum, 1991). The main idea of our hypothesis is that around the point of fastest change, there is a window of heightened vulnerability as well (Charmandari et al., 2003; Larsen & Luna, 2018; Semple et al., 2013). As we detailed in the introduction, emotion regulation is dependent on the maturation of brain structures and systems as well as on age, gender, and contextual factors. These curves, drawn hypothetically in Fig. 2. for the three cohorts that we studied, very clearly show the relevance of a multifactorial view of development that is not simply dependent on chronological age.

Practice implications

The practical message of our results combined with the theoretical scenario described in Fig. 2. is that adolescence is not simply a period of increased vulnerability in the emotional domain, but it is a

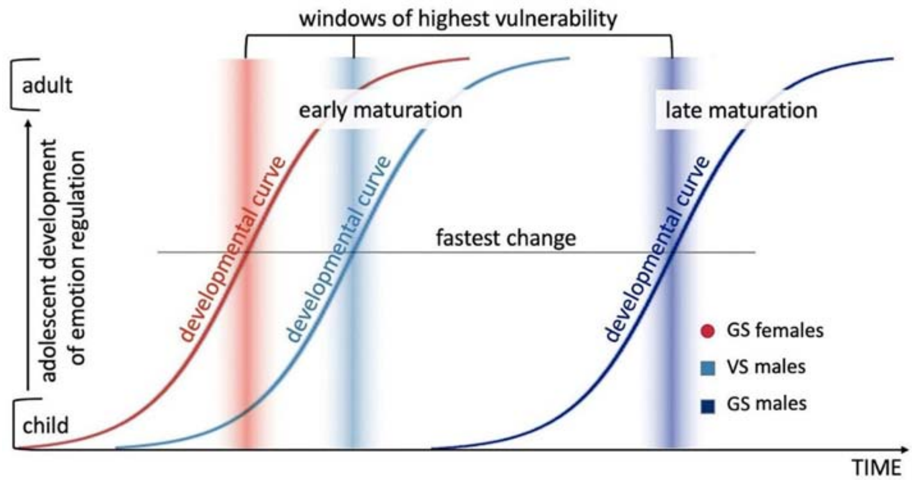

Fig. 2. Schematic representation of the adolescent development of emotional regulation. The hypothetical functions each represent the adolescent course of development between the end of childhood and adulthood. The fastest developmental change occurs at the inflection points of these curves. Assuming similar developmental speed (slope of the curve) in earlier and later maturing groups, the inflection points define the centers of windows of highest vulnerability where development and plasticity are fastest, and vulnerability is greatest. (GS = grammar school, VS = vocational school.)

fine-grained developmental process, with potentially narrow windows for heightened sensitivity and vulnerability. A number of psychopathologies first emerge or manifest in adolescence, or show a dramatic increase in terms of prevalence during adolescence (Giedd et al., 2008). More accurate exploration of the precise timing of these vulnerability windows across the adolescent population would allow health and education professionals to properly time interventions and help in the most critical periods to achieve the best impact. For example, our results suggest that while Caucasian GS females and VS males may need the most intensive attention and help in the 9th grade, Caucasian GS males will need it a grade later. However, we emphasize that the individual variability in timing is very extensive, there are large individual differences in the onset and speed of puberty (Dorn & Biro, 2011; Farello et al., 2019). Alterations in the timing of puberty with respect to peers of the same age has a potential risk of receiving less attention and help at the right time. Several potentially detrimental impacts of early (Mendle et al., 2007; Mendle & Ferrero, 2012) and late puberty (Graber, 2013; Negriff & Susman, 2011) have been identified in the literature, and lifelong negative impacts of these conditions have been demonstrated as well (Graber et al., 2004; Natsuaki et al., 2009). We have shown that the timing of pubertal maturation is related to the window of heightened vulnerability in emotional regulation, therefore intensive attention in pediatric care should be given accordingly, taking the altered maturational speed into account.

Limitations

Finally, a number of potential limitations need to be considered. The most relevant constraint is that exclusively Caucasian students participated in the current study, and the findings on the timing of vulnerability windows may not be transferable to other ethnic groups (see e.g. Herman-Giddens, 2006; Seaton & Carter, 2019). Our study was also limited in age-range. By expanding the age.-range, it might be interesting to see whether the one-year vulnerability window extends to earlier or later grades. We hope, on the other hand, that the COVID-19 pandemic will not provide the grounds for such an investigation because - with the vaccinations introduced widely - the need for constraining the youth will subside.

Conclusion

According to our original purpose, we were able to assess the immediate impact of the current pandemic events on emotion regulation in adolescents. We found a gender difference in the timing of the strongest negative impact; females being affected about a year earlier than males in the GS population. However, it seems that earlier VS maturing males are closer in terms of emotional maturity to GS females than to GS males. This is a novel and very surprising finding as similar comparisons have not been made before. The results might corroborate our hypothesis with respect to the maturational effects in emotional regulation that should determine when a particular individual is most sensitive to stressful events.

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