Real-time psychophysiological and writing correlates of expressive writing

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Abstract

Concealing memories and emotions associated with a traumatic event seems to have negative effects on health. Re-enacting those events through writing is an opportunity to disclose such memories and emotions, and likely for emotion regulation. To study this, 57 university students were randomly assigned to one of two groups. They either completed an expressive writing or a neutral writing task. Real-time writing and psychophysiological data were recorded throughout the experiment to examine writing dynamics associated with emotion regulation and its psychophysiological correlates (EDA and ECG measures). Results showed that the expressive group paused for longer than the control group denoting a positive and medium effect size ($\eta_p^2 = .10$). Furthermore, during and after writing the expressive group showed a higher LF/ HF ratio than the control group, evidencing a positive and large effect size ($\eta_p^2 = .22$). These real-time findings are interpreted as signs of emotion regulation happening during writing.

Keywords: emotion regulation, expressive writing, real-time writing measures, electrodermal activity, heart rate variability

¹ The data file can be accessed online at: <https://osf.io/gje24/>

Real-time psychophysiological and writing correlates of expressive writing

Going through a personal trauma may induce intense and long-lasting emotional effects, frequently associated with cognitive disruption, including rumination and attempts to understand what happened and why (Pennebaker & Chung, 2011). Acknowledging the emotions associated with traumatic events seems to be an important step to cope with the situation (Seeley, Yanez, Stanton, & Hoyt, 2016). To help individuals make sense of challenging experiences, Pennebaker and Beall (1986) devised the expressive writing paradigm. This writing exercise allows people to deal with the emotions associated with traumatic memories. Numerous studies have shown the benefits of writing about traumatic events, including improved well-being and physiological functioning, and reduced symptoms in depressed and cancer patients (e.g., Frattaroli, 2006; Low, Stanton, & Danoff-Burg, 2006; Seih, Chung, & Pennebaker, 2011).

The expressive writing paradigm promotes disclosure of emotional content, likely initiating a meaning making process surrounding the stressful life event (Bourassa, Allen, Mehl, & Sbarra, 2017). This emotional disclosure typically leads to psychophysiological arousal, associated with short-term distress and negative mood (McGuire, Greenberg & Gevirtz, 2005; Pennebaker, Kiecolt-Glaser, & Glaser, 1988). The negative affective arousal is the result of increased emotional expression, but ultimately outweighed by various health benefits (Frattaroli, 2006; Smyth, 1998).

Emotion regulation refers to emotional responses adequate to the context in which emotions occur, both in terms of timing and magnitude, thus facilitating adaptive emotional responses (Appelhans & Luecken, 2006). Strategies have to be put in place to achieve a desired emotional regulation goal and outcome (Gross, 2014). For instance, the goal to decrease negative emotions about an event activates strategies (e.g., escaping) that might lead to the desired outcome. In an influential model, Gross (2014) identified five possible

regulation strategies: (1) situation selection, by taking actions that determine the likelihood of ending up in a situation that gives rise to the desired emotions, such as selecting a traumatic event to write about; (2) situation modification, or changing the emotional impact of a situation; (3) attentional deployment, by directing attention to change an emotion (this particular type of regulation is used when it is not possible to modify a situation); (4) cognitive change, altering the emotional significance of an event (one common form of cognitive change is reappraisal, i.e., thinking in a way that alters the emotional response); and, finally, (5) response modulation, by influencing experiential, behavioral or physiological components of the emotional response. Perhaps the most common form of response modulation is suppression, inhibiting negative or positive expression. Both reappraisal and suppression are commonly used during emotion regulation (Gross, 2014). During expressive writing (EW), possibly all emotion regulation strategies might be put in place.

Concerned with promoting constructive coping after a trauma, Allen (2005) suggested that survivors of trauma should press a “pause button”. The grounding behind this metaphor is that during response modulation an individual might block a dominant response to allow the reappraisal of the situation thus better adapting to the current context. Therefore, Allen suggested that in the presence of an unbearable emotional state, two reactions are possible: (1) self-destructive behaviour or (2) pausing and mentalizing. If the reaction is pausing and mentalizing, the result should be constructive coping.

Perhaps expressive writing could be a privileged method for pausing and mentalizing. Curiously, writing logging techniques have revealed that writing is dominated by pauses and written language bursts (see Lindgren & Sullivan, 2019). Pauses are periods where writing was interrupted, typically for more than 2 s. Bursts are instances of activity between two pauses, in which at least one word was written (Alves & Limpo, 2015; Hayes & Chenoweth, 2007). Pauses are commonly interpreted as resulting from the cognitive load brought on by

the demands of the writing task: the longer the pause, the heavier the load (Schilperoord, 2002). When writers encounter difficulties brought on by the demands of the task, they typically adjust their writing speed by decreasing transcription time and/or increasing pause duration (Fayol, 1999). Fayol (1999) further noticed that two mechanisms can be used to reduce this load: (1) automaticity (faster and more effortless); and (2) task combination strategies, for example, by switching attention, allowing the allocation of cognitive resources according to task demands.

Emotion regulation can be observed across all modalities of emotional responding, including behavior, thoughts, feelings (Koole, 2009), and physiological arousal (Appelhans & Luecken, 2006; Gross, 2014; Koole, 2009) of the autonomous nervous system (ANS). The two branches of the ANS - the parasympathetic (PNS) and sympathetic nervous system (SNS) - operate on different time scales to adapt to situational challenges (Shaffer & Ginsberg, 2017). The ANS plays a critical role in regulating homeostasis (minimizing damage and maximizing functioning), and helping to deal with significant challenges (Levenson, 2014). Thus, the balance between PNS and SNS allows physiological and emotional states to meet situational demands (Appelhans & Luecken, 2006). To measure ANS dynamics it is important to observe its functional fluctuations across an emotional experience (Kahle, Miller, Lopez, & Hastings, 2016). Two widely used measures of ANS are electrodermal activity (EDA) - the variation of the electrical properties of the skin secondary to sweat secretion – and the heart rate, through electrocardiography (ECG; Dawson, Schell, & Filion, 2007). Measures of EDA and ECG represent aspects of electrodermal and cardiovascular processes which are important in emotion (Levenson, 2014). The combination of both allows measuring ANS activity in detail, since EDA reflects mostly SNS activity (Dawson et al., 2007), while ECG reflects the continuous interplay between PNS and SNS activity (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012), particularly through heart rate

variability (HRV) measures (Fookien, 2017). This interplay between the PNS (vagal) and SNS has a dual influence on HR, with the former having an inhibitory influence on HR, and the latter an excitatory influence on HR. Thus, an increase in HR might imply PNS inhibition (vagal withdrawal), SNS activation or both (Appelhans & Luecken, 2006; Berntson, Quigley, & Lozano, 2007). During a situation that necessitates emotion regulation, vagal withdrawal works to support an increase in heart rate and increased attention to the environment, employing the behaviors necessary to deal with challenging situations (Perry, Calkins, & Bell, 2016).

HRV analysis is an important addition to the study of ANS since it allows for the concurrent observation of both PNS and SNS activity. Four common HRV measures are the Standard Deviation of Normal to Normal (N-N) intervals (SDNN), the Root Mean Square of the Successive N-N interval Differences (RMSSD; Camm et al., 1996), High Frequency (HF), and the Low Frequency/High Frequency ratio (LF/ HF ratio). SDNN is a measure that reflects overall autonomic modulation regardless of SNS or PNS dominance (Pichot, Roche, Celle, Barthélémy, & Chouchou, 2016). RMSSD reflects parasympathetically mediated HRV (Camm et al., 1996). The high-frequency band (HF) is thought to represent respiratory sinus arrhythmia (RSA), which is a measure of respiratory influences on autonomic control (Berntson et al, 2007). Since respiratory activity in HR is driven by the PNS, RSA is considered to reflect parasympathetic control (Berntson et al, 2007). Finally, LF/HF ratio estimates the ratio between SNS and PNS activation, and consequently sympathovagal balance (Camm et al., 1996; Malliani, 2000). This is so since variability in the LF band is driven by both branches of the ANS (Berntson et al, 2007). Many have interpreted an increase in LF/HF ratio as indicative of increased SNS activity (Berntson et al, 2007). However, since there is a presence of vagal activity in the LF band, it has been suggested that LF/HF ratio should be interpreted as a conjunction of LF and HF (Camm et al., 1996;

Friedman & Thayer, 1998; Malliani, 2000; Stein, Rottman, Hall, & Kleiger, 1996). During self-regulation, the activity of the PNS and SNS is in dynamic balance, with patterns of organized variability in HR, rather than static levels, being preserved in the face of changing environmental demands (Friedman & Thayer, 1998). Therefore, higher HRV is usually associated with the ability to appropriately react to environmental challenges and better emotion regulation (Appelhans & Luecken, 2006).

Previous studies that have addressed measures of ANS suggest that both PNS and SNS increase during emotional tasks. EDA, particularly skin conductance (SC), has been shown to increase both during neutral and expressive writing (McGuire et al., 2005), suggesting that writing increases SNS activity regardless of writing topic, in experimental settings. HR has also been found to increase during expressive writing (Sloan, Marx, Epstein & Lexington, 2007), particularly when participants were trained to focus on their response a traumatic event (Konig, Eonta, Dyal, & Vrana, 2014).

It has been commonly accepted that higher HRV is linked with better emotion regulation (see Appelhans & Luecken, 2006; Mather & Thayer, 2018). Both SDNN (Seeley et al., 2016) and RSA (Bourassa et al., 2017; Sheerin, Konig, Eonta, & Vrana, 2018), have been found to increase after completing an expressive writing task, more specifically when participants wrote coherent narratives (Bourassa et al., 2017). Furthermore, those with higher RSA at baseline, benefit the most from expressive writing (Sloan & Epstein, 2005). Finally, a study by Kim et al. (2019) using biofeedback, showed that increases in LF/HF activity are associated with greater emotional control.

In this study, we set out to study real-time writing dynamics and ANS activity during expressive writing. We designed a real-time study of expressive writing in which participants were randomly assigned to one of two groups: an expressive group, writing about a traumatic or stressful life experience, and a control group, writing about daily routine. We

simultaneously recorded writing and psychophysiological data. Participants in each group were compared on all collected measures. As writing about a trauma is likely to have higher cognitive and emotional load than writing about a daily routine, we anticipated pauses to be longer in the expressive group. We expected participants in both groups to show increased SNS activation from baseline, since both departed from rest to complete a writing task. Due to the heavier load of writing about a traumatic or stressful life event, we expected the expressive group to show greater SNS (SC) activation when faced with the task. Finally, we expected the expressive writing group to show higher PNS (RMSSD; HF) activation and sympathovagal balance (LF/HF ratio) than the control group, during writing and post-writing, since both are thought to index emotion regulation.

Method

Participants

Participants were 57 psychology undergraduates, recruited and randomly assigned to one of two groups: the expressive group (EG; $n = 29$; range = 17-51 years, $M = 20.1$, $SD = 6.50$; 16 % male) or the control group (CG; $n = 28$; range = 18-39 years, $M = 19.9$, $SD = 4.54$; 21.7 % male). Participants received course-credits for their participation. Estimates of sample size were deemed appropriate by G*Power 3.1 (Faul, Erdfelder, Buchner & Lang, 2009), as a sample size of 56 participants was estimated to achieve .90 power ($f = .30$).

Materials

Positive and negative affect schedule (PANAS). PANAS (Watson, Clark, & Tellegen, 1988; Portuguese version by Galinha & Pais-Ribeiro, 2005) was used to measure mood before and after writing. PANAS has two 10-item mood scales, one positive and one negative. The scales were shown to be internally consistent (positive affect: $\alpha = .86$; negative affect: $\alpha = .89$) and not significantly correlated. Each PANAS item is replied using a 5-point

Likert scale, scoring is done by adding the values for the positive and the negative affect scale (min = 10; max = 50).

HandSpy. We used HandSpy 2.3 (Alves, Leal & Limpo, 2019) and Neo smartpens M1 (Neo Smartpen Inc, Scotts Valley, CA) to record the written texts, and associated writing behaviours. HandSpy was used to measure burst length (number of words), pause duration (ms), number of pauses (pauses threshold was set at 2 s), fluency (words per minute) and burst speed (mm/s).

Writing topics. Participants in the control group wrote about their daily routine, and participants in the expressive group wrote about the most traumatic experience of their life. Participants in the expressive group were free to disclose on any traumatic or stressful life event of their choice. Participants were not selected based on having previously experienced a traumatic or stressful life experience, but every participant had an event to report. This was expected since the prevalence of traumatic experiences is thought to be high in the general population (89.7%; Kilpatrick et al., 2013), and among undergraduates (85%, Frazier et al., 2009). Participants wrote about a variety of experiences, such as domestic violence, problems in romantic relationships, parental divorce, death or a life-threatening moment, bullying or hazing, extreme anxiety, sexual assault, and experience of psychopathology.

EDA and HRV recordings. Raw EDA and HRV (through ECG) were recorded using, respectively, the Bionomadix BN-PPGED-T and BN-RSPEC-T amplifiers, together with the BN-LOGGER, all from Biopac (Biopac Systems, Goleta, CA). Signals were recorded at a sampling rate of 1000 Hz and filtered using a band pass of 0.5 –35 Hz. The EDA measure used for analysis was the mean skin conductance level (the mean EDA value computed across all stimuli; see Dawson et al., 2007). This measure of EDA was chosen as emotion states could be occurring throughout the writing exercise. To clean and divide the raw EDA and ECG data we used Biopac Acqknowledge 5.0. The data was divided into five-

minute segments – baseline (B), writing 1 (W1), writing 2 (W2), writing 3 (W3) and post-writing (PW). Baseline data was collected for 10 minutes, but only the last five minutes were used for the analysis. Baseline was collected at rest to correct for the effects of the writing task on physiological activation (Fichel, Muth, & Hoover, 2007). EDA data from two participants and ECG data from five participants were excluded from psychophysiological analysis due to artifacts (Pichot et al., 2016). HRVanalysis 1.1 (Pichot et al., 2016) was used to calculate the measures of HRV (SDNN, RMSSD, HF; LF/HF). Raw ECG was exported from Biopac Acqknowledge 5.0 to HRVanalysis 1.1, where R-R intervals were automatically detected from the raw ECG. From the R-R intervals, the HRV measures were calculated using wavelet transform, through local linear analysis (Pichot et al., 2016).

Procedure

Participants started by signing an informed consent and completing the PANAS scale. To record EDA two electrodes were placed at the medial phalanges of the non-dominant hand. To record ECG, three electrodes were placed according to a lead III configuration (see Berntson et al., 2007, p.184). Following Pennebaker (2000), great care went to creating strict conditions of trustworthiness and confidentiality for collecting the written texts. Participants wrote in a booth and received their confidential instructions in a closed envelope, unbeknownst to the experimenter. As the experimenters were blind to the experimental condition of the participants, random assignment was done by the second author, who shuffled the envelopes containing the confidential instructions. Participants were asked to “sit in a comfortable position, relax, stay calm, with as little movement as possible for 10 minutes” (baseline), after which they wrote for 15 minutes. The expressive group was instructed according to a modified version of Pennebaker and Beall’s (1986) original expressive writing instructions, as follows: “For the next 15 minutes, I would like you to

write about your very deepest thoughts and feelings about the most traumatic experience of your entire life. In your writing, I would like you to really let go and explore your very deepest emotions and thoughts. You may tie this event to your past, your present, or your future, or to who you have been, who you would like to be, or who you are now. We guarantee anonymity and confidentiality of everything you write. Don't worry about writing the text correctly. Don't worry about spelling mistakes, sentence structure and grammar. The only important rule is that, from the moment you start writing, you keep writing until you are told the time is up". The control group was given the same instructions, replacing traumatic event with daily routine, and removing any mention to emotions. Upon writing, participants completed PANAS again, and then were asked to stay comfortable and relaxed, for five minutes more. Psychophysiological data was recorded from baseline to the end of post-writing. All participants were thanked and debriefed at the end of the experiment.

Data Analysis

The control and expressive group were compared on PANAS scores, real-time writing measures, mean SC, HR, SDNN, RMSSD, HF and LF/HF ratio. Outliers were identified through boxplot analysis based on the interquartile range ($1.5 \times \text{IQR}$) and removed from the database by assigning missing values to the outlier variables (3.7% of all data)¹, as decided a priori. Pre and Post-writing PANAS scores of the two groups were analysed with a mixed-design ANOVA, with the α threshold set at .05. Group differences were tested using independent mixed-design ANOVA conducted for the real-time writing measures (burst length, pause duration, number of pauses, fluency and burst speed), with *group* (EG, CG) as between-subjects factor. Mixed-design ANCOVA were independently performed for EDA (mean SC), HR and each measure of HRV (SDNN, RMSSD, HF, LF/HF), with *group* as between-subjects factor, *time-period* (W1, W2, W3, PW) as within-subjects factor, and *baseline* values of EDA, HR and HRV as covariates. As there is a risk of incurring on type I

¹ The data file can be accessed online at: <https://osf.io/gje24/>

errors (false positives) when testing more than one hypothesis (Chen, Feng, & Yi, 2017), all significant results reported below were corrected for multiple comparisons using the False Discovery Rate method (FDR; Benjamini & Hochberg, 1995). In this study, all results remained significant after the FDR correction.

Results

Descriptive statistics

Table 1 displays descriptive statistics, as well as F and p values, for PANAS, real-time writing measures, SC, HR, SDNN, RMSSD, HF, and LF/HF ratio.

Measures	Expressive		Control		<i>F</i>	<i>p</i>
	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>		
PositiveAffect:						
Baseline	29	26.24 (6.89)	28	25.61 (5.97)	0.13	.72
Post-Writing	29	22.76 (8.80)	28	28.86 (6.60)	8.71	.005
NegativeAffect						
Baseline	29	13.71 (3.68)	28	13.71 (3.63)	0.00	.96
Post-Writing	29	21.71 (9.30)	28	11.25 (1.65)	34.39	.000
Burst length (words)	29	9.93 (3.61)	28	10.20 (3.83)	0.07	.79
Pause duration (ms)	29	4331.26 (902.79)	28	3788.63 (753.68)	5.58	.022
Number of pauses	29	34.29 (9.80)	28	32.57 (10.34)	0.41	.53
Fluency (wpm)	29	19.03 (4.39)	28	21.01 (4.56)	2.81	.10
Burst speed (mm/s)	29	35.20 (11.19)	28	33.63 (9.39)	0.32	.58
Skin Conductance						
Baseline	28	8.01 (3.36)	27	8.20 (4.79)	0.03	.87
Writing segment 1	28	9.41 (4.14)	27	8.67 (4.21)	1.57	.22
Writing segment 2	28	8.47 (4.37)	27	7.62 (3.90)	0.30	.59
Writing segment 3	28	8.53 (4.58)	27	8.23 (4.59)	0.00	.98
Post-writing	28	9.31 (3.61)	27	9.50 (4.62)	0.00	.97
Heart-rate						
Baseline	26	83.85 (12.40)	26	88.10 (11.35)	1.51	.23
Writing segment 1	26	86.42 (10.35)	26	88.29 (10.35)	0.04	.84
Writing segment 2	26	86.17 (11.56)	26	91.66 (12.02)	0.64	.43
Writing segment 3	26	85.57 (11.04)	26	89.07 (9.62)	1.63	.21
Post-writing	26	85.23 (10.24)	26	86.77 (9.34)	0.00	.96
SDNN						
Baseline	26	61.51 (23.70)	26	65.18 (25.95)	0.25	.62
Writing segment 1	26	58.58 (24.89)	26	51.31 (20.90)	1.96	.18
Writing segment 2	26	46.80 (13.47)	26	44.91 (14.67)	0.47	.50
Writing segment 3	26	52.80 (16.27)	26	49.80 (19.59)	2.52	.13
Post-writing	26	81.64 (27.45)	26	76.06 (16.94)	2.10	.16
RMSSD						
Baseline	26	39.77 (16.52)	26	40.31 (18.83)	0.01	.92
Writing segment 1	26	37.84 (24.54)	26	33.87 (11.12)	0.00	.97
Writing segment 2	26	33.08 (14.77)	26	39.54 (21.53)	0.25	.63
Writing segment 3	26	33.60 (12.34)	26	33.88 (12.96)	5.43	.029
Post-writing	26	41.61 (15.85)	26	41.54 (13.35)	0.04	.84
HF						
Baseline	26	610.01 (475.59)	26	549.19 (522.52)	0.17	.68
Writing segment 1	26	470.88 (429.55)	26	346.69 (226.81)	1.49	.23
Writing segment 2	26	404.20 (313.74)	26	279.88 (168.41)	2.35	.14
Writing segment 3	26	348.85 (183.39)	26	318.80 (289.04)	5.71	.026
Post-writing	26	642.82 (473.48)	26	539.32 (324.14)	0.12	.73
LF/HF						
Baseline	26	2.49 (1.72)	26	2.62 (1.73)	0.07	.80
Writing segment 1	26	1.74 (.87)	26	2.02 (1.64)	1.32	.26
Writing segment 2	26	2.54 (1.41)	26	2.02 (1.14)	1.57	.23
Writing segment 3	26	2.60 (1.15)	26	2.43 (1.92)	5.86	.025
Post-writing	26	2.55 (1.06)	26	2.33 (1.28)	6.84	.016

Table 1

Descriptive statistics for collected measures and analysis of variance for between groups comparisons.

Manipulation check: effects of expressive writing on affect

A mixed-design ANOVA revealed an interaction effect of group $\times$ time-period (pre; post-writing) both on positive affect, $F(1, 55) = 14.9, p < .001, \eta_p^2 = .21$, and negative affect, $F(1, 54) = 33.2, p < .001, \eta_p^2 = .38$, and a main effect for *time-period*, $F(1, 54) = 9.3, p = .004, \eta_p^2 = .15$. There was also a main effect of *group* on negative affect, $F(1, 54) = 22.0, p < .001, \eta_p^2 = .29$, with the expressive group showing higher negative affect after writing.

Group differences in real time writing measures

A one-way ANOVA revealed significant differences between groups in pause duration, $F(1, 51) = 5.58, p = .022, \eta_p^2 = .10$, with the expressive group showing longer pauses. No significant differences were found on fluency, $F(1, 56) = 2.81, p = .100$, burst length, number of pauses, and burst speed (all $F < 1$).

Indices of SNS Activation

Group differences in SC (increased SC indexes higher SNS activation). The mixed repeated measures ANCOVA revealed no significant interaction between group $\times$ time-period ($F < 1$). No main effect was found for *group* ($F < 1$), but a main effect of the *time-period* was found for SC, $F(2.25, 112) = 8.13, p < .001, \eta_p^2 = .14$. Pairwise comparisons adjusted for multiple comparisons (Bonferroni), showed that both groups have lower SC in W1 than W2 ($p < .001$), with SC going up again at PW ($p < .001$). .

Group differences in SDNN as a measure of overall HRV (decreased SDNN indexes higher SNS activation). A mixed-design ANCOVA showed no significant interaction between group $\times$ time-period ($F < 1$). It was found a marginal effect of *group* on

SDNN, $F(1, 23) = 3.45, p = .076, \eta_p^2 = .13$, but no main effect was observed for *time-period*, $F(3, 69) = 1.80, p = .16$.

Indices of PNS activation

Group differences in RMSSD (increased RMSSD indexes higher PNS activation). The mixed-design ANCOVA showed no significant interaction between *group* $\times$ *time-period*, $F(3, 66) = 1.73, p = .17$, and no main effects of *group* ($F < 1$) nor *time-period*, $F(3, 66) = 2.12, p = .11$, on RMSSD.

Group differences in HF (increased HF indexes higher PNS activation). The ANCOVA found no *group* $\times$ *time-period* interaction ($F < 1$). No main effect of *group* was found, $F(1, 23) = 2.46, p = .13$, but the ANCOVA revealed a main effect of the *time-period* on HF, $F(3, 69) = 4.83, p = .004, \eta_p^2 = .17$. Pairwise comparisons based on adjustment for multiple comparisons (Bonferroni), showed that both groups have lower HF in W1 ($p = .021$) and W3 ($p = .004$), than PW.

SNS/PNS activation

Group differences in HR (SNS/PNS activation). The ANCOVA showed no significant *group* $\times$ *time-period* interaction ($F < 1$). No main effect was found for *group* ($F < 1$) or *time-period*, $F(2, 54) = 1.22, p = .35$.

Group differences in LF/HF ratio (SNS/PNS activation). The ANCOVA revealed no significant *group* $\times$ *time-period* interaction, $F(3, 63) = 1.10, p = .36$, but showed a main effect of *group*, $F(1, 21) = 5.84, p = .025, \eta_p^2 = .22$, with the expressive group displaying higher LF/HF ratio ($p = .025$; see Figure 1 in Electronic Supplementary Material 1). No main effect was found for *time-period*, $F(3, 63) = 2.04, p = .12$.

Figure 1. Mean LF/HF ratio scores for each experimental group from the beginning to the end of the writing task and post-writing. Greater values indicate higher LF/HF ratio. Line bars represent standard error of the mean.

Discussion

We designed a real-time study of expressive writing to examine writing dynamics associated with emotion regulation and its psychophysiological correlates. We anticipated pauses to be longer in the expressive group, as expressive writing should lead to higher cognitive and emotional load. We also expected participants in both groups to show increased SNS (SC) activation from baseline, since both groups completed a writing task. Finally, due to the emotional load of expressive writing, we expected the expressive group to show higher PNS (RMSSD; HF) activation and LF/HF ratio than the control, during writing and post-writing, as indexed through HRV.

Manipulation check results showed that, as expected, negative affect increased in the expressive writing group after completing the expressive writing task. This is in line with all studies of our knowledge conducted within the expressive writing paradigm (Konig et al., 2014; Pennebaker & Beall, 1986; Smyth, 1998). After writing about a traumatic or stressful life event, participants report increased negative affect.

As expected, expressive writing participants paused for longer than those in the control group. Previous studies showed that, in adult writers, pause duration increases when dealing with a secondary task (Fayol, 1999). In this study the secondary task might have been the emotional load of expressive writing. These findings could mean that pauses are a step to achieve emotion regulation, particularly, to make meaning of the experience. As far as we know this is the first study of expressive writing that has revealed increased pause duration during writing. Future research should study systematically how different emotion regulation strategies might influence pause duration.

Results show that writing is associated with increased ANS activity. Skin conductance results match those shown by McGuire et al. (2005), that found an increase in skin conductance during 15 minutes of writing, for both neutral and expressive writing. This is consistent with the temporal dynamics of the ANS systems, since skin conductance increases more slowly than heart rate (Levenson, 2014), therefore, it might not be a sensitive measure to observe SNS differences in real-time.

In our study, HR did not show significant differences between groups. This is in line with König et al. (2014) who found the same results, when participants were not trained to focus on their emotions beforehand. Another study by Sloan et al. (2007) found an increase in HR after expressive writing. This might be because Sloan, et al. (2007) calculated mean HR across 20 min. and subtracted mean HR at baseline, which we did not do. No significant results were found for SDNN, RMSSD and HF (RSA) between groups, suggesting that in our study there was no specific sympathetic or parasympathetic activation during expressive writing (W1, W2, W3). Previous studies have found that SDNN increased after expressive writing, but only for participants who previously showed high levels of emotional processing (Seeley et al., 2016). Interestingly, we found higher HF (RSA) after writing in both groups. A previous study has also found an increase in RSA after writing, but only in the expressive writing group (Sheerin, et al., 2018). This might be because in Sheerin et al. (2018), RSA data was calculated as logRSA and not HF, and in shorter segments (2.5 min. as opposed to 5min.).

As expected, in this study, participants that completed expressive writing, showed an increase in LF/HF ratio during and after the exercise. Previous studies have linked greater HRV to greater emotion regulation (Appelhans & Luecken, 2006), particularly increased LF/HF ratio (Kim et al., 2019). Therefore, during expressive writing it seems that neither the

SNS (SC; SDNN) nor the PNS (RMSSD; HF) dominated, but a balance between the two was established.

Findings of this study should be viewed under four limitations. First, the participants recruited were college students disclosing on a broad range of traumatic or stressful life experiences. This heterogeneity of negative experiences reported could have led to different levels of negative affect and psychophysiological responses. To circumvent this, future studies might choose to narrow the topic of disclosure or recruit participants sharing a common trauma. Second, future studies could recruit community samples, instead of undergraduates, as they might be similar to the general adult population. Third, we did not study which words were used during moments of high psychophysiological arousal. Future studies should explore the linguistic contents produced, specifically if higher LF/HF ratio is associated with longer pauses. Finally, our study found increased LF/HF ratio, which could suggest increased emotional regulation (Kim et al., 2019) during expressive writing, but other indexes, such as SC, HR, SDNN, RMSSD and HF did not yield significant differences between groups.

Our findings suggest that during expressive writing, participants pause for longer and sympathovagal balance is higher than when writing about a control topic. Findings from this first study provide evidence favoring expressive writing as an opportunity for emotion regulation.

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