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Imagining a positive future reduces cortisol response to awakening and reactivity to acute stress

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ABSTRACT

The positive influence of optimism on health is thought to be due in part to a reduced physiological response to stress, as manifested for instance in activity of hypothalamic-pituitary-adrenal (HPA) systems. Results of previous studies support the notion that dispositional optimism can influence diurnal cortisol secretion as well as cortisol reactivity. The aim of the present study was to examine whether induced optimism can similarly affect HPA activity and thereby potentially have beneficial health effects. We assigned 66 university students to either the Best Possible Self (BPS) or an active control condition, respectively entailing two weeks of daily visualization of a positive future or time management exercises. Before and after the intervention, we assessed diurnal cortisol levels, response to awakening (CAR), and reactivity to the Trier Social Stress Task (TSST), as well as optimism, affect, negative cognitions, perceived stress, and threat appraisal. Effects of the BPS intervention were tested with repeated measures ANOVA (psychological outcomes) and multilevel regression (cortisol outcomes). The BPS intervention was associated with decreases in both the CAR and cortisol responses to acute stress. Compared to controls, BPS participants showed decreased worrying and increased positive affect post-intervention; however, they did not show the expected greater increase in optimism. Within-person decreases in worrying were associated with decreased CARs, whereas both decreased worrying and increased PA were linked to attenuated stress reactivity. Results suggest that the BPS intervention can influence HPA axis reactivity, with effects on well-being variables likely mediating the process. More research is needed to determine longer-term neuroendocrine and health effects of such interventions in at-risk as well as healthy populations.

1. Introduction

Optimism, defined as the global expectation that things will turn out well in the future, has been found to positively influence health. Confirming the results of earlier small-scale studies, long-term epidemiological studies including thousands of individuals have shown benefits of optimism in reducing the incidence and progression of cardiovascular and other diseases, improving wound healing and recovery after surgery, and lowering all-cause mortality (for a recent review see Scheier and Carver, 2018). Recently, optimism has also been linked to exceptional longevity (Lee et al., 2019). One proposed mechanism underlying the beneficial effects of optimism is a reduction in physiological response to stress (Carver et al., 2010), for example as manifested in activity of sympathetic, immune, and hypothalamic-pituitary-adrenal (HPA) systems (Russell and Lightman, 2019). With respect to the HPA axis, not only acute reactivity but also patterns of daily cortisol secretion - overall levels, diurnal slope of decreasing output over the course of the day, and the cortisol awakening response (CAR) - have been linked to stress and well-being (Adam et al., 2017; Chida and Steptoe, 2009; Miller et al., 2007). Hypothetically, all of these relatively independent aspects of HPA activity could be part of the biological pathway connecting optimism with health outcomes.

Results of a number of studies support the notion that dispositional optimism can indeed influence diurnal cortisol secretion: higher levels of optimism were associated with lower salivary cortisol levels in the early morning (Lai et al., 2005) or throughout the day (Puig-Perez et al., 2017), and lower accumulated cortisol levels measured in hair (Milam et al., 2014); another study, however, found no relationship between optimism and cortisol levels on a single day (Endrighi et al., 2011). Jobin and colleagues reported that optimism was associated with lower

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overall cortisol levels and CARs, but only on days when participants perceived higher stress (Jobin et al., 2014). Findings concerning the CAR have been mixed, with lower responses in more optimistic older adults in one study (Endrighi et al., 2011), but no association with optimism in several others (Puig-Perez et al., 2017; Puig-Perez et al., 2018; Puig-Perez et al., 2015).

There is also limited evidence that optimism can influence cortisol reactivity to acute laboratory stressors. Optimism was associated with lower cortisol 120 minutes post-stressor in recently vaccinated healthy males, but not in controls (Brydon et al., 2009); another study reported no difference in peak response during a stress task, but quicker cortisol recovery in optimists (Puig-Perez et al., 2015). Salzman et al. (2018) reported that optimism moderated effects on cortisol reactivity of a brief pre-stressor intervention to increase personal control expectations. In contrast, other studies have found either no relationship between optimism and cortisol responses to stress tasks (Endrighi et al., 2011; Puig-Perez et al., 2017; Taylor et al., 2008) or enhanced reactivity (Solberg Nes et al., 2005).

The above studies all investigated optimism as a trait, and there is abundant evidence that this disposition is largely stable (Scheier and Carver, 2018). Nevertheless, optimism can change, for example increasing slightly with age or decreasing under difficult life circumstances (Scheier and Carver, 2018). Optimism can also be increased by psychological intervention (Malouff and Schutte, 2017), but whether such induced optimism can also have physiological benefits has so far never been examined. The present study set out to assess whether optimism induction can affect HPA activity, as reflected in three cortisol indicators: overall diurnal levels, response to awakening (CAR), and response to a social stressor, the Trier Social Stress Task (TSST) (Kirschbaum et al., 1993). We manipulated optimism by means of a 2-week writing and visualization intervention, the Best Possible Self (BPS) exercise (Peters et al., 2010). In an earlier study, a single writing session followed by 5 minutes of daily visualization for two weeks was found to lead to a significant increase in optimism after one week and a further increase after two weeks (Meevissen et al., 2011).

We hypothesized that, compared to participants in a control condition, participants in the BPS condition would have lower diurnal cortisol levels, a smaller CAR, and greater reductions in their cortisol response to the TSST from pre to post intervention. Because in previous studies the BPS exercise influenced not only optimism but also affective measures (Meevissen et al., 2011; Carillo et al., 2019), we also explored the association of pre to post intervention changes in psychological variables with the three cortisol measures, to gain insight into possible pathways linking the BPS intervention effects to alterations in HPA activity.

2. Methods

2.1. Participants

After study approval by the local IRB, students at Maastricht University were recruited to participate via posters and a dedicated website. Exclusion criteria were having a metabolic disease, cardiovascular disease or epilepsy, post-traumatic stress disorder or depression, circumstances disrupting normal sleep (e.g., jet lag or shift working), smoking, and self-reported recreational drug or alcohol abuse. Of 75 students who were screened, 66 (53 women, 13 men) provided informed consent and were randomized to either the BPS intervention or a control condition. Participants received 75 euro upon completion of the study.

2.2. Interventions

We used the Best Possible Self (BPS) intervention to induce optimism (Meevissen et al., 2011). Participants were instructed to imagine a future in which all life goals would be accomplished and everything had worked out in the best possible way. In the preparation session, participants first thought about and wrote down their wishes for the future in three life domains: personal, relational, and professional. They were given 5 minutes per domain. A powerpoint presentation kept track of the time and signaled when participants could proceed to the next domain. During the next 10 min they summarized these wishes into three statements about their ideal future self in each domain. After a short visualization training (cf. Holmes et al., 2008) they practiced 5 min of audio-guided BPS visualization. The audio recording started with repeating what the Best Possible Self entails. Participants were free to choose one of the three domains for their visualization. After 5 min, the audio recording signaled the end of the visualization period. Participants were instructed to repeat the BPS visualization every evening for two weeks, alternating domains from day to day. An mp3 player was provided to guide the visualization. They also received a workbook that specified the domain on which they should focus on a specific day, and where they briefly wrote down the content of their visualization and rated its vividness.

The control condition was a bogus time-management intervention that entailed writing about daily activities. During the preparation session, participants were instructed to provide an account of their activities over five workdays. They were given 8 min for each day to think back and describe all activities of that day in as much detail as possible and to estimate how effectively they made use of their time in carrying out these activities on a 0 to 100 scale. A powerpoint presentation kept track of the time and signaled when they could proceed to the next day. After finalizing their description of the last day, participants received the visualization training. They were told that this could help them in forming clearer recollections of the activities during a day. At the end of the session, participants received a workbook in which to record their daily activities for the next two weeks, each night before going to bed. For each activity, they were instructed to record how much time it took and how effective it was.

Both the BPS and control training session lasted approximately 50 minutes. In both conditions participants were told that the activity they would perform during next two weeks could improve wellbeing.

2.3. Measures

2.3.1. Cortisol day profiles

Participants were asked to collect four saliva samples (on awakening, 30 min later, at mid-afternoon and evening) on each of four days: two pre and two post intervention. They received polyester swabs (Salivettes; Sarstedt, Germany) in a bottle with an electronic cap (MEMS6, Aardex, Switzerland) that registered opening times, and detailed instructions. They were specifically told to take the first daily sample immediately upon awakening and to avoid brushing teeth or eating until after both morning samples. Participants were instructed to place each saturated swab in a capped salivette tube, record the actual collection time on both the tube and a diary form, and store the tubes in their home freezer or refrigerator until returning them to the university the same week. Samples were then stored at -20 °C until shipment to TU Dresden, Germany, where cortisol concentrations were determined by chemiluminescence immunoassay (IBL, Hamburg, Germany). Mean intra-assay and inter-assay coefficients of variation at this laboratory
are typically < 10%.

Cortisol samples were considered valid if values were physiologically plausible (< 60 nmol/l) (Miller et al., 2013b), collection time were recorded on the tube, and compliance with advised collection times was adequate: first sample (at awakening) taken before 13 h; second sample taken 20-50 min after the first sample, third sample taken between 14h-19:30 h; fourth sample taken between 19:30-24:00 h.

For estimates of overall diurnal cortisol levels, only the first, third and fourth of the daily samples were used, excluding the samples taken 30 min after awakening. The CAR was defined as the change in log-cortisol from the first to the second daily sample. Of 228 available CARs, 35 were excluded for the following reasons: cortisol value > 60 nmol/l (n = 1), missing collection times (n = 28), invalid interval between the two samples (n = 6).

2.3.2. Cortisol stress reactivity

The Trier Social Stress Test (TSST) (Kirschbaum et al., 1993) entailed an 8-min preparation phase, followed by a 5-min oral presentation on a personally relevant academic topic and a 5-min backward-counting task performed before two judges and a video camera. The TSST was performed twice (pre- and post-intervention) with median interval of 28 days between tests (range 28 to 34 days). To prevent participants from practicing for the second TSST, the topic of the presentation was changed, as well as the numbers to be subtracted during the mental arithmetic component.

During each TSST, participants collected 10 saliva samples, at 10-min intervals, with polyester salivettes. For sample storage and assay details, see section 2.3.1. Because the first two cortisol measures, prior to the stress task, were highly correlated (r = .94, p < .001) and not significantly different (t = 0.60, p = .55), we defined lab baseline as the mean of these values. For each TSST, cortisol AUCI (Pruessner et al., 2003) was calculated with respect to this baseline, using log-transformed values.

2.3.3. Questionnaires

We assessed several psychological variables pre and post intervention to explore potential pathways through which the BPS intervention might affect HPA axis activity. The BPS does not only have an effect on optimism but also increases positive affect and – to a lesser extent – might affect HPA axis activity. The BPS does not only have an effect on optimistic but also increases positive affect and – to a lesser extent – might affect HPA axis activity.

Orientation Test-Revised (LOT-R) (Scheier et al., 1994), with six items (plus four filler items) rated on 5-point Likert scales, from strongly disagree to 5 strongly agree. After reversing scores of the three negatively phrased items, we calculated a total optimism score (α = .79 & .75 for the first and second assessment, respectively).

Affect. The PANAS-X (Watson and Clark, 1994) assesses positive affect (PA) and negative affect (NA). Participants rated the extent to which they experienced each of 10 positive and 10 negative affective states over the last week on 5-point scales (1 very slightly or not at all to 5 extremely). Average item scores were calculated for PA (α = .80 & .85) and NA (α = .82 & .88).

Negative cognitions. Worrying was assessed with the 16-item Penn State Worry Questionnaire (PSWQ) (Meyer et al., 1990). Participants rated how typical various thoughts were for them during the past week (1 not at all typical of me to 5 very typical of me). A mean item score was calculated after recoding the five positive items (α = .92 & .92). We assessed rumination with the Rumination-Reflection Questionnaire (RRQ) (Trapnell and Campbell, 1999), averaging the scores of the eight rumination items (rated from 1 totally disagree to 5 totally agree) (α = .88 & .85).

Stress. Participants completed the 10-item Perceived Stress Scale (PSS) (Cohen et al., 1983), rating items on a scale from 0 never to 4 very often during the past week. After recoding the four positively phrased items we calculated a mean item score (α = .87 & .83). The daily diaries completed concurrently with saliva samples included, with the exception of the first sample at awakening, a VAS scale for rating current stress. The six ratings over two days, pre- and again post-intervention, were averaged as a measure of daily stress, which could thus range from 0 to 10. Immediately before each TSST, we administered the Primary Appraisal Secondary Appraisal (PASA) questionnaire (Gaab, 2009). The Threat subscale includes 4 statements that participants rate on a scale from 1 completely disagree to 6 completely agree (α = .76 & .79).

2.4. Procedure

A computer program randomly allocated participants to the optimism or control condition. Immediately before starting the 5-week study, participants gave written informed consent and received materials (salivettes, diaries).

Week 1 began with the pre-intervention daily cortisol assessment on Monday and Tuesday. Participants kept a diary to record wake-up time, hours of sleep, sleep quality, and for each cortisol sample also the time, whether they had smoked, brushed their teeth, had eaten or used alcohol or drugs, and current stress. The psychological questionnaires were completed online on Tuesday.

The first TSST session took place on Wednesday, Thursday, or Friday, between 14:00 h and 19:00 h. Fifteen minutes after arrival, compliance check, and a brief rest period, the first baseline cortisol measure was taken, followed by a second measure 10 minutes later, after the participant was told about the nature of the task and brought to the test room to wait. Anticipatory appraisal measures were completed at this time. Specific TSST task instructions (2 min) and preparation (8 min) took place before the third cortisol measure, followed by the task itself (10 min) and post-task measures (10 min). During a 50-min recovery period, participants watched a neutral film, with saliva samples every 10 min.

Two weeks later (week 3), participants came back to the lab for the intervention training session. As described in section 2.2, they received instruction for the BPS or time management intervention, did the specific writing assignment appropriate for their condition, and practiced visualization. Afterwards, they received instructions for the home practice sessions and were given a workbook. Participants in the BPS condition additionally received an mp3 player.

On the Monday and Tuesday of week 5, participants again collected daily cortisol and kept a diary. On Tuesday they filled out the psychological questionnaires online. The second TSST session was planned, as before, on Wednesday, Thursday, or Friday between 14:00 h and 19:00 h. The procedure was identical to the first TSST, except that instead of the rest period participants now started with 5 min of BPS visualization or reporting on their daily schedule, depending on condition.

Participant flow through the procedure and subsequent data analysis is schematically depicted in Fig. 1. Comparison of the 15 excluded
participants with the 51 who were included in analyses of one or more cortisol outcome variables revealed no significant differences in gender, age, assigned experimental condition, or questionnaire measures (see Table S1, Supplementary Online Materials).

2.5. Statistical analyses

Saliva samples for cortisol diurnal profile measures were collected on two days pre and two days post intervention and, in the case of samples used to estimate overall levels, several times each day. Because of this nesting of data at different levels, we performed multilevel regression analyses for all analyses with cortisol as dependent variable, using Stata/MB v13 (Stata Corp., College Station, TX), procedure MIXED with maximum likelihood estimation. In these models, fixed effects are expressed as unstandardized beta coefficients; $\beta$ divided by its standard error (SE) is approximately $Z$-distributed. Statistical tests are two-tailed, with $p < .05$ considered significant. Effects of the BPS intervention are reflected in the Pre-Post x Condition interaction estimate.

Cortisol values were log-transformed to normalize their distribution prior to further calculations and statistical analyses. Continuous independent variables were centered around the sample grand mean. For analyses testing optimism induction effects on daily cortisol output, multilevel regression models had four levels: cortisol measures (level 1) were nested within days (level 2), pre or post intervention (level 3), within participants (level 4). Random intercepts were modelled at each level. We controlled for cortisol’s diurnal rhythm by including the variable time of day (hours since midnight) and time$^2$ as level 1 predictors, estimating a random slope for time. Preliminary analyses also tested, in separate models, fixed effects on cortisol of age, gender, Age x Gender interaction, and BMI.

Models estimating effects on the CAR had three levels: one CAR each day (level 1), pre or post intervention (level 2), within each participant (level 3). Preliminary analyses revealed no effects of the potential confounders mentioned above. The interval between the two saliva samples was not related to CAR magnitude, but time at awakening and cortisol at awakening both had significant effects and were therefore controlled for.

All analyses of cortisol response (AUCi) to the TSST controlled for lab baseline, as higher baseline values are often related to lower cortisol responses, especially when values are log-transformed (Miller et al., 2013a). Given some variation in the starting time of the sessions (mean...
3. Results

3.1. Sample characteristics

As depicted in Fig. 1, 51 participants completed the intervention and sufficient cortisol measures pre- and post-intervention for inclusion in the analyses. The BPS group comprised 25 women and 2 men, the control group 16 women and 8 men. Almost all of the women (38 of 41) used oral contraceptives. Although the automated randomization program was meant to balance the two conditions by sex, men were underrepresented in the BPS condition ($\chi^2 = 5.42, p = .033$). The sample had a mean age of 21.2yr, $SD = 2.48$, range 18 to 30; mean BMI was 21.8, $SD = 2.4$, range 17.6 to 28.4. BPS and control groups did not differ in age ($t = 1.05, df = 49, p = .30$) or BMI ($t = 1.01, df = 48, p = .32$).

3.2. Intervention effects on cortisol patterns

3.2.1. Overall cortisol level

For analyses of diurnal levels, 41 participants had valid samples both pre and post intervention. On average, included participants collected 5.59 of the 6 planned pre-intervention samples and 5.73 of the 6 planned post-intervention samples, yielding a total of 464 cortisol measures (94.3% of those planned).

Table 1a summarizes results of multilevel regression models estimating effects on overall cortisol levels, based on saliva samples taken during normal daily activities, before and after the intervention. As expected, cortisol levels declined over the course of the day (significant main effect of time). The Pre-Post x Condition interaction effect, which tests the hypothesized effect of the BPS compared to the control condition on overall cortisol level, was not significant.

3.2.2. Cortisol awakening response (CAR)

Analyses were based on the 42 participants who had at least one valid CAR measure both pre- and post-intervention (159 CAR measures). Mean time at the awakening sample was 08:06 h ($SD = 88$ min; range 4:22h - 12:58h). The mean interval between the two morning samples was 30.24 min ($SD = 2.26$ min; range 20 - 40 min). Over all measures, mean cortisol at awakening was 16.71 nmol/l ($SD = 7.89$), with a mean CAR of 4.07 nmol/l ($SD = 6.86$).

Table 1b shows results of the multilevel regression analysis. Later awakening and higher cortisol levels at awakening were independently associated with a smaller CAR. The main effect of experimental condition was non-significant, but the CAR decreased from pre to post intervention. This main effect of Pre-Post was no longer significant after addition of the hypothesized Pre-Post x Condition interaction to the model, which indicates that only the BPS intervention was associated with a significant decrease in the CAR. Descriptive data support this interpretation. Whereas the percentual change in cortisol levels was similar in the control group pre and post intervention (mean increases of 32.6% and 36.4%, respectively, above levels at awakening), BPS participants showed a pre to post intervention decrease in the CAR, from 53.6% to 24.6%.

Negative CARs (27% of the total) could bias results, if the first daily sample was taken too late after awakening. To control for this possibility, we repeated the analysis in the subsample of positive CARs.

Table 1

|                      | Diurnal level                  |       |       |
|----------------------|--------------------------------|-------|-------|
|                      | $\beta$                       | SE    | $p$   |
|                      | 95% CI                         |       |
| Intercept            | 1.961                         | 0.053 | < .001| [1.857, 2.064] |
| Control variables    |                                |       |       |
| Time of day (hr)     | $-0.130$                      | 0.006 | < .001| [-0.141, -0.118] |
| Time                  | $-0.004$                      | 0.001 | < .001| [-0.006, -0.003] |
| Main effects and interaction |                  |       |       |
| Pre-Post             | 0.030                         | 0.042 | .470  | [-0.052, 0.113] |
| Condition            | $-0.032$                      | 0.094 | .737  | [-0.216, 0.153] |
| Pre-Post x Condition | $-0.114$                      | 0.084 | .173  | [-0.278, 0.050] |

Note. For all models, Pre-Post is coded 0 Pre, 1 Post; Condition is coded 0 control, 1 BPS. Regression coefficients represent fixed effects and are unstandardized. Significant results are shown in boldface. For diurnal levels, estimates are based on 464 logcortisol measures, nested within 41 participants, who each completed from 8 to 12 valid saliva samples. The model intercept represents logcortisol at the midpoint of the sampling times (14:40 h). Results of preliminary models indicated no significant effects of age, gender, or BMI % change in raw cortisol per unit change in predictor = $exp(\beta) - 1$. For the CAR, analyses were based on 159 measures, nested within 42 participants. For response to the TSST, estimates are based on 94 AUC measures, nested within 47 participants.
This confirmed the main finding (a significant Pre-Post x Condition effect, with decreased CAR following the BPS but not the control intervention): $\beta = -0.158$, SE $= 0.078$, $p = .042$, 95% CI $[-0.310, -0.006]$.

3.2.3. Cortisol reactivity to the TSST

The analyses of cortisol reactivity included the 47 participants who completed the TSST both pre and post intervention: 23 control group participants (15 women, 8 men) and 24 BPS group participants (22 women, 2 men). Prior to the intervention, lab baseline cortisol levels averaged 7.32 nmol/l, $SD = 4.02$, with no significant difference between BPS and control groups (means of 6.93 versus 7.45 nmol/l, $t = 0.97, df = 45, p = .82$). At the second, post-intervention TSST, lab baseline cortisol did not differ significantly from pre-intervention levels and was again similar in the two conditions, with means of 7.67 nmol/l in the BPS group and 7.06 nmol/l in the controls. The pre-intervention stress task induced an average peak increase of 6.53 nmol/l (+113.3%) above baseline; mean peak response to the post intervention TSST was 4.42 nmol/l, an average increase of 69.0% above baseline.

Results of regression analyses investigating predictors of cortisol response to the TSST are summarized in Table 1c. Higher lab baseline cortisol values (mean logcortisol for measures 1 and 2) were associated with lower cortisol AUCi. On average, men had significantly higher cortisol responses than women. We controlled for these variables in subsequent models. Cortisol responses were lower during the second compared to the first TSST (significant main effect of Pre-Post). In the final model, the Pre-Post x Condition interaction effect indicates a significantly greater decrease in cortisol response to the stress task following the BPS intervention, compared to the control intervention. Fig. 2 shows observed changes in cortisol secretion throughout the lab procedure, pre and post intervention, in the two groups. Response to the TSST is illustrated by plotting untransformed cortisol values over the 90-min lab session, with untransformed AUCi measures for comparison.

3.3. Intervention effects on psychological variables

Table 2 presents descriptive statistics for optimism, affect, negative cognitions, stress measures, and anticipatory threat appraisals of the TSST at pre-intervention baseline, as well as pre to post intervention change measures. The BPS exercise was designed to induce optimism. Although optimism appeared to increase in both conditions, pairwise $t$-tests indicated that these changes were not significant. Moreover, ANOVA results failed to confirm greater increases in optimism following the BPS compared to the control intervention (non-significant Pre-Post x Condition effect). Pre-Post x Condition effects were found for positive affect, worrying and daily stress ratings. Participants in the BPS

![Fig. 2. Cortisol response to the TSST pre and post intervention in BPS and control groups. The first cortisol sample was taken 15 min after arrival at the lab. AUCi represents total cortisol response, relative to the participant’s mean pre-task baseline (samples 1 and 2). For procedural details, see section 2.4.](image-url)
condition showed significant increases in positive affect and decreases in worrying whereas participants in the control condition did not show a significant change. The Pre-Post x Condition interaction effect in ratings of daily stress can largely be attributed to an increase in daily stress in the control group, with a non-significant decrease in stress ratings in the BPS group. When PA, worrying, and daily stress variables were simultaneously included as dependent variables, MANOVA results for the Pre-Post x Condition interaction approached significance, with a non-significant decrease in stress ratings of daily stress can largely be attributed to an increase in daily worrying whereas participants in the control condition did not show a significant increase. Increases in positive affect and decreases in worrying were related to cortisol measures. For cortisol diurnal levels, none of the psychological characteristics showed either a significant between-person or within-person effect. Results for the cortisol awakening response (CAR) and cortisol reactivity to the TSST (AUCi) are shown in Table 3.

### 3.4. Associations of psychological variables with cortisol levels, CAR, and acute stress response

As described in section 2.5, we estimated a series of multilevel regression models to explore associations between psychological characteristics significantly affected by the intervention (results in Table 2) and each of the three dependent cortisol measures, disaggregating between- and within-person effects. Within-person effects are the most relevant for understanding intervention effects, as they indicate whether pre to post intervention changes were related to variability in the cortisol outcome measure. Between-person effects indicate whether differences between individuals in specific psychological characteristics were related to cortisol measures. For cortisol diurnal levels, none of the psychological characteristics showed either a significant between-person or within-person effect. Results for the cortisol awakening response (CAR) and cortisol reactivity to the TSST (AUCi) are shown in Table 3.

Controlling for bp effects, larger within-person increases in positive affect were associated with reduced cortisol reactivity to the TSST, but were unrelated to changes in the CAR. Within-person variability in worrying was significantly associated with both the CAR and the AUC response, with lower worrying predicting smaller CARs and attenuated stress reactivity. Although daily stress had a significant between-person effect on the CAR, within-person changes in this measure were not associated with either the CAR or the acute stress response.

## 4. Discussion

The current study is, to our knowledge, the first to examine the effect of the Best Possible Self intervention on HPA activity. The BPS intervention was not associated with significant changes in overall cortisol levels, but resulted in robust decreases in both the CAR and the cortisol response to a social stress task. The starting point for the study was the question whether optimism induction can affect HPA activity. BPS imagery was the intervention of choice because it had previously been shown to be effective in increasing optimism (Carillo et al., 2019; Mevissen et al., 2011), with more powerful effects than other interventions (Malouff and Schutte, 2017). Contrary to expectation, BPS participants did not report significant post-intervention increases in optimism. They did, however, show increases in positive affect and decreases in worrying. The increase in positive affect is in accordance with previous studies (Carillo et al. 2019); the decrease in worrying is a new finding. Notably, within-person fluctuations in positive affect and worrying were associated with one or both cortisol reactivity measures. Increases in positive affect and decreases in worrying were related to reduced TSST responses, and decreases in worrying were also associated with a smaller CAR. These findings suggest that not optimism but changes in positive affect and worrying may have mediated the effects of the BPS intervention on the neuroendocrine system. It is important to note that we did not test mediation directly, given the complexity of estimating multilevel mediation models with more than two levels.

In the control condition daily ratings of stress increased over time. This suggests that the bogus time management intervention may not have been entirely neutral. One can imagine that monitoring routine daily activities and evaluating their effectiveness might be stressful. Nevertheless, there were no detrimental effects on affect, cognitions, or global perceived stress. Moreover, it is unlikely that increased stress in the control group was responsible for the observed intervention effects on cortisol measures, as we found no evidence linking within-person increases in daily stress to larger CARs or heightened responses to the TSST.

In recent years, there has been increasing interest in using indices of HPA activity as outcome measures in intervention or treatment studies. Systematic reviews (Ryan et al., 2016; Laufer et al., 2018) cite investigations of cortisol levels, diurnal slope, CAR, and acute stress reactivity following a wide variety of psychosocial interventions, in
particular cognitive behavioral therapy, stress management, and mindfulness training, but also gratitude, social cognition, and compassion training, among others, and the list continues to grow. Almost all of these previous studies focused on the effects of the intervention on either diurnal cortisol or cortisol response to the TSST, but not both. Moreover, studies that did study cortisol reactivity typically only assessed it once, after the intervention. Our study is unique in that it combined the assessment of cortisol day profiles, CAR, and the cortisol response to the TSST in a pre-post design. Another difference from previous studies is that these have generally reported the effects of longer and more intensive interventions, often under direct supervision. The current findings indicate that even a 5-min exercise performed daily for 2 weeks by participants who have received only a brief in-person training can affect cortisol patterns, in particular response to awakening (CAR) and acute stress reactivity (TSST).

To what extent might the 5-min visualization exercise immediately before the second TSST have enhanced the effect of the intervention on stress reactivity? Two recent studies comparing effects of different psychological manipulations administered minutes before a stress task demonstrated that such brief interventions can have an immediate effect on cortisol reactivity (Erickson et al., 2017; Salzmann et al., 2018). In contrast to the current study, however, the experimental interventions in those studies were designed directly to affect participants’ appraisals, goals, and strategies for dealing with the task. Our finding that the BPS intervention did not affect anticipatory threat appraisal suggest that the visualization exercise immediately before the second TSST was less crucial than the 2 weeks of daily practice sessions. The observed post-intervention reduction in the CAR clearly cannot be attributed to immediate effects of BPS imagery, as the most recent visualization exercise was performed the previous evening.

Previous studies with the BPS have mainly focused on its effects on psychological states and traits; the present study is the first to demonstrate that its effects may extend to physiological parameters. Although there is evidence that the effects of BPS imagery on psychological measures can persist (e.g., Molinari et al., 2018), it remains to be determined whether this also applies to physiological measures. Future research should examine longer-term neuroendocrine effects of the BPS interventions in at-risk as well as healthy populations and determine the optimal frequency and duration needed to achieve persistent beneficial outcomes. Furthermore, it is still an open question whether the neuroendocrine effects of the BPS intervention might translate into advantageous health outcomes similar to those established for dispositional optimism and other indices of subjective wellbeing, such as positive affect (Rozanski et al., 2019; Diener et al., 2017). However, because psychosocial stressors are common and frequently chronic or repetitive, even small physiological effects may be clinically relevant.

The current study had some limitations. First, the sample was relatively small (41 to 47 participants, depending on the analysis), with considerable drop-out from pre- to post-intervention and exclusions from specific analyses due to missing cortisol data or sample collection times. Although statistical comparison of included versus excluded participants indicated no significant differences between these groups on baseline psychological measures that might have biased results, results should be replicated in a larger sample.

Second, the sample was not characteristic of the population at large, which limits generalizability of the findings. As is typical for this university student population, the sex ratio was highly skewed in favor of females, almost all of whom used oral contraceptives. As expected, men showed enhanced cortisol responses to the TSST but did not differ from women in cortisol levels or the CAR. Random allocation to condition did not result in equal distribution of males over the two groups, such that included males were underrepresented in the BPS condition. This meant we were unable to evaluate whether gender moderated the effects of the BPS and control interventions on cortisol measures. Gender differences remain an important topic for future studies. In general, more research is needed to identify personal characteristics that moderate effects of the BPS intervention (Loveday et al., 2018). There may be specific characteristics, e.g., stress sensitivity, self-esteem, or psychopathology, that enhance or attenuate the effects of the intervention on cortisol indices.

Third, we cannot completely rule out inaccuracy in CAR measures. In adherence to current guidelines (Stalder et al., 2016), electronically timed CAR samples were obtained, pre and post, on two consecutive days, at waking (w) and w + 30 min; to reduce participant burden the recommended w + 45 min measure was omitted. For the purposes of our study, we believe this design decision was justified and unlikely to have biased results (Hoyt et al., 2016). Participants reported good compliance with instructions about sample timing and were aware that collection times were being monitored electronically, which in itself is known to improve compliance (Broderick et al., 2004). We did not, however, have access to the monitoring data, nor were we able to confirm actual awakening times, for example with actigraphy.

Our study also has several strengths. We assessed indices of HPA activity both before and after two weeks of BPS visualization and compared this to the effects of an active control intervention. By comparing cortisol reactivity pre- and post- intervention, individual variability can be controlled, yielding more reliable results. In addition, multiple well-defined characteristics of cortisol secretion were assessed: cortisol day profiles (levels, CAR) and cortisol reactivity to an acute social stressor. These indices are thought to be largely independent, reflecting different aspects of HPA regulation. Moreover, electronically monitored saliva sampling was repeated on two consecutive days, before and again after the intervention, thus increasing reliability of the day profiles. During the two lab visits, frequent saliva sampling continuing well beyond the TSST also increased reliability and allowed accurate assessment of the cortisol response. Compensating for the relatively small number of participants, design features that improve reliability and the multilevel statistical approach increase power; this may underlie the observed robust pattern of results, which confirmed hypothesized effects of the BPS intervention on two of the three cortisol indices: lowered CAR and response to the TSST.

In conclusion, our findings indicate that imagining a positive future by means of the Best Possible Self intervention can affect HPA axis activity. More research is needed, however, to determine the longer-term effects. Moreover, future studies should further examine the underlying mechanism through which the BPS intervention exerts its beneficial effects. Previous studies have found that this intervention increases optimism, but the current study was unable to replicate this. Future studies might also investigate whether the BPS intervention can reduce affective and physiological reactivity to real-life stressors. Techniques that boost optimism, improve mood, or reduce negative cognitions may prove effective if they can help individuals to cope better with acutely stressful life circumstances, including daily hassles. If so, practicing the Best Possible Self exercise might not only be able to improve quality of life and wellbeing, but also health.

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Author contributions

MP conceptualized the study, MP, YdBM, and NN designed the study protocol. YdBM was responsible for data collection and management. NN conducted the statistical analysis. NN and MP wrote the original draft and manuscript revisions. All authors critically reviewed the manuscript for content and approved the final version.

Declarations of Competing Interest

The authors have no competing interests to declare.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.psyneuen.2020.104677.

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