Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Psychology

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Unlocking Well-Being; The Interplay of Emotion Regulation, Sleep Quality and Well-being.

Bachelor's thesis in Psychology
Supervisor: Francesca Parisi
Co-supervisor: Gerit Pfuhl
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Preface

The project was organized by the project leaders and was a part of a Doctor of Philosophy (PhD) project, conducted by Francesca Parisi. Students had the opportunity to add additional questionnaires, if needed for their research. Student contributions were formulating the consent form, which was done in a group. In addition, students recruited participants, at least five each, and tested participants in the flexilab. In total, we were able to recruit 56 participants for testing. Special acknowledgement is given to my co-students who recruited participants far beyond the requirement, ensuring a large sample size.

The hypotheses and predictions were my own, with guidance in finalizing and reducing them from both supervisors. After discussions with Gerit, we decided to add “sleep quality for the past week” to the study’s setup. Instructions on how to conduct testing in the lab was given by Francesca, who also prepared the final dataset and translated the measurements, ie. heart rate variability. The writing process, including the choice of literature was independent, but with guidance and feedback from both supervisors throughout the semester on the introduction, method, and analysis sections. EndNote was used as a referencing tool.

I am thankful for our bachelor’s group, with inspiring, and hardworking students who continued to ask questions and give answers. I wish to thank my advisors, for their continued encouragement, feedback, and guidance. I especially want to thank Gerit for entertaining all my ideas, even if they were outside of the scope of this bachelor’s thesis. In addition, I want to thank Francesca for all the support in the flexilab, and with analysis. I wish to thank my family for being so excited about the project, that it made me even more motivated. I can honestly say that I enjoyed working on this project, and this is partly due to the overwhelming support and encouragement from my fellow students, supervisors, friends, and family.

Sammendrag

Denne studien forsøkte å undersøke det komplekse samspillet mellom emosjonsregulering, søvnkvalitet og subjektiv-velvære. Teoretisk bakgrunn fra «The Process Model of Emotion Regulation» og «The Neurovisceral Integration Model” la grunnlaget for forskningen. Selv om assosiasjoner mellom HRV, kognitiv revurdering (cognitive reappraisal) og uttrykksdemping (expressive suppression) var utforsket, fokuserte hoved analysen på HRV og kognitiv revurdering som mål på emosjonsregulering. Studien hadde ett endelig utvalg på 55 deltagere, som gjennomførte ERQ, WHO-5 og svarte på spørsmålet; «hvor godt har du sovet den siste uken?». HRV ble målt med PPG. Det ble gjennomført en Kendalls Tau bivariat korrelasjonsanalyse for å undersøke forholdet mellom variablene, HRV, kognitiv revurdering, uttrykksdemping, søvnkvalitet den siste uken og WHO-5. Resultatet avslørte at HRV ikke var signifikant korrelert med kognitiv revurdering, uttrykksdemping, søvnkvalitet eller WHO-5. Kognitiv revurdering var assosiert med WHO-5, men resultatene var ikke signifikante etter det ble kontrollert for gjentagende testing. I tillegg, var kognitiv revurdering ikke signifikant korrelert med søvnkvalitet den siste uken. En medium positiv korrelasjon ble oppdaget mellom søvnkvalitet den siste uken og WHO-5. Resultatet indikerer at det er sammenheng mellom søvn kvalitet og subjektiv velvære, men videre forskning må gjennomføres for å forstå hvordan emosjonsregulering, søvnkvalitet og subjektiv-velvære fungerer sammen. Hypotesene ble både støttet og ikke støttet av resultatet, men åpnet opp for en diskusjon om forholdet mellom de tre variablene og den mulige medierende rollen til velvære i forholdet mellom emosjonsregulering og søvn.

Abstract

The main objective of this study was to explore the complex interplay between emotion regulation, sleep quality, and subjective well-being. Theoretical background from *The Process Model of Emotion Regulation* and *The Neurovisceral Integration Model* laid the groundwork for investigations. While associations between HRV, cognitive reappraisal, and expressive suppression was explored, the main analyses focused on reappraisal and HRV for emotion regulation. The study contained a final sample of 55 participants, who completed the ERQ, the WHO-5 and answered the question; "how well have you slept the last week". HRV was measured through PPG. Kendall's tau bivariate correlation analyses were performed to explore the relationships between the variables, HRV, cognitive reappraisal, expressive suppression, sleep quality for the past week, and WHO-5. The results showed that HRV was not significantly correlated with reappraisal, suppression, sleep quality or WHO-5. Cognitive reappraisal was associated with WHO-5, though results were nonsignificant after correcting for multiple testing. In addition, cognitive reappraisal was not significantly correlated with sleep quality for the past week. A medium positive correlation was revealed between sleep quality for the past week and WHO-5. The results indicate that there is an association between sleep quality and subjective well-being, but further research is a necessary to understand how emotion regulation, sleep quality and subjective well-being work together. The hypotheses, were both supported and not supported by the results, allowing a discussion on the relationship between the three variables, and the possible mediating role of well-being, in the relationship between emotion regulation and sleep.

Unlocking Well-Being; The Interplay of Emotion Regulation, Sleep Quality and Well-being.

It has long been understood that the definition of human health must include more than simply the absence of illness. One attempt at expanding this definition is the inclusion of well-being in human health.

“The core hypothesis of positive health, in fact, is that the experience of well-being contributes to the effective functioning of multiple biological systems, which may help keep the organism from succumbing to disease, or when illness or adversity occurs, may help promote rapid recovery” (Ryff et al., 2004, p. 1383).

As a requisite mechanism of human health, the experience of well-being aids in upholding the functions of a healthy body and mind. Researchers, throughout the ages, have been interested in understanding the factors necessary for attaining a state of well-being. One such factor is the quality of sleep, which has been observed to promote well-being, while simultaneously being a biological system supported by it (Hamilton et al., 2007). One component of subjective well-being, the balance of positive and negative affect, has been associated with sleep quality repeatedly within literature (Allen et al., 2016). *Emotion regulation*, strategies which enable modulation of emotional experiences, is another factor contributing to well-being. When functioning optimally, emotion regulation can enhance emotional resilience, improve interpersonal relationships, and make individuals more capable of reflection and nuanced thinking. However, poor sleep quality has been observed to reduce emotion regulation ability (Dahl, 1996). Previous studies, have mostly focused on either sleep quality, or emotion regulation in association with well-being, however there is a growing interest in the relationship between all three variables (Zaccaro et al., 2019). In this study, how these variables, emotion regulation, sleep quality and subjective well-being, work together will be explored. Although, the relationship between measures of emotion regulation will be explored, the study will be limited to focusing cognitive reappraisal as emotion regulation strategy for the main analysis, as it has been proposed to be more conducive to positive emotion and a state of well-being than suppression (Gross & John, 2003).

Conceptualization

Well-being

There are various definitions of well-being, though Ryan and Deci's (2001) integrative review was the origin of one of the more clearly articulated frameworks (Keyes et al., 2002; Ryan & Deci, 2001). From their perspective *well-being* is a two-part construction which includes both psychological well-being, also named eudemonic well-being and subjective well-being, often referred to as hedonic well-being.

Psychological well-being is described as having a state of agency in one's approach to life, whereby the individual can pursue personal development, challenged thriving and a sense of meaningful existence throughout their life. (Hamilton et al., 2007; Keyes et al., 2002). *Subjective well-being* relates to one's subjective experience of pleasure, happiness and life satisfaction (Ryff et al., 2004). The field of hedonic psychology can be defined as "the scientific study of what makes experiences and life pleasant and unpleasant" (Kahneman et al., 1999, p. ix). It will often include the components life satisfaction, the presence of positive affect, and the absence of negative affect. The two elements, psychological and subjective well-being will reciprocally influence each other. However, a model wherein the two are correlated but distinct facets of well-being has been strongly supported through factor analytic studies (Hamilton et al., 2007; Keyes et al., 2002). Moreover, psychological well-being is primarily related to individuals' external life and how they approach this life, seeing as it includes the components, self-acceptance, positive relations with others, autonomy, environmental mastery, purpose in life and personal growth (Hamilton et al., 2007).

Subjective well-being is largely associated with individuals' internal experience, i.e. the emotions that our external life provokes internally. Thereby, emotion regulation will play a significant role in an individual's subjective well-being as it mediates the balance of positive and negative emotions (Gross & John, 2003).

Emotion regulation

Emotion regulation refers to the process through which individuals modulate their emotional experiences, expressions, and responses to adhere to their changing environment (Gross & John, 2003). There are several ways to measure individuals' ability to regulate their emotions. One method is measuring the use of different emotion regulation strategies. Regardless, "The defining feature of emotion regulation is the activation of a goal to influence the emotion trajectory" (Gross, 2015, p. 5). Effective emotion regulation strategies enable the individual to manage stressors, navigate interpersonal relationships and adapt to various challenges, ultimately contributing to well-being. However, it is necessary to explore what constitutes effective strategies. In *The Process Model of Emotion Regulation*, emotion regulation is described as a series of strategies differentiated based on the timing with which they are applied within the sequence of emotional response (Gross & John, 2003). Gross theorizes that emotions initiate through an assessment of emotional cues, prompting a synchronized set of response tendencies. Once the response tendency arise it can be modulated in various ways.

Because emotion regulation strategies are distinguished based on their timing, Gross and John differentiates between antecedent-focused strategies, applied early in the emotion generative process, and response-focused strategies, applied later. The antecedent-focused strategies are applied before any response changes have been activated. They centre around selection of situation, modification of situation, attentional deployment, and lastly cognitive change. The response-focused strategies refer to changes in behaviour we apply once the emotion is already experienced, and thereby they centre around response modification. Seeing as antecedent-focused strategies occur before an emotion has been fully generated, they have the power of altering the entire emotion trajectory. For this reason, they can effectively reduce the impact of negative emotions, and heighten the experience of positive ones. Contrarily, response-focused strategies are applied only after the emotion has been experienced. Thereby, they only have the power to affect the outwardly expression of emotion. Response-focused strategies will have limited efficacy in reducing an individual's experience of negative affect.

Gross and John present *cognitive reappraisal* as an example of an antecedent-focused strategy. It is a cognitive adaptation technique that entails interpreting a potentially emotion-triggering situation in a manner which changes its emotional impact. Reappraisal serves to alter an individual's perception of a situation in a way that elicits fewer negative emotions and more positive ones. According to one study, the use of cognitive reappraisal has been positively correlated with positive emotion, as measured by PANAS, $r = .42$, $p < .05$ (Gross & John, 2003). In addition, it has been correlated with self-reported experience of 6 discrete positive emotions, $r = .35$, $p < .05$. Moreover, reappraisal was negatively correlated with negative emotion measured by PANAS, $r = -.51$, $p < .05$, and with self-reported experience of 6 discrete negative emotions, $r = -.47$, $p < .05$. Lastly, reappraisers reported a higher satisfaction in life, $\beta = .30$, $p < .05$. Thereby, cognitive reappraisal has been found to correlate with all three aspects of subjective well-being. Although less relevant to the present study, positive correlations have also been reported between reappraisal and psychological well-being.

Expressive suppression is a response-focused strategy of emotion regulation. It involves inhibiting initiated emotional expressions (Gross & John, 1998). Therefore, suppression should be an effective tool for reducing behavioural expressions of negative emotion, e.g. anger or sadness, but may also affect expression of positive emotion. The expression of emotion, both negative and positive serves to influence the people around us, and functions as a driving force in conflict as well as connection. It helps us to resolve interpersonal as well as personal issues. The suppression of emotional expression requires effort that would normally be centred towards ideal performance in social contexts (Gross & John, 2003). Moreover, it creates dissonance between an individual's internal experience and outer expression. This inauthenticity may strengthen the initial negative emotion, as well as isolate the individual from the people around them. In fact, expressive suppression has been negatively correlated with positive emotion, and positively correlated with negative emotion, measured by PANAS. The study by Gross and John also found significant negative correlations between expressive suppression and satisfaction with life. In contrast to cognitive reappraisal, the response-focused strategy was negatively correlated with the components of subjective well-being, signifying that when individuals use expressive suppression as their dominant strategy, their well-being is affected.

Heart rate variability

Another way of measuring emotion regulation ability is through heart rate variability (HRV). *Heart rate variability* refers to the fluctuation in the time intervals between consecutive heart beats (Quintana & Heathers, 2014). A heart beats, when electrical signals from the sinoatrial (SA) node initiates the contraction of heart muscles (Ernst, 2017). Nevertheless, the rate of heart beats is carefully mediated by the automatic nervous system (ANS), which acts automatically in controlling various organ systems. It is divided into a sympathetic and parasympathetic component. With the former being an activation agent, responsible for the "fight or flight" response and the latter being a relaxation agent, responsible for the "rest and digest" response. During sympathetic nervous system (SNS) activation, the release of the neurotransmitter norepinephrine works to speed up the heart rate by stimulating the SA node. Contrarily activation of the parasympathetic nervous system

(PNS) leads to the release of acetylcholine which slows down the heart rate by inhibiting the SA node. These mechanisms contribute to the adaptability of the ones heart and, consequently, the variability of the heart rate to respond to the demands of the environment.

According to *The Neurovisceral Integration Model*, heart rate variability is an indicator of emotion regulation ability due to the connectivity observed between the central autonomic network (CAN), ANS and the SA node of the heart (Thayer & Lane, 2000). The CAN is “an integrated component of an internal regulation system” (Thayer & Lane, 2000, p. 204), through which the brain controls internal organ function, the interaction between the nervous and hormonal systems, and behavioural responses. These functions are all necessary for emotional behaviour modification and emotional adaptability. The CAN includes several brain regions, including different parts of the prefrontal cortex and the central nucleus of the amygdala. The output of the CAN is facilitated through neurons in the ANS. These neurons extend to the SA node of the heart through the stellate ganglia and the vagus nerve, which is why heart rate variability often is described as a reflection of “vagus tone”. The Neurovisceral Integration Model proposes that the CAN and emotion regulation structures are one and the same functional network. According to Thayer and Lane, the network of structures is responsible for the process of emotional response organization and selection. Processes which are outlined in The Process Model of Emotion Regulation.

It has been reported that a high HRV indicates a healthy balance between the two components of the ANS, as it suggests that both neurotransmitters are being released effectively and in appropriate proportions (Mather & Thayer, 2018). A high HRV indicates a dynamic automatic nervous system, reflecting a flexible psychological state conducive to well-being. The reasoning being that the nervous system manages to shift between an activation and relaxation state easily and effectively. In fact, “having high heart rate variability is associated with higher emotional well-being, including being correlated with lower levels of worry and rumination, lower anxiety, and better regulated emotional responding" (Mather & Thayer, 2018, p. 98). Thereby, a high heart rate variability would indicate a well-adapted emotion regulation ability and stress resilience, whereas a low HRV would signify the opposite. In one laboratory experiment, a significant difference was revealed between participants' baseline HRV and HRV when utilizing cognitive reappraisal, $t(41) = 2.69$, $p = .01$, d =44 (Denson et al., 2011). However, no significant change in HRV was found for participants in the expressive suppression condition or the control condition. This research suggests that cognitive reappraisal can potentially increase HRV, which again reflects a greater ability to emotion regulate.

Nevertheless, findings in the research on HRV as a biomarker of emotion regulation strategies are quite inconsistent. Significant positive associations have been reported (Capuana et al., 2014; Gentzler et al., 2009; as cited in Holzman & Bridgett, 2017), although effect sizes vary. A handful of studies have not found any significant correlations, (Gyurak & Ayduk, 2008; as cited in Holzman & Bridgett, 2017; Santucci et al., 2008).

Sleep quality

Sleep is an essential prerequisite of human health, necessary for the maintenance of well-being and for the balance of positive and negative emotion (Fairholme & Manber, 2015). It is an established fact that people need sleep. However, sleep duration has been proven to have little predictive value on human health, well-being, or emotion regulation ability. Aspects of sleep that prove more significant is the quality of sleep. The sleep disruptions evident in sleep disorder patients usually presents themselves as sleep fragmentation, i.e. short arousals that interrupt sleep (Vandekerckhove & Cluydts, 2010). Such fragmentations reduce sleep quality while sleep quantity is left intact. Seeing as sleep is essential for human health, it is necessary to understand the effect of sleep for human functioning (Fairholme & Manber, 2015).

There is extensive research done on the effect of sleep quality on emotional functioning. To understand the impact of poor sleep quality on emotions the brain structures involved in emotion regulation have been studied (yoo et al., 2007). First of all, the pre-frontal cortex is highly relevant for top-down cognitive control. Attention, information processing and the ability to modify thoughts and behaviours are all aspects of cognitive control also necessary for emotion regulation. Furthermore, the amygdala plays a key role in emotion generation. When an individual is sleep deprived there is a reduced functional connectivity between the PFC and amygdala (Fairholme & Manber, 2015; yoo et al., 2007). In fact, sleep deprivation weakens the influence of the PFC over several other brain regions, which results in a decreased regulation of emotions, drives and impulses (Baglioni et al., 2010). This indicates that the emotion regulatory processes that rely on cognitive control will be impaired with reduced sleep quality. Cognitive reappraisal will thereby suffer, as one has to be able to redirect one's attention to new information, keep that information in mind and assume a different perspective to utilize this strategy (Muzur et al., 2002; yoo et al., 2007). Seeing as the goal of cognitive reappraisal is to increase positive emotions and decrease negative ones, a reduction in sleep quality would possibly have the opposite effect as it impairs an individual's ability to cognitively reappraise. In fact, McCrae et al. reported positive within-group correlations between sleep quality rating and positive affect, measured by PANAS, $r = .22$ $p < .05$ (McCrae et al., 2008). In addition, a negative within-group correlation was reported between sleep quality rating and negative affect, $r =- .30$ $p <.001$. Similar correlations were found between groups. The correlation indicates that higher sleep quality increases positive and decreases negative affect, while a lower sleep quality would decrease positive and increase negative emotion.

Expressive suppression is dependent on the ability to not act on impulses but rather constrain them. Such regulation of behaviour is effortful. However, when sleep deprived there is a reduction in the cognitive-energy resources required for behavioural control (Baglioni et al., 2010). There are some studies which prove that sleep quality may be associated with maladaptive emotion regulation strategies, however results about the association with suppression are inconclusive (Boon et al., 2023). Results from one study showed that impaired sleep quality is associated with more difficulty to inhibit responses to negative events. However, there is also evidence against this hypothesis. It is important to note that both theory and research suggests that expressive suppression is not a very effective strategy in emotion regulation and may not contribute to an improved well-being (Gross & John, 2003).

Relative to the vast field of literature on sleep quality's effect on emotion regulation, fewer studies have focused on the effect that regulation of emotion has on sleep quality. It would be appropriate to suggest that an individual who, around bedtime, experiences a lot of negative emotions such as stress, anxiety, sadness or anger, would find it more difficult to fall asleep and have a lower sleep quality once they do. Resilience to stress has previously been measured by HRV (Mather & Thayer, 2018). Moreover, the effect of stress on sleep quality has been well documented within the field. Stress can be defined as a psychophysical state which produces "a range of emotions with negative valence and high arousal" (Fairholme & Manber, 2015, p. 51). Stress has been proven to increase sleep onset time, number and length of awakenings. In addition, research shows a decrease in the time spent in rapid eye movement (REM) sleep and slow wave sleep (SWS). Seeing as stress generates a range of negative emotions, there may be a relationship present between emotion regulation and sleep.

The present study

The present study seeks to explore the interplay between the variables, emotion regulation, sleep quality and subjective well-being. The question asked is "what is the relationship between emotion regulation, as measured by HRV and ERQ, sleep quality and subjective well-being, measured by WHO-5?". Past hypothesis 1, cognitive reappraisal and HRV will be of main interest for emotion regulation. The reason behind this choice is that reappraisal has been proven to be more effective than suppression, and thereby most conducive to well-being. To address the research question, the following hypotheses were formulated. All hypotheses were preregistered on OSF (https://doi.org/10.17605/OSF.IO/G3RB9). If hypothesis 1 is falsified, the two measures of emotion regulation will be treated separately in the following analyses.

H1: Heart rate variability is related to score on the emotion regulation questionnaire.

Prediction a: higher HRV is related to a higher score in cognitive reappraisal.

Prediction b: Higher HRV is related to a lower score in expressive suppression.

H2: Emotion regulation is related to subjective well-being.

Prediction a: Higher HRV is related to a higher score on the WHO-5.

Prediction b: Higher score of cognitive reappraisal (ERQ) is related to a higher score on the WHO-5.

H3: Emotion regulation is related to sleep quality.

Prediction a: Higher HRV is related to a higher sleep quality the past week.

Prediction b: Higher score of cognitive reappraisal is related to a higher sleep quality the past week.

H4: sleep quality is related to subjective well-being.

Prediction: Higher sleep quality the past week is related to a higher score on the WHO-5.

Method

Sample

Data for the current study was collected from a sample of 56 participants recruited through convenience sampling. One participant was excluded due to not meeting the inclusion criteria. The final sample was *N*=55. Bachelor students recruited participants through their social networks, with the aim of ensuring diversity within the sample. Inclusion criteria required participants to be at least 18 years of age and without any serious diagnosed psychological or neurological conditions, e.g. major depression, epilepsy, brain tumour or Parkinson's disease. Informed consent was obtained from all participants, who received consent forms prior to entering the lab. The final sample consisted of 26 men and 29 females, with a mean age of 24.73 years (*SD*=4.37). Participants' ages ranged from 20 to 42 years old. Three scores were removed from the HRV sample, due to noise in the ppg recording. In addition, there were four missing values from the ppg. One score was removed from the WHO-5 and the ERQ samples, because the participant was not a native Norwegian speaker and thus did not understand the questions being asked. Four scores were missing from the variable sleep quality for the past week.

Measures

Descriptions of all measures were formulated in collaboration with the project supervisor. All measurements within the study can be found on OSF (see link in procedure section).

WHO-5 Well-being Index

Well-being was measured using the WHO-5 wellbeing questionnaire (Topp et al., 2015), which assesses subjective well-being. The questionnaire was published in 1998 and developed at the Mental Health Centre North Zealand in Hillerød, Denmark (Kaiser &

Kyrrestad, 2019). It was translated into Norwegian by Olaf Bakke in 2004. The WHO-5 has served as both an outcome measure in clinical trials and as a screening tool for depression. The questionnaire asks respondents to rate how they have been feeling the last two weeks and takes approximately three minutes to answer. It consists of 5 statements which the participants rated on a Likert scale (1= *none of the time* to 6 = *all the time*). In the original version scores ranged from 0 to 25, with a higher score reflecting greater subjective well-being. In this study scoring was from 5 to 30. The Norwegian version of the WHO-5 has a high internal consistency with Cronbach's alpha of α= .873 and McDonald's omega of ω= .879 (Nylén-Eriksen et al., 2022). In the present study Cronbach's α was .743 (95% CI .613; .835) and McDonald's ω coefficient was .746 (95% CI .639; .853; (Parisi et al., 2024)).

Photoplethysmography (PPG)

Emotion regulation ability was determined through measuring heart rate variability and the Emotion Regulation Questionnaire (ERQ,10 items)(Gross & John, 2003). HRV was recorded by use of an optical plethysmographic (PPG) method on the non-dominant index finger, using the BioPac system. PPG makes use of a light source and a photodetector on the surface of the skin to measure the changes in blood volume in the circulation (Park et al., 2022). After recording, PPG was translated into heart rate activity. It was recorded on AcqKnowledge 5.0, for a minimum of 5 minutes while the participant was in a state of rest and before any other tests were conducted. R-wave times of heartbeats were initially detected automatically, with subsequent visual inspection. Actual peaks missed by automatic detection were added, misidentified peaks and noise were removed. Missing data estimation was omitted intentionally, so that the analysis was rooted solely in actual R-wave times and not estimations. RMSDD was calculated as the primary time-domain measure for the vagally mediated changes reflected in HRV (Parisi et al., 2024). A higher HRV with high R-R intervals indicated better emotion regulation ability and higher stress resilience (Mather & Thayer, 2018).

Emotion regulation questionnaire (ERQ)

The Emotion Regulation Questionnaire was developed in 2003, by Gross and John (Gross & John, 2003). The instrument is one of the most employed measures for assessing emotion regulation and has demonstrated strong psychometric qualities in both clinical and population samples (Haver et al., 2023). It was translated into Norwegian by Annie Haver and approved by the developer James Gross. The Emotion Regulation Questionnaire holds 10 items, with two subscales, which measure two different emotion regulation strategies. The first being cognitive reappraisal and the second, expressive suppression. Participants responded to each item on a 7-point Likert scale with scores ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). For the cognitive reappraisal subscale, scores ranged from 4 to 28, while for the expressive suppression subscale, scores range from 4 to 28. For the English version, Cronbach's alpha was $\alpha = .75$ for cognitive reappraisal, and $\alpha = .68$ for expressive suppression. Test–retest reliability across three months was .69 for both scales (Gross & John, 2003). In the present study internal consistency for the cognitive reappraisal subscale was Cronbach's alpha of .836 (95% CI: .755; .895) and McDonald' omega of .842 (95% CI .778; .907. For the expressive suppression subscale Cronbach's alpha was .77 (95% CI: .652; .854) and McDonald's omega was .785 (95% CI: .691; .879; (Parisi et al., 2024)).

Sleep quality past week

Sleep quality was measured by a single-item self-report scale. The question asked was "how well have you slept the last week?". The participants answered on a scale from 0 (*really bad*) to 10 (*amazing*). A visual analogue scale (VAS) was used, which increases the sensitivity of the measure (Snyder et al., 2018). The single-item scale utilized resembles the single-item sleep quality scale (SQS) which has been proven to enable a rating of sleep quality over a one week recall period while minimizing the cognitive demands on the patient. The SQS scale has been validated through two clinical trials, one insomnia study and one depression study.

Procedure

The study was conducted in the flexilab at NTNU, with two test administrators, usually bachelor students, present. One participant was tested at a time, and each test lasted approximately two hours. Participants received a 300 kroner voucher to Kiwi as compensation for participating. Firstly, participants filled out the consent form, which they had been sent prior to their lab appointment. Testing commenced with the measuring of participants' HRV and was followed by the completion of various questionnaires. The measures relevant for the current research were the first to be completed. The test administrators went into a separate room during photoplethysmography (PPG) recording, and while the participant filled out the questionnaires, however they were always within reach. This study was a part of a larger laboratory study, and included several questionnaires, tests and psychological measures (https://osf.io/g9cwf/?view_only=54027d1f69f14ea09b4c7a8d9684ed19). The project was approved by the ethics committee at NTNU and SIKT has approved our processing of personal data. Data was collected in the period between the 15th of February and the 22nd of March 2024

Analysis

The analyses were conducted in the statistical software JASP 0.18.3.0. All analyses were confirmatory and preregistered in OSF. First of all, assumptions were checked, and it was determined that Kendall's tau would be applied as method of analysis. The reasoning being that neither normal distribution nor linearity of data could be guaranteed. Bivariate correlation analyses were performed, assessing the relationship between; cognitive reappraisal, expressive suppression, HRV, sleep quality the past week and subjective well-being. Before performing the analyses, three datapoints were excluded from the HRV sample, due to noise. In addition, one participant was removed from all questionnaires (e.g ERQ and WHO-5) because of the language barrier. Analysis for hypothesis 1 will be performed to check if there is a clear relationship between the two different measurements of emotion regulation; HRV and the ERQ, and if I thereby can treat them together. If there is no relationship, the measurements will be kept separate in following analyses. Analyses conducted for hypotheses 2 to 4 represent the main analyses, with the aim of exploring the research question. Analysis for hypothesis 1 is conducted first with the purpose of understanding the variable, emotion regulation, but also to understand the relationship between HRV and cognitive reappraisal. To correct for multiple testing, the false discovery rate will be applied using the Benjamini-Hochberg procedure so that false-positive results may be identified. If the corrected p-values are $p < .05$, the results will be considered significant.

Results

For the variable heart rate variability, the mean was 0.056 sec (*SD*=0.028), based on a sample of *N*=48. Scores ranged from 0.014 sec-0.148 sec, with a range of 0.134 sec. The Emotion Regulation Questionnaire (ERQ) and the WHO-5 Well-being Questionnaire had a sample size of *N*=54. The mean score for cognitive reappraisal was 26.57 (*SD*=6.45), with a range of 31 (scores ranged from 6 to 37). Expressive suppression had a mean score of 13.06 (*SD*=4.51), with a range of 17 (scores ranged from 4 to 21). For the WHO-5 questionnaire, the mean score was 19.44 (*SD*=4.23), with a range of 17 (scores ranged from 11 to 28). Regarding sleep quality over the past week, the sample for the variable sleep quality was *N*=51, with a mean score of 6.02 (*SD*=2.07). The range was 9 (scores ranged from 1 to 10).

For hypothesis 1, analysis revealed that there were no significant correlations between HRV and cognitive reappraisal, $\tau\_b(46)$ =- .02, p = .876 or between HRV and expressive suppression, $\tau\_b(46)$ =- .15, p = .138. Thereby, both predictions, a and b, were not supported, and I will continue to treat the variables as separate, without the assumption that they measure the same aspect of emotion regulation.

Table 1

Kendall's Tau Correlations

Variable		HRV (rmssd)	ERQ - reappraisal	ERQ - suppression
1. HRV (rmssd)	Kendall's Tau B	—		
	p-value	—		
	Upper 95% CI	—		
	Lower 95% CI	—		
2. ERQ - reappraisal	Kendall's Tau B	−0.016	—	
	p-value	0.876	—	
	Upper 95% CI	0.169	—	
	Lower 95% CI	−0.201	—	
3. ERQ - suppression	Kendall's Tau B	−0.153	0.022	—
	p-value	0.138	0.822	—
	Upper 95% CI	0.055	0.221	—
	Lower 95% CI	−0.361	−0.177	—

For hypothesis 2, emotion regulation is related to well-being, analysis revealed no significant correlation between HRV and WHO-5, $\tau\_b(45)$ = .001, p = .993. The 95% confidence interval ranged from -0.203 to 0.205. However, there was a significant positive correlation between cognitive reappraisal and WHO-5, $\tau\_b(52)$ = .022, p = .024, with 95% confidence intervals ranging from 0.048 to 0.396. This means that there was a significant association between a participants score on the cognitive reappraisal subscale and their score on subjective well-being. However, even though the results were significant, the size of the association is very small. Thereby, prediction b "Higher score of cognitive reappraisal (ERQ) is related to a higher score on WHO-5" is somewhat supported by the analysis.

For hypothesis 3, emotion regulation is related to sleep quality, there was no significant correlations between HRV and sleep quality for the past week, $\tau\_b(43)$ = .10, p = .345 (95% CI: -0.081-0.288), or between cognitive reappraisal and sleep quality, $\tau\_b(48)$ =- .08, p = .453 (95% CI: -0.259-0.099).

For hypothesis 4, sleep quality is related to well-being, analysis revealed that there was a medium positive correlation between sleep quality the past week and well-being as measured by the WHO-5, $\tau_b(48) = .31$, $p = .004$. The 95% confidence interval ranged from 0.123 to 0.490. Thereby, the analysis supports the prediction "Higher sleep quality the past week is related to a higher score on WHO-5".

Table 2

Kendall's Tau Correlations

			Kendall's tau B	p	Lower 95% CI	Upper 95% CI
HRV (rmssd)	-	ERQ - reappraisal	−0.016	0.876	−0.201	0.169
HRV (rmssd)	-	Sleep quality - week	0.104	0.345	−0.081	0.288
HRV (rmssd)	-	WHO-5	9.537×10^{-4}	0.993	−0.203	0.205
ERQ - reappraisal	-	Sleep quality - week	−0.080	0.453	−0.259	0.099
ERQ - reappraisal	-	WHO-5	0.222	0.024	0.048	0.396
Sleep quality - week	-	WHO-5	0.306	0.004	0.123	0.490

After correcting for multiple testing using the Benjamini-Hochberg procedure the adjusted p-values were as follows; prediction 2a, p_{adj}= .993, prediction 2b, p_{adj}= .060, prediction 3a, p_{adj}= .566, prediction 3b, p_{adj}= .566, prediction 4, p_{adj}= .020 (in the same order as reported above). After applying the false discovery rate, the correlation between sleep quality the past week and WHO-5 was the only relationship that remained significant, $\tau(48)$= .31, p_{adj}= .020.

Discussion

The aim of this study was to further understand the intricate interplay between emotion regulation, sleep quality and subjective well-being. Before the main analyses, an exploration of the relationship between the measures of emotion regulation, HRV and the ERQ was deemed necessary. Unexpectedly, analyses revealed no significant correlation between neither HRV and cognitive reappraisal, nor HRV and expressive suppression. In exploring hypothesis 2, a positive correlation was uncovered between cognitive reappraisal and the WHO-5, though after correcting for multiple testing the results did not remain significant. No significant relationship was found between HRV and the WHO-5. Additionally, no significant correlations were found between HRV, cognitive reappraisal and sleep quality for the past week. In line with hypothesis 4, analysis revealed a medium positive correlation between sleep quality in the past week and the WHO-5. The adjusted p-value was $p_{adj} = .020$.

No correlations were found between HRV and either subscale of the ERQ. Given that both are considered measures of emotion regulation, correlations in scores between the two were expected. In fact, there is substantial support for an expected relationship from theory, i.e. The Neurovisceral Integration Model (Thayer & Lane, 2000), and neurobiological interconnectivity observed between the prefrontal cortex, the ANS and the SA node of the heart (Holzman & Bridgett, 2017). Nevertheless, the results were not entirely surprising. Findings in the literature exploring the relationship between heart rate variability and emotion regulation strategies are inconsistent at best. For those studies that do report significant positive associations, effect sizes vary greatly.

Denson et al. has reported a significant difference between participants' baseline HRV and HRV when applying cognitive reappraisal, in an experimental study, $t(41) = 2.69$, $p = .01$, $d = 44$ (Denson et al., 2011). These results indicate that HRV increases when participants use cognitive reappraisal. However, HRV returned to baseline after the experimental condition was completed. Additionally, there were no differences in post-experimental HRV between participants in the reappraisal, suppression, and control conditions. Therefore, one possible explanation for the discrepancy of results is that individuals' HRV may be a reflection of an ongoing emotion regulatory process rather than a marker of a particular tendency to use one strategy over another. No significant change was found in HRV for participants applying expressive suppression as emotion regulation strategy, $t(44) = 1.55$, $p = .13$, $d = .23$. In the current study, HRV was measured at rest, which may explain why no significant relationship was present between HRV and the subscales of the ERQ. Consistent with this study, several others have found no significant relationship between HRV and emotion regulation strategy measurements (Gyurak & Ayduk, 2008; as cited in Holzman & Bridgett, 2017; Santucci et al., 2008).

Another possible reason for the inconsistency in research is that emotion regulation is not the only top-down regulatory process which effects heart rate variability. Although, the ERQ measures the use of specific emotion regulation strategies, HRV is often described as a measure of the balance between the two components of the automatic nervous system. The conceptualization of HRV as a biomarker of emotion regulation is based on the connectivity found between the prefrontal cortex and cardiac activity (Thayer & Lane, 2000). The prefrontal cortex, while responsible for CAN functioning, is also responsible for several other top-down executive functions. In fact, while The Neurovisceral Integration Model initially proposed that HRV was a biomarker of emotion regulation, the model has since been expanded to include "several aspects of executive functioning, including inhibitory control, attentional regulation, and working memory" as influences on HRV (Holzman & Bridgett, 2017, p. 236; Thayer et al., 2009). In conclusion, the relationship between HRV and emotion regulation processes is likely influenced by several other moderators stemming from the prefrontal cortex.

Even if HRV is a measure of broader top-down self-regulation rather than specifically targeting emotion regulation, one would still expect to observe a relationship between HRV and well-being, given that a greater self-regulation capacity presumably increases well-being. However, this was not the case. The current study found no significant relationship between HRV and subjective well-being, measured by WHO-5. One possible explanation may be that PPG does not successfully capture HRV. Traditionally, an electrocardiogram (ECG) is used to measure heart rate variability. This method requires the placing of electrodes on the participants body (ChuDuc et al., 2013), and can be seen as more invasive than other measures of HRV. PPG measures has been recognized as a promising alternative, with research showing a sufficient accuracy when compared to HRV measured by ECG in healthy subjects at rest (Pinheiro et al., 2016). Despite this, one major obstacle in measuring HRV by using PPG, is its sensitivity to movement. Because of this sensitivity, breathing patterns have been found to alter the characteristics of PPG measured HRV (Han et al., 2019). This sensitivity may prevent a correct estimation of HRV and mask any existing relationship between HRV and well-being. Nevertheless, research critical to the use of PPG mostly refers to HRV measurements done by wrist-worn devices. Data from these devices is usually collected from home, with participants wearing the watch throughout the day. Therefore, there is no way of controlling for confounding variables, e.g. breathing and movement. For the current study, PPG was recorded in the lab, as the first test completed, with participants instructed to keep their hand still and move as little as possible. In addition, PPG was recorded from the non-dominant index finger using the BioPac system and not a wrist-worn device. Therefore, the explanation that PPG did not capture HRV successfully is unlikely. In this instance, the explanation that other mediating factors influence HRV in a way which conceals any relationship between the two variables is plausible. Especially considering that I initially found a significant relationship between cognitive reappraisal, another emotion regulation measure, and the WHO-5.

In the present study, participants who scored higher on the use of cognitive reappraisal as emotion regulation strategy also scored higher in subjective well-being, as measured by WHO-5. However, the results did not remain statistically significant after correcting for multiple testing. Initially, the findings supported the notion of reappraisal as an adaptive emotion regulation strategy, conducive to a greater well-being and provided additional support to the Process Model of Emotion Regulation. However, in comparing the results to a previous study (Gross & John, 2003), which explored the correlations between cognitive reappraisal and the separate components of subjective well-being, the association initially found in the current study was notably weaker, well under the threshold for a weak association (i.e. τ_b = .06; (Gilpin, 1993). This threshold was calculated, based on the Pearson's r threshold for a weak relationship, i.e. r = .10 (Field, 2018). The study by Gross and John found significant correlations between reappraisal and positive emotion (PANAS), r = .42, negative emotion (PANAS), r =- .51, and satisfaction with life, β =. 30. The fact that the association in the current study is so weak, is likely the reason why the results did not remain significant after correcting for multiple testing. Regardless, the current research contributes to the growing understanding of antecedent-focused emotion regulation strategies and the influence they have on subjective well-being, as they allow for manipulation of the emotional response trajectory.

Neither HRV nor cognitive reappraisal was correlated with sleep quality for the past week. The expectation that higher HRV is correlated with higher sleep quality aligns with previous research (Fairholme & Manber, 2015). According to Fairholme and Manber, stress has been proven to decrease several aspects of sleep quality. A resilience to stress, as high

HRV indicates (Mather & Thayer, 2018), would thereby increase the same aspects. Moreover, poor sleep quality has been found to reduce the functional connectivity between the pre-frontal cortex, responsible for emotion regulation, and several other brain regions, impacting one's ability to use cognitive reappraisal (Fairholme & Manber, 2015; yoo et al., 2007). Because cognitive reappraisal allows individuals to increase positive and decrease negative emotion, higher sleep quality would be expected to also induce more positive and less negative emotion. This expectation aligns with results from a previous study, who reported positive within-group correlations between sleep quality rating and positive affect, and negative within-group correlations for negative affect, (McCrae et al., 2008). These results may support the notion that cognitive reappraisal is associated with sleep quality. However, it is possible that other processes were responsible for the prevalence of positive and negative emotion in the mentioned study, rather than the use of cognitive reappraisal.

One possible explanation for why my results did not correspond with previous research is that the use of a subjective single-item measurement may not be suitable for capturing sleep quality in this context. First of all, a discrepancy have been highlighted, across research, between objective sleep estimations and perception of sleep quality in clinical populations, including insomnia disorders (Cudney et al., 2022). Overall, objective measures of sleep and subjective experiences of quality of sleep are not as closely related as was previously believed. According to Cudney et al., the duration of sleep, wake after sleep onset, the state of mind before bedtime (e.g. experience of stress), and mood upon awakening are important determinants of subjective sleep quality ratings. Furthermore, the participant's feelings the next day has been reported as the most important variable used by participants for self-reported sleep quality. Thereby, it seems that subjective judgements of sleep quality may reflect aspects unrelated to objective sleep quality.

Nevertheless, several studies have pointed out that we lack objective sleep indicators that are financially feasible, while also being valid and reliable methods to measure sleep (Cudney et al., 2022). The single-item scale used for sleep quality in the present study closely resembles the SQS, which is developed based on “a literature review of key aspects of sleep quality, critical components of the PSQI and the MQI, and direct expert and patient input (Snyder et al., 2018, p. 1850)”. The PSQI and MQI are both multi-item validated measures. The scale used in the study by Snyder et al., appeared to be both face and content valid. In their study, the single-item sleep quality scale was favourable to an objective measure as it decreased the patient’s burden and allowed insight into the patient’s subjective perception of sleep quality. Moreover, the measure has been deemed appropriate when several questionnaires or experiments are to be conducted in the same study, as was the case in the current study. Thereby, even though there is considerable research criticising the use of subjective single-item measurements, there are also studies which defends its use.

However, this study included participants in a clinical sample, where it is more important to protect the patient’s energy resources than in the general population. In addition, the SQS included instructions which stated “please think about the quality of sleep overall, such as how many hours of sleep you got, how easily you fell asleep, how often you woke during the night (except to go to the bathroom), how often you woke up earlier than you had to in the morning, and how refreshing your sleep was” (Snyder et al., 2018, p. 1851). Such instructions remind the patients of elements such as sleep duration, sleep latency and sleep fragmentation and strengthen the quality of the measure. Because we did not have any instructions, it is more difficult to determine which element of sleep the participants focused on. It may be possible that our single-item sleep quality measurement is responsible for the results not corresponding to earlier research. Another possible explanation is that the relationship between sleep quality and emotion regulation is mediated by one or more moderators.

Although no significant correlations were found between cognitive reappraisal and sleep quality, there was a medium positive correlation between sleep quality the past week and the WHO-5, $\tau\_b(48) = .31$, $p_{adj} = .020$. The results were in line with hypothesis 4 and give further support for an association between sleep quality and the components of subjective well-being, presence of positive affect, absence of negative affect and life satisfaction. The results correspond to research exploring correlations between sleep quality, positive and negative affect (McCrae et al., 2008). In the study by McCrae et al., sleep quality was significantly correlated with positive emotion, $r = .22$, $p < .05$, and with negative emotion, $r =- .30$, $p < .001$.

It may seem counterintuitive that sleep quality did not correlate with cognitive reappraisal, when the strategy promotes the experience of more positive affect over negative, and it does in fact correlate with subjective well-being, which includes the presence of more positive affect and less negative affect. Based on the results of this study, the proposed explanation is that well-being has a mediating role in the relationship between emotion regulation and sleep quality. Of course, it is possible that cognitive reappraisal, and sleep quality independently influence well-being, however it is equally possible that emotion regulation is associated with sleep quality through its influence over well-being. In this view, cognitive reappraisal might improve well-being, which in turn positively affects sleep quality. Considering this in the reverse order is equally valid, sleep quality may also be associated with emotion regulation through its influence over well-being. To my knowledge, research has yet to explore the proposed relationships.

Strengths and limitations

One strength of this study is that it is a laboratory study. While most research using questionnaires, allow their participants to answer questionnaires from home, having them answered in the lab ensures that each participant is in the same environment. Distractions such as noise, mobile devices or other people was controlled, so that participants could use their full attention on the task at hand. Additionally, the setting allowed the researchers to control that heart rate variability was measured at rest. If heart rate variability was measured using smartwatches or similar wrist-worn devices, we could not be sure that the participant was sitting still, not moving their hand, or even if the watch was worn by the participant in question.

Additional strengths are that all hypotheses were preregistered in OSF, and that the false discovery rate was applied to correct for multiple testing. Preregistration adds to the credibility of the research because the hypotheses and analyses were committed to before seeing the data. This prevents a biased analysis of data or interpretation of results. Moreover, correcting for multiple testing using the Benjamini-Hochberg procedure helps reduce the risk of false positive results when conducting multiple tests, as it controls for the type I error rate.

In acknowledging the limitations of this study, the use of convenience sampling as sampling method should be addressed. Although convenience sampling facilitates swift data collection and minimizes logistical challenges, there are several limitations to the method that must be recognized. Firstly, relying on convenience sampling introduces the risk of a selection bias. Because participants were chosen based on their accessibility rather than through random sampling methods there is an increased chance that the sample is not representative of the general population. To exemplify, the age span of the current sample was 20 to 42 years old. However, the mean age of the sample was 24.73 (*SD*=4.37), meaning that many of the participants were on the younger side. HRV, emotion regulation strategies and sleep quality have all been seen to change with age (Zaccaro et al., 2019). Consequently, the representativeness and resulting generalizability of my findings will be compromised. Additionally, other contextual factors may influence the data. Seeing as the researchers responsible for recruiting were students, it is likely that many of our participants were university students or graduates. Despite these constraints, efforts were made to mitigate biases when selecting participants to recruit. It was ensured that participants were recruited from several different fields of study, some were recruited through work, whereas others were more randomly chosen.

Furthermore, confounding variables were not controlled for in this study. Factors not accounted for could potentially influence the relationship between the variables under investigation, namely emotion regulation, sleep quality and well-being. For example, age, gender, exercise, socioeconomic status, or pre-existing health conditions could serve as confounding variables, impacting the observed outcomes. The lack of control for these potentially influential factors introduces a level of uncertainty that should be considered. Future research should consider incorporating control measures for these confounding variables to enhance the validity and reliability of the study findings.

Lastly, some limitations that have previously been discussed should be mentioned. The single- item, self- report format of the sleep quality scale introduces some limitations. The format does reduce the reliability of a sleep quality scale compared to validated multi-item scales, as it may not consistently measure the intended construct across situations or over time. In addition, the validity is in question as the measure may not be capable of capturing the multidimensional construct that is sleep quality. Factors such as sleep duration, latency, efficiency, and fragmentations are all aspects of sleep quality not accounted for through a single item. In future research, it may be advisable to make use of a validated multi-dimensional measure of sleep quality, e.g. PSQI, or even utilize an objective method of measuring sleep quality, e.g. polysomnography. The self-report format, while offering a practical means of data collection, introduces a risk of further biases. Firstly, self-report measures rely on participants' ability and willingness to accurately recall and report their thoughts, feelings, and behaviours. Thereby, answers can be influenced by both memory and social desirability bias. Additionally, self-report questionnaires may not capture the full complexity of the constructs, as individuals may interpret questions differently or struggle to reduce nuanced experiences into numbered responses.

Implications and future research

The study provides a new insight into the relationship between emotion regulation, sleep quality and well-being, which holds significant implications for various fields, including psychology, public health, and clinical practice. The identification of a positive correlation between sleep quality for the past week and subjective well-being can inform effective interventions aimed at promoting better sleep as well as the enhancing of well-being. In recognising the interplay of these relationships, the importance of holistic approaches to health promotion is underscored. Often when discussing initiatives seeking to improve one aspect of life, e.g. sleep quality, the focus lies on direct actions. While advice like improving sleep hygiene, reducing screen time before bed, not eating heavy meals or, doing hard exercise before bedtime may be beneficial. By addressing emotion regulation, well-being, and sleep quality concurrently, more comprehensive strategies can be developed to improve each of them, subsequently enhancing the health outcomes in the population. As an example, improving individuals' well-being, may be an effective strategy to enhancing their sleep quality. Overall, this study underscores the interconnectedness of emotion regulation, sleep quality, and well-being, emphasizing the importance of further research and interventions in these areas.

For future research, exploring the potential mediating role of well-being in the relationship between emotion regulation and sleep quality, is interesting for a clearer understanding of how these functions work together. Employing statistical analyses such as mediation models could shed light on the underlying mechanisms through which these variables interact and influence each other over time. Additionally, exploring potential moderating factors, e.g. demographic differences or individual differences in regulation strategies could shed light on the nuanced dynamics of these relationships. Lastly, future research may want to include expressive suppression in their analyses, to further understand these relationships, and how they relate to different emotion regulation strategies, not only cognitive reappraisal. By uncovering this interplay, future research can inform the development of targeted interventions and personalized approaches to promote optimal emotion regulation, sleep quality and subjective well-being. Further research is needed to understand the complexity of these relationships.

Conclusion

In conclusion, my findings supported the notion that sleep quality and subjective well-being are associated concepts. Although there was substantial rationale for a relationship between cognitive reappraisal and well-being, the significance identified did not remain after controlling for multiple testing. Bivariate correlation analyses revealed no significant relationships between HRV, cognitive reappraisal and expressive suppression, nor between HRV, cognitive reappraisal, and subjective well-being. In addition, no significant relationships were revealed between emotion regulation and sleep quality. Thereby, the relationship between the variables heart rate variability, cognitive reappraisal, sleep quality and subjective well-being remains unclear, and further research is necessary to understand how they work together. This study has only brushed the surface of the interplay between emotion regulation, sleep quality and well-being. However, it has laid the groundwork for further exploration of factors necessary for each of these processes, and ultimately a greater understanding of human health.

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