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# Balancing Heart and Mind: Heart Rate Variability and Cognitive Reappraisal as Predictors of Child Self-Esteem

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Emotion Science

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CIÊNCIAS SOCIAIS
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Department of Social and Organizational Psychology

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*Research is formalized curiosity. It is poking and prying with a purpose.*

*- Zora Neale Hurston, Dusk Tracks on a Road, 1996*

*This work is dedicated to the courageous people in the world who face the complexity of our realities with humour and curiosity and who repeatedly resist the temptation to be lulled into simplistic explanations.*

*A quality that I am fortunate to experience on a daily basis in my work with children.*

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# Resumo

Esta dissertação investigou as relações entre duas estratégias de regulação emocional (RE) (reavaliação cognitiva (RC) e supressão expressiva (SE)), a variabilidade da frequência cardíaca (HRV) e a autoestima (AE) no contexto escolar. Compreender as interações entre estas variáveis e identificar o contributo de fatores de regulação emocional (subjetivos e fisiológicos) em relação à autoestima pode ser relevante para a promoção da saúde e da resiliência nas crianças. Para o presente estudo, foram recolhidos dados de 270 alunos do 3º e 4º ano ($M$ = 8.68 years, $SD$ = 0.85, 43,7% do sexo feminino) de escolas de Territórios de Intervenção Educativa Prioritária (TEIP) em Lisboa. Os participantes preencheram uma versão portuguesa do Questionário de Regulação Emocional para Crianças e Adolescentes, bem como a Escala de Autoestima ao Longo da Vida. Os índices de HRV foram calculados a partir de registos de Eletrocardiograma. Ao medir as respostas subjetivas e o funcionamento fisiológico durante o período de aulas, foi adotada uma abordagem com validade ecológica, que complementa os conhecimentos em investigação laboratorial. Foi realizada uma análise de regressão para testar se a interação entre as medidas de regulação emocional (subjetivas e fisiológicas) podem prever melhor as diferenças na AE do que indicadores subjetivos isoladamente. Os resultados identificaram que a RC, mas não a SE, é um fator preditor significativo e positivo da AE. A HRV não moderou a relação entre a RC e a AE, mas mostrou-se um preditor positivo da AE na análise de regressão. Estes resultados sugerem que a HRV em conjunto com o recurso a RC como constituem variáveis preditoras da AE. As relações entre as variáveis individuais e a AE são consistentes com a teoria e com investigações anteriores. No entanto, foram efetuados poucos estudos com crianças e nenhum estudo anterior analisou a combinação das estratégias da RE e da HRV como fatores de previsão da AE na meia-infância. A avaliação do funcionamento cardíaco isoladamente poderá não constituir um indicador suficiente de regulação autonómica para explicar a autoestima, sendo a dimensão do seu efeito preditor muito reduzido. Para estudos futuros seria importante a triangulação de medidas de regulação emocional (subjetivas, fisiológicas e comportamentais), incluindo outros sinais corporais para uma investigação mais abrangente de modelos inter-sistemas do funcionamento autonómico em contextos naturalistas.

*Palavras-chave:* Variabilidade da Frequência Cardíaca, Regulação da Emoção, Auto-Estima

Categorias e códigos de classificação da APA PsycInfo:

**2560** Psicofisiologia

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# Abstract

This dissertation investigated the relationship between two emotion regulation (ER) strategies (cognitive reappraisal (CR) and expressive suppression (ES)), heart rate variability (HRV) and self-esteem (SE) in the school context. Understanding the interactions between these variables and identifying the contribution of emotional regulation factors (subjective and physiological) in relation to self-esteem may be relevant to promoting health and resilience in children. For the present study, data was collected from 270 3rd and 4th grade students (M = 8.68 years, SD = 0.85, 43.7% female) from schools in Priority Educational Intervention Territories (TEIP) in Lisbon. The participants completed a Portuguese version of the Emotional Regulation Questionnaire for Children and Adolescents, as well as the Lifelong Self-Esteem Scale. HRV indices were calculated from electrocardiogram recordings. By measuring subjective responses and physiological functioning during class, an approach with ecological validity was adopted, which complements the knowledge in laboratory research. A regression analysis was carried out to test whether the interaction between emotion regulation measures (subjective and physiological) can better predict differences in SE than subjective indicators alone. The results identified that CR, but not ES, is a significant and positive predictor of SE. HRV did not moderate the relationship between CR and SE but proved to be a positive predictor of SE in the regression analysis. These results suggest that HRV together with the use of CR are predictive variables of SE. The relationships between the individual variables and SE are consistent with theory and previous research. However, few studies have been carried out with children and no previous studies have analysed the combination of ER strategies and HRV as predictors of SE in middle childhood. The assessment of cardiac functioning alone may not be a sufficient indicator of autonomic regulation to explain SE, as the size of its predictive effect is very small. For future studies, it would be important to triangulate measures of emotional regulation (subjective, physiological, and behavioural), including other bodily signals for a more comprehensive investigation of inter-system models of autonomic functioning in naturalistic contexts.

*Keywords:* Heart Rate Variability, Emotion Regulation, Self-Esteem

APA PsycInfo Classification Categories and Codes:

**2560** Psychophysiology

**3560** Classroom Dynamics & Student Adjustment & Attitudes

# Table of Contents

# List of Acronyms

**ACC** - Accelerometer

**ANS** - Autonomic Nervous System

**CAB** - Cardiac Autonomic Balance

**CAR** - Cardiac Autonomic Regulation

**CNS** - Central Nervous System

**CR** - Cognitive Reappraisal

**ECG** - Electrocardiogram

**EDA** - Electrodermal Activity

**ER** - Emotion Regulation

**ERQ-CA** - Emotion Regulation Questionnaire – Children and Adolescents

**ES** - Expressive Suppression

**HF** - High Frequency

**HR** - Heart Rate

**HRV** - Heart Rate Variability

**vmHRV** - Ventrally mediated Heart Rate Variability

**LSE** - Lifespan Self-Esteem Scale

**RCT** - Randomized Control Trial

**MR** - MindRegulation

**RMSSD** - Root Mean Square of Succesive Difference

**RSA** - Respiratory Sinus Arrythmia

**PNS** - Parasympathetic Nervous System

**SDG** - Sustainable Development Goals

**SE** - Self-Esteem

**SNS** - Sympathetic Nervous System

**TEIP** - Territórios Educativos de Intervenção Prioritária
(Educational Territories for priority Intervention)

**VIF** - Variance Inflation Factor

**WHO** - World Health Organisation

# Introduction

Growing up in the 21st century means growing up in times of uncertainty, diversification, and rapid change (Conceição, 2022). The experiences children make in their early life shape their views of the world and their own roles within it. Being able to act on and transform one's predispositions and idiosyncrasies into capabilities requires a conjunction of circumstances that work together in synergy. Resilience and mental health can be considered to indicate a successful teamplay between those diverse factors (Ungar & Theron, 2020). Data from the World Health Organisation (WHO, 2017) suggests that nearly half of adult's mental health problems start to show themselves in early adolescence which makes childhood a crucial period to trailblaze future life outcomes as the rapid development of brain structures and other bodily systems holds chances as well as vulnerabilities. National and international institutions and organisations including the WHO (2023), the European Commission (2024) and UNICEF Portugal (UNICEF, 2024b) have recognized the importance of topics such as emotional well-being and socio-emotional competences for positive life outcomes and integrated them in their policies. To support children in their world exploration efforts and enable them to make responsible decisions means to foster the development of recourses that allow them to flexibly respond and adapt to the variety of different experiences life holds for us. Understanding how those resources interact allows us to provide a better support through everyday life interactions, implementation of interventions or policy design.

The ability to regulate emotional (Djambazova-Popordanoska, 2016; Izard et al., 2008; Rawana et al., 2014) and physiological states (Hastings et al., 2008; Porges, 2009) has been associated with successful adaptation. A meta-analysis by Robson et al. (2020) concluded that "self-regulation in childhood can predict achievement, interpersonal behaviors, mental health and healthy living in later life" (p. 2). In addition, Duckworth and Carlson (2013) stated that "[s]ubstantial empirical evidence suggests that children's ability to regulate attentional, behavioral, and emotional impulses paves the way for success in school" (p. 222). Being able to meet environmental demands is associated with feelings of safety and control that are linked to autonomic functioning which in return feeds into our self-esteem (Greenberg & Arndt, 2012). Self-esteem can than act as buffers that help us cope with stress and maintain well-being (Cummins et al., 2002; Orth et al., 2012; Orth & Robins, 2022). Investigating children's regulatory abilities on both subjective and objective levels and their association with self-esteem as an important developmental outcome is thus highly relevant. To the best of our knowledge there is no research that has investigated the interaction between self-reported emotion regulation strategies in children with real-life physiological regulation in predicting self-esteem. Due to the recent development of smaller wearable toolkits for monitoring physiological signals in a less intrusive way, it is now possible to measure autonomic regulation on a large scale within naturalistic settings. Using this new approach, we hope to add valuable insight to laboratory investigations and to inspire more research on children's functioning in their natural environments (Obradović & Armstrong-Carter, 2020).

For the present study, we collected data from 270 3rd and 4th grades of schools located in priority educational intervention territories (Territórios Educativos de Intervenção Prioritária [TEIP]) in the metropolitan area of Portugal's capital Lisbon. The study is part of a larger research project, the MindRegulation Randomized Control Trial (MR-RCT, Galinha et al., 2024) which is described in more detail in the Appendix. In addition to self-reports on emotion regulation strategies and self-esteem we assessed the autonomic functioning of the students during morning classes. We want to explore how physiological measures of real-life regulatory capacity interact with subjective measures of self-regulation in explaining global self-esteem. In accordance with prior literature (Teixeira et al., 2015), we would assume that cognitive reappraisal (CR), as an emotion regulation strategy, would be associated with higher levels of self-esteem (SE) (H1). Expressive Suppression (ES), on the other hand, is expected to show a negative relation with SE (H2). HRV as a measure of regulatory capacity (Thayer & Lane, 2000) and embodied safety (Porges, 2022) should moderate these relationships. As CR has been found to be especially beneficial in contexts that are perceived by the individual as less controllable and safe (Schwerdtfeger et al., 2019) we presume that the association between CR and SE is stronger for individuals with low levels of HRV (H3). For the relationship between ES and SE on the other hand we would expect to find a buffering effect of HRV (H4) (Brown et al., 2022).

Five chapters will guide the reader through this dissertation. The first chapter addresses the importance of the research question by outlining its relationship with global and national guidelines. The concept of TEIP schools will be introduced to inform the reader about the specific research setting. Chapter two provides the theoretical framework from which the research questions stem and introduces recent knowledge and concepts about the variables of interest and their relations. Polyvagal theory (Porges, 2022) is used to link HRV to feelings of safety while the neurovisceral integration model (Thayer & Lane, 2000) draws the line between HRV and overall regulatory capability. Gross` Process Model of Emotion Regulation (Suri & Gross, 2016) explains the role of different emotion regulation strategies on psychological functioning. Valuable insights from Terror Management Theory (Pyszczynski et al., 2015) and Cummins et al. (2002) model of subjective well-being underline the central role of self-esteem for well-being. We than link the variables based on theoretical and empirical findings and introduce our research goals and hypothesis. The research method is presented in chapter three followed by the presentation of the results in chapter four. Finally, chapter five discusses the results, limitations of the study, the implications for theory and practice and questions for further research.

CHAPTER 1

# Contextualising the research

## 1.1. Promoting Self-Regulation and Self-Esteem to Achieve the SDG

Mental health has been declared an important goal on the route to sustainable development. As stated in target SDG 3.4., ensuring healthy lives at all ages implies „[promoting] mental health and well-being" (United Nations, n.d.-a). Mental health has also been declared a basic human right by the WHO (2022). The 2021 released action plan by the WHO to improve mental health worldwide states that:

> [w]ith respect to children, an emphasis is placed on the developmental aspects, for instance, having a positive sense of identity, the ability to manage thoughts, emotions, as well as to build social relationships, and the aptitude to learn and to acquire an education, ultimately enabling their full active participation in society (p.1)

Self-esteem and emotion regulation are thus considered inherent to the concept of mental health and societal participation, and their importance has been acknowledged by international organisations (WHO, 2021) local actors (Make Mother Matter & SDG Watch Europe, 2019; United Nations, n.d.-b) and academia (Okunlola et al., 2022).

Quality education (SDG 4) has been found to contribute to and determine the allocation of resources needed to enact one's potential and participation in society. It thus exerts a transformative power over most of the other goals and is a powerful tool for human development (Unicef, 2024a; United Nations, n.d.-b). Although education and learning happen everywhere throughout live, childhood and schools form an especially close bond with education. The individual's success within institutionalized forms of education such as school is highly dependent on emotions, their regulation and transformation into motivations (De Neve et al., 2023). Furthermore, the experiences we make in the context of learning shape how we think about ourselves (Gottschalk & Burns, 2020). Children's functioning in school relates to developmental outcomes such as self-regulation and self-esteem. Understanding their interrelationship should help to design educational spaces and policies that provide the best possible context for quality learning and equal opportunities.

Committed to these goals Portugal has released various guidelines and national policies including the National Mental Health Plan (Direção-Geral da Educação, n.d.) and the National School Health Programme (Direcção-Geral da Saude, 2006). Such initiatives provide a legal framework to foster the implementation of actions for mental health (European Commission, 2023). Those measures are especially important considering the worrying numbers of decreased mental health in Portuguese youngsters as indicated through increases in reported unhappiness and self-injury in the 2021/22 Health Behaviour in School-aged Children (HBSC) study (Fábio et al., 2022) as compared to the results observed in 2018 (HBSC, n.d.). The TEIP programme, that will be introduces in the following section provides an important basis for the implementation of intervention that tackle such issues, strengthen those most at risk.

## 1.2. Portugal's TEIP Schools: An Attempt to Tackle Social Inequalities Through the Promotion of Socio-Emotional Learning and Well-Being

In 1996 a public policy for priority educational intervention territories (TEIP) was established in Portugal with the aim of reducing social inequalities and tackling the high dropout rates in schools, located in neighbourhoods that have been identified as a particularly challenging context due to heightened levels of poverty, social exclusion, violence, and school detachment (Direção-Geral da Educação, n.d.; Pinho et al., 2022; Sampaio & Leite, 2021). The main pillars of the programme include the allocation of extra resources to the schools, decentralisation, and school autonomy as well as local networking. This means that schools are responsible for defining goals, implementing measures, and evaluating them as they are understood to be the main experts on the context specific challenges and meaningful ways to overcome them (Pacheco et al., 2020). The goals of the programme are in accordance with the educational standards as defined by The Profile of Students Leaving Mandatory Schooling (Ministério da Educação & Direção-Geral da Educação, 2017) to enable the individual to become a free, responsible, and self-aware participator in society that is embedded in family and community. Since 2006 the number of schools participating in the TEIP programme has increased greatly with a current number of 146 aggregations of schools taking part in the 3rd TEIP circle (Direção-Geral da educação, n.d.).

The project MindRegulation (MR) is a research project that wants to evaluate the assumed beneficial effects of guided imagery and relaxation interventions implemented in TEIP schools (Galinha et al., 2024). It follows the rational of socio-emotional learning frameworks (SEL) that have been found to be especially beneficial for children at risk, be it due to a lower socio-economic status, experienced poverty and violence or discrimination that often comes along with such circumstances (Taylor et al., 2017). The declared goals of the intervention include the promotion of regulatory capacity and the enhancement of self-esteem in 3rd and 4th graders through guided relaxation and mental imagery containing SEL content. Physical indicators such as HRV are used in addition to subjective surveys and cognitive tests to reach a more comprehensive understanding about the multifaceted functioning of and the intervention effects for the students.

## 1.3. Purpose of the Presented Study

The special interest of this dissertation lies in investigating the interaction between different emotion regulation strategies (CR and ES) and HRV on the association with global self-esteem in primary school children. We hope to be able to highlight the need for psychophysiological research in the context of naturalistic settings to create spaces that meet children's needs in the present and prepare them to a self-determined and healthy life in the future.

CHAPTER 2

# Conceptual Framework

My tongue will tell the anger of my heart,
Or else my heart concealing it will brake.

- William Shakespeare, The Taming of the Shrews, 1592

Our bodies are essential for navigating and interacting with the world and it is through our bodies that others perceive us and reflect our images of selves back to us perpetually shaping our identities and the possibilities to act upon them (Butler, 1993). It is through the interaction of representations of the body and the world as perceived by our senses that we develop a self that can be thought of as embodied (Damasio, 1999). Psychophysiology as a field of science investigates those body-mind associations.

> [It is] based on the dual assumptions that human perception, thought, emotion, and action are embodied and embedded phenomena; and that the measures of the processes of the corporeal brain and body, and the information revealed by them, can shed light on the human mind and behavior. (Cacioppo et al., 2017, p.14)

Although philosophers, physiologists, psychologists, and artists have tried to understand the relationship between body and mind for centuries, psychophysiology as a distinct field of study, was only established in the mid-fifties (Stern et al., 2001). Since then, it is undergoing various changes. Initially focusing on the peripheral nervous system and mostly describing each system within the organism separately, the trend of the last decades has been to shed light on the interaction of different systems with an increased attention allocated to the central nervous system (CNS). This shift has probably been fostered by the many achievements in the development of measurements and tools to understand the various signals of the human body. Although it is tempting to infer a straight relationship between physiological measures and psychological events, psychophysiological correlations cannot be causal. To address the complexity of the field, recent research on the roles of cultural and social context on psychophysiological responses has been encouraged as well as research from the fields of animal, molecular and computational studies (Cacioppo et al., 2017).

As children grow and mature the functioning of the organism changes constantly to allow adaptation and development within the specific environment with its wide variety of stimuli. One of the main goals of developmental psychophysiology is thus to better understand and differentiate the interplay of environmental and individual factors and their relationship with developmental outcomes over time. Developmental psychophysiology looks at dynamic processes of adaptation and their contribution to enabling multifinal (similar conditions result in different outcomes) as well as equifinal pathways (different conditions result in similar outcomes) (Beauchaine & Webb, 2017).

From an evolutionary point of view our survival depends largely on the maintenance of homeostatic balance, which is understood to be the process of optimal distribution of resources to the different body parts in order to function well and allow restoration, growth and healthy development. Allostasis, conceptualized as a mechanism that reduces homeostatic load by predicting possible changes in energy demands and adjusting resource allocation in an anticipatory manner, is thought to contribute to the organisms adaptive responding to changing circumstances (Schulkin & Sterling, 2019). Those processes however require the monitoring and management of bodily states (e.g., through the autonomic and the central nervous system) and their appraisal in terms of valence. Damasio and Carvalho (2013) argue that feelings and emotional states contribute to that monitoring process as they nudge the individual to pay attention to its current state thus fostering learning. Emotions are physiologically embedded phenomena that have been associated with autonomic functioning (Mendes, 2016). They are a crucial component in (self-referential) evaluative processes informing goal directed behaviour and thinking (Clore & Schiller, 2016). Therefor successful emotion regulation is often considered to be a basic pre-requisite of adaptation that allows the individual to shape when, where and how to experience and express different emotions (Suri & Gross, 2016).

The ability for self-regulation is deeply entangled with both physiological and psychological functioning and the following chapter will outline some conceptual grounds and empirical evidence that try to shed light on those relations. It will provide the reader with a brief overview of the autonomic nervous system as a key player in body – brain communications. Based on empirical evidence we will argue that HRV can serve as an index for autonomic functioning reflecting the body's ability to respond to contextual demands. As successful regulation is found to be associated with a state of safety that allows us to engage in learning and social communication and meaningful learning experiences and social interaction fosters the genesis of genuine self-esteem, the link between self-regulation and self-esteem will be drawn. In this context, valuable insights from the Gross process model of emotion regulation will be presented discussing the adaptiveness of two specific regulation strategies. Deducted from the reviewed research findings our hypothesises will be presented initiating the practical part of the work.

## 2.1. Heart Rate Variability as a Measure of Adaptive Responding and Experienced Safety

### 2.1.1. Heart-Brain Communication Pathways

One of the important functions our heart fulfils, is to insure the supply with oxygen and nutrients throughout the body. It does so by receiving deoxygenized blood through the veins and sending it to the lungs. While we breathe our lungs nourish the blood with oxygen. The oxygenated blood will than enter the heart again and be pumped through the arteries to be distributed to the entire body (Centers for Disease Control and Prevention [CDC], 2020). This two-phase pumping action that is based on the spread of electric impulses is known as the cardiac circle and can be recorded in an electrocardiogram (ECG). The different phases of depolarisation, contraction and repolarization are represented in the ECG as the p-wave, the QRS-complex and the T-wave, respectively. The event of the heart's contraction, represented in the QRS-complex, is called the heartbeat. The number of beats that the heart generates in a minute (bpm) is known as the heart rate (HR). Cardiac outputs depend on a multitude of internal (e.g., based on the anatomy of blood vessels, thickness of blood) as well as external (neural and hormonal) regulatory mechanisms. The brain, as a locus where sensory input gets integrated, plays a central role in the regulation of the heart and other organs to manage allostatic load and maintain homeostasis (Berntson et al., 2017). The interaction of brain activity and heartbeat patterns have already been studied by Claude Bernard (1813-1878), who was a pioneer in establishing experimental research standards in physiology.

> Claude Bernard also repeatedly insists, and this deserves especial notice, that when the heart is affected it reacts on the brain; and the state of the brain again reacts through the pneumo-gastric [vagus] nerve on the heart; so that under any excitement there will be much mutual action and reaction between these, the two most important organs of the body. (Darwin, 1897,p. 69)

Nowadays a growing body of empirical evidence confirms the existence of a variety of communication paths between heart and brain with the autonomic nervous system being one of the big highways for reciprocal interaction. The autonomic nervous system consists of two main branches namely the parasympathetic and the sympathetic branch that extend through the body and innervate different organs. Through complex patterns of interaction, the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) contribute to the regulation of body functioning and the reduction of allostatic load. Despite the complexity a common observation has been that the SNS serves an excitatory function and supplies the body with great amounts of energy that is needed when the organism is under threat while the PNS calms down the organism to restore energy and engage in growth processes (Berntson et al., 2017).

The sinoatrial (SA) node, known to be the principal pacemaker of the heart, is innervated by both, parasympathetic and sympathetic fibres that adjust pace and strength of the heart's muscular contraction. In accordance with the above-mentioned pattern the SNS fibres usually speed up the hearts beat while PNS fibres slow down its natural rhythm. Interestingly, differences in the reaction speed of the two systems, due to the different time spans with which the neurotransmitters acetylcholine (released by the PNS) and norepinephrine (SNS) take their effect on the heart, result in more rapid changes and greater flexibility of heartbeat patterns through parasympathetic control (Martens et al., 2008; Wendt & Thayer, 2024). Brainstem reflexes such as the baroreceptor reflexes contribute to autonomic regulation of the heart by communicating changes in blood pressure through the nucleus tractus solitarius (NTS) to the brain. Often those changes are related to the respiratory cycle where HR increases during inhalation and slows down when exhaling, a phenomenon captured under the term respiratory sinus arrythmia (RSA). The NTS is a meeting point in the heart-brain communication system where efferent (from the CNS to the periphery of the body) and afferent fibres (from the periphery to the CNS) meet. Patterns derived from NTS control have mostly been observed to be reciprocal in nature which means activation of one system (e.g., SNS) occurs with inhibition of the other (e.g., PNS). Higher neural structures such as the anterior cingulate and insular cortex, the amygdala, the hypothalamus, and the prefrontal cortex are however able to complexify those patterns by controlling, inhibiting, or bypassing the lower reflex mechanisms. As a result, autonomic pattern of coactivation or coinhibition as well as independent outflows of the sympathetic and the parasympathetic branch complement the pattern of their reciprocal activation (Berntson et al., 2017). A variety of cognitive and emotional processes related to self-evaluation (Qin et al., 2020), emotion regulation and threat and safety detection (Thayer et al., 2012) engage such neural structures and have been associated with cardiovascular outcomes. Heart rate variability (HRV) for example captures the time differences between successive heartbeats mirroring a variety of influences that come together to control blood flow. Psychophysiological research has thus used and investigated HRV as an indicator of integrated functioning between the autonomic and central nervous system and its associations with psychological functioning and overall health (Thayer et al., 2012)

### 2.1.2. Heart Rate Variability

HRV has been developed as a quantitative marker of autonomic activity. The importance of having such an indicator is based on the observation that both reduced vagal and increased sympathetic activity tend to be associated with dangerous cardiac arrythmias (Task Force, 1996). Generally, HRV reflects changes in the time interval between successive heartbeats, also called the Interbeat Interval (IBI), RR-Interval (to describe the interval between two successive R-peaks) or NN-Interval (focusing on normal R-peaks that are clear of artifacts and represent the electrical impulses originating from the sinus node). In practice those terms are often used interchangeably. A certain level of variability in the hearts beating rhythm is considered healthy as it suggests a successful internal energy management of the body (Wendt & Thayer, 2024). Dependent on the individual goals, different measures of HRV can be calculated and analysed that are thought to reflect different processes of autonomic regulation. An overview of those measures has been described among others by Shaffer and Ginsberg (2017). The root mean square of successive difference (RMSSD) is one of the most frequently used time domain measures of vagally mediated (vm) HRV. It captures the beat-to-beat alias short-term variance in HR that has been conceptualized as being closely linked to the faster effect mechanisms of parasympathetic control mediated through the vagus nerve (Berntson et al., 2017). Another measure of vmHRV and highly correlated with RMSSD is the high frequency band (HF) also referred to as respiratory band. This measure is understood to capture parasympathetic activity related to the phenomenon of RSA and therefore complements the insights from the time domain measure of RMSSD (Shaffer & Ginsberg, 2017; Task Force, 1996)

HRV, especially when related to parasympathetic control has been investigated and used as a powerful proxy for various psychophysiological processes and as an indicator of autonomic functioning and overall health (Thayer et al., 2012; Wendt & Thayer, 2024). How those association are thought to be knotted is the content of the following two theories.

### 2.1.3. Neurovisceral Integration Model

Thayer and Lane (2000, 2009) two of the main exponents of the neurovisceral integration model describe the interplay between autonomic, cognitive, and affective systems as an integrated network and highlight the importance of effective communication between the systems for successful adaptation to environmental demands. Emotions are thought to play a crucial self-regulatory role within that system as they contain the inputs of various stimuli, interpreted, and transformed into goal-directed behavior. Thayer and Lane (2000) illustrate this process as follows:

> For example, when faced with a potentially dangerous situation, a Defensive Behavior System might be activated. The first stage of the behavioral sequence could involve the experience of anxiety, a shift toward relative sympathetic autonomic activity including increased heart rate, and a selective search for signs of danger. If a source of danger is identified the next stage in the behavioral sequence might involve fear and the mobilization of the organism for fight or flight. In another sense, an emotional response represents a selection of an appropriate response and the inhibition of other less appropriate responses from a more or less broad behavioral repertoire. (p.202-203)

On a neuro-physiological level this process of inhibition and disinhibition is based on the observation that cortical structures (such as the prefrontal cortex) exert a tonic inhibitory control over the amygdala. The central nucleus of the amygdala (CeA) in turn has been known to be one of the major modulators of cardiovascular and autonomic responses. In situations of threat such as described above the inhibitory control of the more deliberative working prefrontal cortex over the amygdala is thought to be repealed to facilitate automatic response activation. A des-inhibition of the CeA leads to a des-inhibition of sympathoexcitatory neurons on one hand and an inhibition of parasympathic activity on the other hand resulting in HR increases and vmHRV decreases. The response patterns activated in such a way however do not foster great response flexibility as they mostly represent evolutionary developed default models (Thayer & Lane, 2009).

As sympathetic and parasympathetic activation patterns exert a great influence on attentional processes, sympathetic des-inhibition has also been associated with less flexibility and fine tuning in shifting attention to relevant stimuli. It is noteworthy that those mechanisms are thought to follow a bottom-up as well as a top-down feedback loop. While autonomic states influence the accessibility of cortical processes that inform perception, thought and behaviour, cortical experiences in return can trigger and regulate autonomic reactions. It has been assumed that it is for that reason that anxious individuals find it hard to detect cues of safety in their environment, which usually lead to sympathetic inhibition and parasympathetic activation, allowing more flexible responses (Thayer & Lane, 2000).

Those results highlight the importance of context appropriate emotion regulation that enables the individual to perceive the situational requirements most accurately and choose a best fitting response. The evaluation of risk and safety plays a crucial role here and has been described in detail by Stephen Porges.

### 2.1.4. Polyvagal Theory

The polyvagal theory was in great parts developed by Stephen Porges and offers conceptual explanations of the relationship between HRV and different psychological phenomena in the context of social interaction (Porges, 2022). It describes the mechanisms by which the autonomic nervous system and the central nervous system conjointly contribute to the regulation of visceral states in mammals. A special focus of the theory lies in its phylogenetic approach towards the continuous development of the vagal pathways and the functioning of the autonomous nervous system in social mammals, especially humans (Porges, 2023). The central role of the myelinated vagus nerve and its integration with nuclei, that among others control muscles responsible for facial expression and listening, assumes a face-heart connection and embraces the importance of social engagement systems in regulatory processes (Porges, 2009).

The neuroanatomical explanation that underlies polyvagal theory assumes that visceral efferent pathways regulating the heartbeat as well as those controlling striated muscles of the face and head have developed an integrated communication network in the brain stem. This network is conceptualised as the ventral vagal complex and is thought to enable the vital coordination of sucking, swallowing, and breathing in new-borns as well as the sharing of visceral states through vocalisation and facial expression thus facilitating basic developmental premises such as social communication and co-regulation (Porges, 2023). The availability and effectiveness of such mechanisms depends according to Porges on the dynamic interplay of three autonomic subsystems that support different behaviours, namely social communication (e.g facial expression, vocalisation, listening), mobilization (especially fight and flight responses) and immobilization (e.g., freeze responses and behavioural shutdown). It allows the organism to respond adaptively to safe, dangerous and life threating situations and involves control of the myelinated vagus, sympathetic pathways, and the unmyelinated vagus (respectively). Porges embraces the Jacksonian principals of dissolution (Jackson, 1884) that assumes a hierarchy among those three systems regarding their activation and dominance. Following that logic, the phylogenetically older defence systems of mobilisation and immobilisation mediated through the sympathetic nervous system and the unmyelinated vagus are understood to be activated only if the newer circuits fail to provide a sense of safety (Porges, 2009).

The evaluation of risk and safety is based on a multitude of complex and intervened processes that we only begin to understand. The term of neuroception has been introduced to describe unconscious and reflexive neural mechanisms that take part in such an evaluation by integrating external environmental stimuli as well as afferent feedback from within the body, allowing the individual to either engage in pro-social behaviour and foster homeostatic functions of growth and restoration by inhibiting natural defence mechanisms or trigger those mechanisms in order to protect the organism from perceived threats (Porges, 2004). Senses of safety are thus understood to be embedded in autonomic processes and serve as central premises for social behaviour (Porges, 2021). Which kind of cues, situations, thoughts, and feelings are perceived as threatening and under which conditions is in great parts dependent on the individuals' history that continuously formed the bonds between body systems to support the survival and functioning of the organism within its specific environment (Porges, 2022).

#### 2.1.5. Normative Values and Individual Differences of Autonomic Functioning in Children

Adaptive autonomic functioning as indicated through HRV plays a crucial role in child development and has been found to be positively related to socio-emotional outcomes such as positive affect, social engagement, regulation capacity and empathy as well as to neural abilities such as sustained attention and cognitive evaluation, which among others again enable regulatory mechanisms (Beauchaine & Webb, 2017).

The median resting HR changes as we age, usually increasing during the first month after birth (peaking at 145bts/min) and showing a decreasing tendency until the age of 18 (70bts/min). A similar decreasing trend can be observed in respiratory frequency from child- to adulthood (Fleming et al., 2011). As HRV is closely connected to HR and respiration, it is not surprising that changes can also be observed regarding the different HRV parameters. However there seems to exist less congruence and comparability between study results, due to different research designs (long-term vs. short term) and parameters of interest (time vs. frequency domain). While Massin and von Bernuth (1997) report a positive linear correlation between different time and frequency domain parameters and age (including RMSSD) during 24h recordings, Silvetti et al. (2001) found that a linear positive correlation between HRV derived from 24h recordings and age only occurred for the HRV index SDANN. On the other hand, they found that RMSSD only increased until the age of 10 and was significantly lower in the age group of 1 to 5 years old. Using HRV parameters from short time recordings that were corrected for HR, Gasior et al. (2018) observed that the dependency of HRV indices on age was only weak. Regarding gender, Koenig et al. (2017) identified a small to moderate effect of sex on cardiac vagal activity in which girls were found to show lower resting state cardiac vagal activity and greater mean HR relative to boys. The meta-analysis also indicated that RMSSD in girls was lower at younger age and that the direction of sex difference seems to change during puberty where girls showed higher vagal activity as compared to boys. Studies included in this analysis looked at children and adolescence between the age of 6-18 years and used HRV measures derived from short-term recordings.

Most HRV indices represent autonomic control on a dichotomous scale. This conceptualisation however might not be enough to grasp the complexity of autonomic functioning and researchers have thus been engaged in developing and testing alternative models to enrich our understandings in the genesis of illness and the promotion of health. The autonomic space model (Berntson et al., 1991) is one result of such efforts that has been found to be useful in describing and predicting psychophysiological phenomena. It advocates the conceptualisation of autonomic functioning as a two-dimensional space, looking at the sympathetic and parasympathetic functioning as two independent dimensions that can be entangled in various ways. As already mentioned above those modes can be described as coupled reciprocal, coupled nonreciprocal and uncoupled. The coupled reciprocal mode describes the commonly observed pattern of high activation in one system and low activation in the other. Coupled nonreciprocal modes lead to patterns of coactivation in which both branches are active while coinhibition is characterized by decreases in both systems activity. Uncoupled modes on the other hand indicate activity in one branch with no change in activity in the other branch.

Developmental research has adapted the insights from autonomic space models and investigated the autonomic functioning of children in terms of different profiles that describe a multitude of autonomic response, baseline and recovery modes and their interaction with developmental outcomes (Zeytinoglu et al., 2022). Alkon et al., (2011) found that reciprocal modes of sympathetic activation mostly expressed active coping. A similar result was observed by Zeytinoglu et al. (2022) as children with this profile showed better executive functioning and emotion regulation. Non-reciprocal coupled modes on the other hand might impede successful coping due to a lack of efficient energy mobilisation in coinhabited individuals (El-Sheikh & Erath, 2011). Zeytinoglu et al. (2022) however found that children with a coinhabited profile showed better emotion regulation as reported by their preschool teachers compared to their colleagues with high sympathetic activation.

How emotion regulation is performed, and under which condition different strategies can be considered adaptive is the topic of the next section.

## 2.2. Emotion Regulation

Emotion regulation is a phenomenon that has been largely investigated due to its association with mental health and well-being outcomes as well as with psychopathological syndromes (Djambazova-Popordanoska, 2016; Gross & John, 2003; Hu et al., 2014; Morrish et al., 2019; Rawana et al., 2014). Emotion regulation as a concept is complex and researchers have been struggling in defining and measuring it extensively since the early 90th. Although emotions can also exert a regulatory function, the term emotion regulation is mostly used to describe the mechanisms by which emotions and emotion responses are regulated. Emotion regulation can happen voluntarily or automatically, and scholars have been discussing if emotion genesis and emotion regulation are really two distinct phenomena or if they are so deeply entangled that a separation of these two processes is impossible. Nowadays mutual understandings are shared across the research community that acknowledge the synergy of genetic, (neuro-) physiological, behavioural, and psychological systems in co-creating diverse patterns of emotion regulation. Additionally, the development of emotion regulation is found to be embedded in socio-cultural structures and dependents on individual as well as collective aspirations and their complex interplay (Stifter & Augustine, 2019).

Association between ANS activity as described above and emotion regulation are complex. The entanglement of emotion experience and regulatory approach as well as the differences in research design make generalized interpretations of research results challenging. In addition, the maturation process of bodily systems creates an instability of autonomic (re-) activity during childhood (Hastings & Kahle, 2019). Smith et al. (2011) found that children experiencing anger during a provoking task but suppressing the emotional expression, showed either low or high levels of sympathetic activity. Other studies have found smaller (Calkins, 1997) as well as larger increases (Davis et al., 2016) in children's RSA in relation with greater state regulation. Regarding the often-observed positive relation between HRV and emotion regulation Mather and Thayer (2018) argue that this link is based in their shared engagement of brain structures such as the prefrontal cortex and the amygdala (see neurovisceral integration model). Through their analysis of biofeedback studies, the authors suggest a causal relationship between HRV and emotion regulation. They argue that brain network dynamics including these regions can be strengthened through HR oscillations. Through paced breathing for example a synchronisation of baroreflexes and respiratory frequency can be created. As a result, the higher amplitude of blood flow oscillations can lead to enhanced functional connectivity. This seems to be especially true for emotion regulation network that show a highted sensitivity to such changes. However, it remains unclear which kind of oscillations build the core of HRV and if resonance is a key feature.

There exist a variety of approaches for investigating emotion regulation. One model that has been used and validated in many studies is the process model by Suri and Gross (2016). It considers emotion regulation as a meta-valuation process that aims at complementing and fine-tuning the basic valuation process that is involved in emotion genesis. This valuations process has been embedded conceptually in a four-stage cycle model (W-PVA cycle), consisting of world input (W), perception (P), valuation (V) and action (A), that occur in a repetitive and partly overlapping pattern, resulting in a spiral development of emotion genesis and emotion regulation over time. According to this model sensory input from the internal as well as external world (W) is perceived by the organism (P) and evaluated at different levels of complexity (V). Based on that valuation process a multitude of action patterns emerge (A) including physiological and mental responses. Based on the different valuation processes those action tendencies can be supporting or opposing one another. Emotion regulation within this model is thought to occur most frequently if action tendencies are conflicting. The emotion itself than becomes the input (W-P) of the regulatory W-PVA cycle. In accordance with situational demands and personal resources different emotion regulation strategies get evaluated (V) and are than applied (A), feeding into new W-PVA cycles. It is noteworthy that different emotion regulation strategies can target different stages of those cycles. Suri and Gross (2016) have focused their research on five main regulatory approaches, namely situation selection, situation modification, attention deployment, cognitive change and response modulation. While situation selection and situation modification tackle the state of the world (W), attentional deployment plays into the perception (P) part of the cycle. Together with the strategy of changing the way we appraise certain events (V) those regulatory mechanisms aim at changing the way we might feel before the emotional response has fully developed and are thus labelled as antecedent focused emotion regulation strategies. Response modulation on the other hand aims at changing our action tendencies (A) and is thus considered response focused. Different regulatory mechanisms work conjointly to provide the most adaptive responses (Suri & Gross, 2016). Bearing in mind that adaptiveness of a certain set of regulation strategies highly depends on contextual factors, investigators have been interested in understanding the advantages and disadvantages of individual strategies. A common approach has been to compare antecedent focused (e.g., cognitive reappraisal) and response focused (e.g., expressive suppression) strategies (Gross & John, 2003).

Expressive suppression (ES) as an emotion regulation strategy aims at not showing certain emotion expressions that would reflect the emotional experience. It is a common strategy in both adults and children that requires the ability to identify emotional states and understand that there might exist gaps in expressed and experienced emotions. It also requires the capacity to distinguish between actual emotions and desired emotional states. Furthermore, the motivation to engage in complex emotion regulation highly depends on the sense of self and it´s relation to socially and culturally acquired norms and display rules.

All those requirements are closely linked to the rapid development of the prefrontal cortex between the years 2-5 where children's ability to actively suppress emotions strongly improves (Gross & Cassidy, 2019). As children mature ES becomes part of a larger repertoire of regulation strategies that children can choose of based on the situational demands and individual resources. With increasing age children broaden their understanding of self and society. The desire to belong and the heightened awareness about possible negative social consequences of deliberate emotion expression may explain why older children engage more in ES compared to younger children (Gross & Cassidy, 2019). This trend complexifies at adolescence with mixed research results that report either decreases (Sai et al., 2016) no changes (Lantrip et al., 2016) or increases (Hollenstein et al., 2012) in the use of ES. Another factor that seems to contribute to differences in ES in adults is gender (Rogier et al., 2019). However, associations are complex and studies investigating gender differences in the use of ES in children find no differences (Yeh et al., 2017) or a greater use of suppression by boys (Gullone & Taffe, 2012). The interplay between socialisation and culture norms with gender as well as the variation in regulating specific emotions such as anger versus sadness has been used to explain such mixed findings (Chaplin & Aldao, 2013).

Being a response focused emotion regulation strategy that is applied only when the emotion experience has already unfolded, ES requires a lot of cognitive resources and more time to evoke change in the emotional state which might in parts explain its association with negative psychological outcomes (Schäfer et al., 2017). Yeh et al. (2017) however found that ES can serve adaptive functions under special environmental conditions, including aversive environments. Investigating the physiological correlates of ES, researchers found that they appear differently for children as they do for adults. Various studies showed that trait ES was not associated with vmHRV for young individuals (Gross & Cassidy, 2019; Sætren et al., 2019) but correlated with increased SNS responses (Gross, 2015).

Cognitive reappraisal is conceptualized as an emotion regulation strategy that arises early in the emotion generative process and changes the way we evaluate or appraise a certain stimulus. Although emotions themselves can become the target of cognitive reappraisal the emotion regulation questionnaire by Gullone & Taffe (2012) conceptualizes cognitive reappraisal as changing the way a person thinks about a given situation. Cognitive reappraisal as an emotion regulation strategy thus requires the development of cognitive processes such as working memory and attention shifting (McRae et al., 2012). Instances of cognitive reappraisal attempts have been observed in children as young as 3 years old. Those regulatory attempts however were guided or accompanied by significant adults (Stansbury & Sigman, 2000). Independent use of cognitive reappraisal as an emotion regulation strategy have been observed in 5-year-olds (Davis et al., 2010). Looking at psychophysiological studies results in mixed findings on the effectiveness of CR in down-regulating negative emotions in children younger than eight and remain somewhat heterogenous during middle childhood and adolescence with a trend in increases in effectiveness with age (Willner et al., 2022). Most experimental studies did not observe an impact of CR on SNS reactivity or only small decreases (Gross, 2015).

In summary, the mixed findings highlight the importance to consider moderating factors when studying emotion regulation strategies that would depend not only on the emotion to be regulated, the underlying goals, the research design or measurement methods, but also on individual differences of the participants in their psychological and (neuro-) physiological functioning (English et al., 2017; Gross & Cassidy, 2019; Schwerdtfeger et al., 2019; Troy et al., 2016).

## 2.3. Self-Esteem as a Key Component of Positive Child Development

Self-esteem is an important dimension of mental health (Orth & Robins, 2022) and plays a crucial role in the maintenance of subjective well-being (Cummins et al., 2002). It has been studied as a concept in psychological and sociological research and vividly debated for its relevance for human behaviour and development for decades (Mruk, 2006b). The large scope of research on self-esteem throughout the years might be grounded in the observation that self-esteem relates to various positive life outcomes. In their literature review, Orth and Robins (2022) found that higher levels of self-esteem were significantly related to good physical and mental health, positive work and academic outcomes, better social relations, and less antisocial behaviour. These relationships were observed throughout life and across groups that differed in sex, racial and ethnic identity. Those results should also consider personality development through experience, suggesting a positive feedback loop between self-esteem and the life outcomes.

In one of the first American handbooks on psychology William James (1892) introduced the construct of self-esteem as the ratio of our success and our pretentions. Since then, scholars have investigated self-esteem using different approaches. Smelser (as cited by Mruk, 2006b) summarizes the different components self-esteem entails as follows:

> There is first, a cognitive element; self-esteem means characterizing some parts of the self in descriptive terms: power, confidence, and agency. It means asking what kind of person one is. Second, there is an affective element, a valence or degree of positiveness or negativeness attached to those facets identified; we call this high or low self-esteem. Third, and related to the second, there is an

> evaluative element, an attribution of some level of worthiness according to some ideally held standard. (p. 11)

Self-esteem can be considered a fluid dynamic state like response mechanism to environmental challenges or a trait encapsulating the accumulated experiences of e.g., mastery and societal appreciation. It is noteworthy that self-esteem can be measured on a global scale or in relation to specific domains such as social interactions, work related abilities, physical attractiveness, talents, or academic success (Heatherton & Wyland, 2003)

Work from the area of psychophysiology has looked at the physiological underpinnings of self-esteem, conceptualizing self-esteem as a general feeling of safety that serves a buffering function against potential threats (Cummins et al., 2002; Martens et al., 2008). According to terror management theory (TMT, Pyszczynski et al., 2015) self-esteem develops in early childhood as the result of the caregiver's shared attention, love and support that enables the individual to regulate states of arousal and navigate through everyday live challenges. The ability to live up to the standards of significant others and receive their protection and devotions is thought to become inherently associated with a sense of being worthy and secure. Those associations are supported by different studies showing that higher levels of self-esteem correlate with greater HRV (Martens et al., 2008; Schwerdtfeger et al., 2019) and reduced SNS reactivity in experimental designs (Martens et al., 2008). In a social evaluation context, Brummelman et al. (2022) found that children predisposed to high levels of self-esteem showed lower sympathetic arousal as children predisposed to narcissism. No differences were however found for HRV.

The development of self-esteem requires an understanding of the self which is closely linked to the cognitive development of the child within its biosocial context. Children prior to the age of 7 seem to enact self-esteem through their behaviour. Concepts of self in that age group largely depend on the moment and separated attributes that can be either physical (e.g. appearance), social (e.g. having a grandma), psychological (e.g. being angry) or related to activity (e.g. jumping) (Harter, 2006). The creation and sharing of narratives foster the integration of those different aspects of identity to form a coherent although multifaceted understanding of self. In middle to late childhood attributes related to the self, become more generalized. For example, rather than running fast and jumping high, children would describe themselves as being sporty. In addition to domain specific manifestations of self-esteem that have been reported by younger children, expressions of global self-esteem delineate, indicating a landmark of cognitive development. Interpersonal dimensions gain in importance, with social comparison and perspective taking as core referential systems for the construction of the self. The ability to differentiate between ideal and real self together with the increasing consciousness of cultural values and social demands add to the pool of self-evaluation mechanisms that are understood to generate self-esteem in that age group (Harter, 2006). It is noteworthy that the significance of the social other diversifies from childhood to adolescence with classmates, peers and teachers supplementing the strong influence of primary caregivers (De Neve et al., 2023; Harter, 1996).

The meta-analysis conducted by Orth et al. (2018) on the changes of self-esteem throughout live indicates an increase in self-esteem during early and middle childhood and a subsequent stability during adolescence. Throughout adulthood self-esteem continues to increase and only starts to fall around the age of 70. Testing for the effect of possible moderators such as gender, ethnicity, or country of residency the authors found no significant difference in effect sizes. It is worth mentioning that in accordance with recent knowledge on the development of self-esteem as described above, the measurement tools used in early to middle childhood cohorts (4-8 years) assessed domain specific rather than global dimensions of self-esteem.

Several factors are known to impede the development of genuine self-esteem. Genetic predispositions seem to explain between 40 – 50% of the variance in global self-esteem (Neiss et al., 2002; Stieger et al., 2017). The impact those predispositions have on the individual's level of self-esteem largely depends on the interaction of such factors with the environment within which the child grows up. For example, temperamental features, idiosyncrasies, abilities, disabilities, or even physical appearance can be either appreciated or neglected within the social and cultural surrounding, thus fostering, or boycotting the opportunities to make experiences of competence and worthiness within the world (Harter, 2006; Neiss et al., 2003). Unsurprisingly, parental style, experienced trauma and socio-economic status are also identified as correlates of self-esteem (Mruk, 2006a). Differences in global self-esteem between genders and people of different skin colour have been reported from middle childhood onwards with lower values being reported for females and white individuals (Harter, 2006).

## 2.4. Goals and Hypothesis

In this research, we want to explore the extent to which different measures of children's emotional regulation (subjective and physiological) predict self-esteem and determine if an interaction between these predictors better explains self-esteem than these measures in isolation. We hope to highlight the need for more large-scale psychophysiological research in naturalistic contexts adding to the knowledge gained from laboratory settings.

### 2.4.1. Emotion Regulation as a Predictor of Global Self-Esteem

People seem to have a tendency to maintain a positive, stable and congruent self-view. Events that threaten the self are usually associated with negative emotions while affirmative events of positive self-evaluation are usually accompanied by positive emotions. This tendency seems to occur even when the eliciting events are not directly associated with notions of well-being (Leary & Gohar, 2015). Sociometer theory (Leary, 2021) ascribes those effects to the social evaluative need of the individual to monitor concepts of selves in relation to the environment, anticipating social rejection. The match between self-view and incoming information seems to play a crucial role in determining the valence of the emotional reaction. While verifications of one's own believes primarily cause pleasant reactions, perceived dissonance is found to be predominantly experienced as unpleasant. Cognitive dissonance theory (Harmon-Jones & Mills, 2019) was one of the first frameworks to explore the phenomenon that even advantageous information can be perceived as disturbing when conflicting with prior beliefs tracing that effect back to the perceived loss of control and predictability.

We expect that children who regulate the emotional experience by using cognitive reappraisal are better able to reframe self-relevant events as confirmative and empowering, reducing feelings of discrepancies that impede self-esteem. Thus, self-reported use of cognitive reappraisal as an emotion regulation strategy should be associated with higher levels of global self-esteem (H1).

On the other hand, a mismatch between the emotional experience and the emotional expression as a cause of expressive suppression would increase feelings of discrepancy. Therefore, stronger self-reported use of expressive suppression as an emotion regulation strategy is expected to be associated with lower levels of global self-esteem (H2)

Those associations are a common observation in prior studies (Fernandes et al., 2022; Gómez-Ortiz et al., 2016; Mouatsou & Koutra, 2023; Nezlek & Kuppens, 2008; Teixeira et al., 2015).

#### 2.4.2. HRV as a Moderator in the Relation of Emotion Regulation and Self-Esteem

HRV can be conceptualized as an embodied phenomenon of safety and control (Schwerdtfeger & Rominger, 2024). Children with different levels of HRV might therefore differ in their perception of safety which impacts the effect mechanisms of the different emotion regulation strategies.

Cognitive Reappraisal as an emotion regulation strategy has been observed to be especially beneficial in contexts where individuals have little control over the situation (Schwerdtfeger et al., 2019). Children with low HRV might experience their environment as less controllable and safe. We would therefor assume the positive relation between CR and self-esteem to be greater for children with low HRV (H3).

On the other hand, research results indicate that vmHRV can play an important part in buffering the negative effects of ES on psychological functioning (Brown et al., 2022). Children with higher HRV might feel safe and capable to use ES in a flexible and beneficial manner. We would thus assume that individuals who report stronger expressive suppression would suffer less from lower self-esteem if they showed higher HRV (H4).

CHAPTER 3

# Method

## 3.1. Participant Characteristics and Sampling Procedure

Data has been collected from a total of 270 3rd and 4th graders from TEIP schools (7-14 years old, mean age = 8,68 years, *SD* = 0.85, 43,7% female) who submitted informed consent. Invitation to participate in the MindRegulation study have been issued to the directors of the study population, consisting of all schools that were classified by the Portuguese government as being eligible for priority intervention (TEIP schools) in the area of Lisbon and who have not priorly participated in the MindRegulation imagery intervention programme. From the schools that accepted the invitation 17 classes were randomly selected. An overview of the sampling procedure can also be seen in Figure 1 in the Appendix.

From the total sample, 30,7% of students (*n* = 83) have been excluded from analysis. Reasons for exclusion consisted in missing data, either physiological (*n* = 18) or because students have not filled out the socio-psychological questionnaires of interest (*n* = 25). Additionally, the data of 17 students was excluded as they were not able to fill out the questionnaires independently because of insufficient language skills (*n* = 15) or because they showed general difficulties in answering the questions by themselves (*n* = 2). Eighteen participants answered in a pattern that indicated careless responding (Dunn et al., 2018) and were also excluded. Finally, the physiological data of five participants could not be analysed due to bad physiological signal quality (> 5% corrected beats, Kubios Oy, 2023). The percentage of missing data on each questionnaire was inspected and as none exceeded the exclusion threshold of 50%, the final sample for analysis consists of 187 students (age *M* = 8,65 years, *SD* = 0.75, 47,1% female).

## 3.2. Ethical Requirements

All procedures of the study are in line with the codes of conduct outlined by the American Psychological Association (2017), the Society for Research in Child Development (Society for Research in Child Development (SRCD), 2021), the Declaration of Helsinki (World Medical Association, (WMA), 2013), and the National Children's Bureau Guidelines for Research (C. Shaw et al., 2011). The research project and informed consents underwent evaluation and approval by the Institutional Review Board (IRB) from the CIP-UAL research centre (Centro de Investigação em Psicologia da Universidade Autónoma de Lisboa). Before obtaining assent from the students, informed consent has been obtained from their parents or legal guardians. Prior to applying the electrodes for the physiological measurement of cardiovascular activity and electrodermal activity additional oral consent of each individual student was asked for by the researchers. Participants were informed that they could repeal their participation at any given moment without any negative consequences.

Data has been anonymised by creating participant code numbers. Identifiable information (e.g., names, contact details) of the participants has been recorded in a separate file. The file linking participant code numbers to personal information has been password-protected and can only be assessed by the project coordinator. Parents may access or modify their children registered personal information at any time by contacting the scientific coordinator. No information was collected beyond what was consented to. Participant anonymity will be maintained throughout the whole study-project.

## 3.3. Measures

### 3.3.1. Heart Rate Variability (HRV)

Physiological indicators of autonomic functioning and regulatory capacity (ECG, EDA and ACC) have been recorded using the BITalino (r)evolution toolkits by Plux. BITalino is an easy-to-use open-source bio signal platform for measuring various physiological signals. It is compatible with the visualisation software OpenSignal that has been used to monitor the recordings (*BITalino*, 2024). All recordings were made at a 100Hz sampling rate to reduce interruptions while simultaneously recording various ECGs. These sampling rates were found to deliver satisfactory output and allowed for the simultaneous recording of the data (Kwon et al., 2018; Task Force, 1996). Gelled electrodes for the ECG recording where placed in two fingers below the left and right clavicula of the child following Einthoven lead I configurations (Proença & Mrotzeck, 2020). A maximum of 20 BITalinos were used to record physiological responses of children simultaneously, with max. five Bitalinos being connected via Bluetooth to one single Laptop. To the best of our knowledge, it has been the first time that this high number of BITalinos has been used simultaneously in a real-life setting.

### 3.3.2. Emotional Regulation Questionnaire—Children and Adolescents (ERQ-CA)

To access the use of the different emotion regulation strategies of expression suppression (ES) and cognitive reappraisal (CR), the Portuguese version (Teixeira et al., 2015) of the Emotion Regulation Questionnaire for Children and Adolescents (ERQ-CA, Gullone & Taffe, 2012) was applied. The ERQ-CA measures these two emotion regulation strategies as traits and has shown adequate reliability in the validation study (Teixeira et al., 2015). It asks participants how much they agree on different statements about their emotion regulation on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The ES scale consists of four items such as “I control my feelings by not showing them.”. The CR scale includes six items (e.g., “I control how I feel about things by changing the way I think about them”).

#### 3.3.3. Lifespan Self-Esteem Scale (LSE)

Self-esteem was measured using the Lifespan Self-Esteem Scale (LSE, Harris et al., 2018) comprised of four unidimensional items measuring global self-esteem on a 5-point Likert scale. Questions such as “When you think about yourself, how do you feel?” are answered by marking one of the illustrated faces that are thought to express feelings, ranging from 1 (really bad = crying face) to 5 (really satisfied = smiling face showing teeth). The LSE has been validated for individuals aged 5 to 93 years. The Portuguese version has been translated and back translated by two psychologists (one bilingual English-Portuguese), and will be validated within the scope of the RCT project.

#### 3.3.4. Additional measures

Additional measures were collected within the MindRegulation RCT project but were not analysed within the scope of this thesis. For a detailed description of these measures see  Galinha et al. (2024).

## 3.4. Procedures

The data collection occurred during three consequent school days, with socio-psychological and cognitive data being collected on day one, physiological data at day two, and a total of 7 cortisol samples during day one and two. The socio-psychological questionnaires including the ERQ-CA and the LSE were distributed and read out to the whole class by the research team consisting of three researchers in the presence of the teacher. The research team would support students demonstrating difficulties in filling out the questionnaires. For students without sufficient understanding of the Portuguese language, the items were translated to English or a native language of the child by classmates or the researchers at the moment of application.

On day two and three physiological data (ECG, EDA, ACC) was collected by a second research team of (under-) graduate students who have participated in a two-day formation about how to use the physiological equipment (BITalino) and software (OpenSignal). Physiological measurements were collected during normal classes between approximately 9:30h and 11:00h, ensuring a minimal recording duration of 40min. Students put on the bracelet containing the BITalino by themselves under the guidance of researchers. Electrodes to measure electrodermal activity (EDA) and cardiac responses (ECG) were applied by the research team after permission was granted by the child.

Participation posters indicating all procedures of the study protocol were distributed to the classes. Smiley stickers were pasted individually under each completed procedure either by the researchers or the teachers or the children themselves. The children received pencils and rulers as gifts for their participation in two phases of the study.

## 3.5. Data Pre-Processing and Data Analysis Strategy

Data was analysed using different statistical tools and analysis software.

The ECG data was pre-processed and cardiological parameters were calculated using the Kubios HRV Scientific software (version 4.1.; Kubios Oy, 2023). The ECG files of the first day recordings of each participant were visually inspected, and a 15-minute segment was chosen that demonstrated the lowest levels of noise. If the first day recording did not provide an acceptable quality, the second day recording was inspected for a suitable segment. This decision was made to obtain relatively comparable data from a real-life context that would reflect cardiovascular activity as free as possible from physical movement. The selected segment was located towards the end of the recording. This time window has been identified as being the most comparable moment across classes. For one thing students would have had the chance to habituate themselves to the equipment. Also, classes would not be interrupted at that time by teacher changes and artefacts due to movement would be minimal as students were usually engaged in the learning activities and not occupied with distributing materials and organizing their activity area. Artifacts within the chosen R–R series were visually detected, and if needed manually corrected after applying an individual automatic artifact correction level for every participant (Kubios Oy, 2023). In our analysis, we included the following measures that were automatically calculated by the programme: mean HR (bpm), RMSSD (ms), HF-power (FFT), PNS index and SNS index.

The RMSSD is a time domain measure of HRV. It is calculated by first squaring each time difference between successive heart beats, averaging the results, and finally extracting the square root of the total score (Shaffer & Ginsberg, 2017). While reflecting PNS modulation of heart rate, the RMSSD is thought to be relatively free of respiratory influences and has thus been identified as most reliable in research with children, who are known to have a faster breathing rate (Gasior et al., 2018; Shaffer & Ginsberg, 2017) We log-transformed (ln) the RMSSD to obtain a normal distribution (Ellis et al., 2008).

Usually highly correlated with RMSSD is HF power, also called the respiratory band. It is a frequency domain measure of HRV and is set between 0.15-0.40Hz. Like RMSSD it is thought to reflect parasympathetic activity, although the HR variation is more related to the respiratory cycle (RSA). We used a HF index that derived from Fast Fourier Transformation (FFT), which has been automatically log transformed by Kubios (Kubios Oy, 2023; Shaffer & Ginsberg, 2017).

The PNS and SNS indexes were also calculated by Kubios. For the PNS index the Mean RR Interval, the RMSSD and the Poincaré plot index SD1 in normalized units were used while the SNS index included the Mean HR, the Baevsky´s Stress Index and the Poincaré plot index SD2 in normalized units (Kubios, 2024). The parameters are developed to reveal average activity of the respective branch as compared to the population norm. However, as the individual parameters are standardized against normal adult values (Nunan et al., 2010) they should be interpreted with caution when using data of children.

Cardiac autonomic balance (CAB) was estimated by subtracting the SNS index from the PNS index (PNS – SNS = CAB). They express the reciprocal activation of the sympathetic and parasympathetic branch with higher scores indicating higher parasympathetic dominance. Cardiac automatic regulation (CAR) scores were calculated by summing both indexes (PNS + SNS = CAR) indicating activation patterns of coinhibition (low scores) and coactivation (high scores). This approach to calculate CAB and CAR scores is however exploratory, although based on the prior conceptualization of these indexes by Berntson et al. (2008). Additionally, we asked Kubios support to understand if we could use the PNS and SNS indexes to estimate CAB and CAR. Previously, these indexes were calculated as described by using RSA as an index for PNS control and pre-ejection period (PEP) as a proxy for SNS control which is the time in milliseconds between electrical stimulus initiating ventricular contraction and opening of the aortic valve, obtained thru impedance cardiograms (Berntson et al., 2008).

Additionally, we used the IBM SPSS statistic software (version 29.0., IBM Corp., 2022) to estimate reliability of the ER dimensions and self-esteem and to calculate the mean for each variable. For generating the descriptive and correlation tables, we used the R statistical language (version 4.3.2; R Core Team, 2023), applying the packages *modelsummary* (version 2.1.1; Arel-Bundock, 2022) and *apaTables* (version 2.0.8; Stanley, 2021).

To conduct a multilevel analysis, with students being nested within classrooms and schools, we used the linear mixed model (LLM) module in Jamovi (version 2.5.; The jamovi project, 2024). A hierarchical data structure was initially assumed since students who share the same classroom and are also in the same school might respond more similarly than students from other classrooms or schools. This also violates the assumption of independence and increases the risk of type I errors and may bias results when traditional analysis procedures are used (Peugh, 2010). However, the LMM analysis resulted in an (almost) singular fit suggesting that our model was either too complex to be supported by the data or that random effects where to small (M. Shaw & Flake, n.d.) leading to the decision to test our hypothesis with fixed parameters and slopes.

Subsequently, a multiple linear regression (MLR) was run, also using Jamovi (2024) to test whether the interaction between subjective and physiological measures of self-regulation would add explanatory value to our model assuming a non-hierarchical data structure. We first entered cognitive reappraisal, expressive suppression and RMSSD as predictors of global self-esteem (model 1), and in a second step, both the interaction of RMSSD and ES and between RMSSD and CR (model 2).

Emotion regulation scores were mean centred prior to applying linear regression (Field, 2017).

CHAPTER 4

# Results

## 4.1. Reliability of the Scales

In addition to using the conventional Cronbach's alpha (α), we calculated McDonalds Omega (ω) as it has been found to be more robust in case of violations of most of alpha's statistical assumptions (Kalkbrenner, 2023). In our analysis, scores for both were however almost identical (see Table 1).

An analysis of the internal consistency of the self-report measures revealed questionable (ω = .63, α = .62 for LSE-scale) to acceptable (ω = .72, α = .73 for CR-subscale) reliability scores. Total item analysis revealed that the low score for the self-esteem scale (ω = .63, α = .62) could be improved (ω = .65, α = .65) by excluding one item (Q97: "When you think about yourself, how do you feel?"). For the following analysis we calculated the mean for each self-report measure, using the three remaining items for the global self-esteem while keeping the other scales unchanged.

**Table 1**

*Internal Consistency of Scales and Sub-Scales*

| (Sub-) Scales | Number of items | Cronbach´s α | McDonald´s ω | *M* | *SD* |
|---|---|---|---|---|---|
| Emotion Regulation | - | - | - | - | - |
| Expressive Suppression (ES) | 4 | .66 | .67 | 3.31 | 1.02 |
| Cognitive Reappraisal (CR) | 6 | .73 | .72 | 3.70 | 0.78 |
| Self-Esteem (original) | 4 | .62 | .63 | 3.89 | 0.70 |
| Self-Esteem (SE) | 3 | .65 | .65 | 3.94 | 0.77 |

*Note. n* = 187. The use of two emotion regulation strategies (ES and CR) was assessed using a Portuguese version of the Emotional Regulation Questionnaire—Children and Adolescents (ERQ-CA, Teixeira et al., 2015). The Lifespan Self-Esteem Scale (LSE, Harris et al., 2018) used to assess global self-esteem consisted of 4 items. Reliability scores could be improved by excluding one item. For the subsequent analysis' we used the three – item mean. Both questionnaires used a 1-5 Likert-scale with higher scores representing stronger self-reported use of the respective strategy for CR and ES and higher levels of self-reported SE.

## 4.2. Association between Emotional Regulation, Heart Rate Variability, Self-Esteem, and Sociodemographic Variables

Table 2 provides an overview of the descriptive statistics of the physiological measures, survey responses and age in month. Physiological indices of HR and HRV varied within the appropriate range that has been reported for that age group (Fleming et al., 2011; Gasior et al., 2018). The mean scores for CR and ES were slightly higher than the average reported in the Portuguese validation study of the ERQ-CA by Teixeira et al. (2015). Similar to the validation study, our participants reported a medium to high use of both ER strategies with higher values reported for CR. Also, comparable with the study results by Teixeira et al. 2015) were the rather high self-esteem scores as indicated by the left skewed distribution.

Correlational analysis (Table 3) revealed a very strong and highly significant correlations between HF-HRV and RMSSD ($r$ = .95, $p$ < .001) indicating a good quality of the measures. For the further analysis we will thus only include RMSSD as an indicator of vmHRV as it has been suggested that time domain parameters can be estimated with less bias and variability then frequency-domain parameters (Kuss et al., 2008). Additionally, the RMSSD also correlated significantly and positively with the PNS ($r$ = .93, $p$ < .01) and the CAB scores ($r$ = .90, $p$ < .01) and negatively with the SNS score ($r$ = -.83, $p$ < .01) and HR ($r$ = -63, $p$ < .01). RMSSD was not found to be correlated to any of the psychological measures. Mean HR showed moderate to very strong correlation with all the other physiological measures and a very weak positive correlation with sex ($r$ = .16, $p$ < .05) indicating the commonly observes trend of faster HR in females as compared to males. Apart from that result, sex as well as age did not correlate with other measures. PNS and SNS showed a very strong negative association ($r$ = -.91, $p$ < .01). While PNS showed a strong positive association with CAB ($r$ = .97, $p$ < .01) the direction of that association was reversed for SNS and CAB ($r$ = -.98, $p$ < .01). Interestingly, only SNS and not PNS showed a significant association with CAR ($r$ = .49, $p$ < .01), while CAR and CAB were slightly negatively associated ($r$ = -.30, $p$ < .01).

Regarding the subjective measures, we found that reappraisal but not suppression correlated with self-esteem ($r$ = .48, $p$ < .01). Curiously, we also observed a significant positive although weak correlation between the two emotion regulation strategies ($r$ = .29, $p$ < .01), and a very weak but significant negative association between expressive suppression and CAR ($r$ = -.15, $p$ < .05).

**Table 2**

*Psychometric and Physiological Properties for the Study Variables*

| | Min | Max | *M* | *SD* | *Med* | Histogram |
|---|---|---|---|---|---|---|
| Age (month) | 94 | 138 | 109.5 | 9.0 | 109.0 |  |
| Heart Rate (bpm) | 66.9 | 115.3 | 92.5 | 9.2 | 93.0 |  |
| RMSSD (ms) | 11.4 | 150.8 | 48.5 | 22.5 | 43.9 |  |
| RMSSD (log) | 2.4 | 5.0 | 3.8 | 0.5 | 3.8 |  |
| HF (Power, FFT, log) | 3.7 | 9.2 | 6.7 | 0.9 | 6.7 |  |
| Parasympathetic Nervous System (PNS) Index | -2.9 | 2.4 | -1.0 | 0.9 | -1.2 |  |
| Sympathetic Nervous System (SNS) Index | -0.5 | 5.5 | 1.8 | 1.0 | 1.7 |  |
| Cardiac Autonomic Balance (CAB) | -8.4 | 2.6 | -2.8 | 1.9 | -2.9 |  |
| Cardiac Autonomic Regulation (CAR) | -0.2 | 2.6 | 0.7 | 0.4 | 0.6 |  |
| Cognitive Reappraisal (CR) | 1.6 | 5.0 | 3.7 | 0.8 | 3.8 |  |
| Expressive Suppression (ES) | 1.0 | 5.0 | 3.3 | 1.0 | 3.5 |  |
| Self-Esteem (SE) | 1.0 | 5.0 | 3.94 | 0.77 | 4.00 |  |

*Note*. *N* = 187; HR = Heart Rate; bpm = beats per minute; RMSSD = Root Mean Square of Successive Difference; ms = milliseconds; log = logarithm transformed; HF = High Frequency; FFT = Fast Fourier Transform. Emotion regulation and SE were evaluated on 1-5 Likert scales with higher scores representing stronger self-reported use of the respective strategy for CR and ES and higher levels of self-reported SE.

**Table 3**

*Correlations Among the Variables with Confidence Intervals.*

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Sex | - | | | | | | | | | | | |
| 2. Age (month) | -.14 | - | | | | | | | | | | |
| | [-.28, .00] | | | | | | | | | | | |
| 3. HR (bpm) | .16* | -.14 | - | | | | | | | | | |
| | [.01, .29] | [-.27, .01] | | | | | | | | | | |
| 4. RMSSD (log) | -.04 | -.00 | -.63** | - | | | | | | | | |
| | [-.18, .11] | [-.15, .14] | [-.71, -.53] | | | | | | | | | |
| 5. HF (log) | .02 | -.00 | -.52** | .95** | - | | | | | | | |
| | [-.12, .17] | [-.14, .14] | [-.62, -.41] | [.94, .97] | | | | | | | | |
| 6. PNS | -.11 | .05 | -.81** | .93** | .85** | - | | | | | | |
| | [-.25, .04] | [-.09, .19] | [-.85, -.76] | [.91, .95] | [.81, .89] | | | | | | | |
| 7. SNS | .12 | -.10 | .94** | -.83** | -.74** | -.91** | - | | | | | |
| | [-.02, .26] | [-.24, .04] | [.92, .95] | [-.87, -.78] | [-.80, -.67] | [-.93, -.88] | | | | | | |
| 8. CAB | -.12 | .08 | -.90** | .90** | .81** | .97** | -.98** | - | | | | |
| | [-.26, .02] | [-.06, .22] | [-.92, -.87] | [.86, .92] | [.76, .86] | [.96, .98] | [-.98, -.97] | | | | | |
| 9. CAR | .07 | -.14 | .54** | -.03 | .01 | -.08 | .49** | -.30** | - | | | |
| | [-.07, .21] | [-.27, .01] | [.43, .63] | [-.17, .11] | [-.13, .16] | [-.22, .07] | [.37, .59] | [-.43, -.17] | | | | |
| 10. Reappraisal | .06 | .01 | .06 | -.08 | -.05 | -.07 | .06 | -.07 | .02 | - | | |
| | [-.08, .21] | [-.13, .15] | [-.08, .21] | [-.22, .07] | [-.20, .09] | [-.21, .08] | [-.08, .21] | [-.21, .08] | [-.13, .16] | | | |
| 11. Suppression | .04 | .14 | -.14 | .04 | .03 | .05 | -.11 | .09 | -.15* | .29** | - | |
| | [-.11, .18] | [-.00, .28] | [-.27, .01] | [-.11, .18] | [-.11, .17] | [-.09, .20] | [-.25, .03] | [-.06, .23] | [-.29, -.01] | [.15, .41] | | |
| 12. Self-esteem | .08 | .07 | .06 | .09 | .11 | .04 | .00 | .02 | .08 | .48** | .06 | - |
| | [-.06, .22] | [-.07, .21] | [-.08, .20] | [-.05, .23] | [-.03, .25] | [-.11, .18] | [-.14, .15] | [-.13, .16] | [-.06, .22] | [.36, .59] | [-.08, .20] | |

*Note.* Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). Sex (0 = male; 1 = female) HR = Heart Rate; bpm = beats per minute; RMSSD = Root Mean Square of Successive Difference; log = logarithm transformed; HF = High Frequency; FFT = Fast Fourier Transform; PNS = Parasympathetic Nervous System; SNS = Sympathetic Nervous System; CAB = Cardiac Autonomic Balance (higher scores indicate PNS > SNS); CAR = Cardiac Autonomic Regulation (higher scores indicate coactivation)

* $p < .05$. ** $p < .01$.

## 4.3. Emotional Regulation and Heart Rate Variability as Predictors of Self-Esteem

Results of the regression analysis are presented in Table 4. Consistent with the initial correlation analyses, CR but not ES was a significant predictor of SE in model 1 ($b$ = .52, $p$ < .01). Surprisingly RMSSD also became a significant predictor of SE ($b$ = .23, $p$ < .05). Although small and nonsignificant RMSSD and CR shared some variance, as indicated by the linear correlation analysis ($r$ = -.08), the Variance Inflation Factor (VIF) scores between 1.04 and 1.15 indicated that multicollinearity was not an issue. For this reason, we proceeded with the analyses, but assumed that RMSSD might enact as a suppressor, as the shared variance accounted for in the regression analysis revealed RMSSD as a relevant predictor of SE. To check if those results could indeed be explained by suppression, we additionally analysed the squared semi-partial coefficient ($sr^2$) of CR and SE as well as the $sr^2$ of RMSSD and SE. The $sr^2$ indicates the unique contribution of a predictor variable in explaining the variance in the outcome variable when controlling for other predictors. Comparing the results from the simple linear regression (CR: $sr^2$ = .23, RMSSD: $sr^2$= .01) with the results from the multiple regression (CR: $sr^2$ = .25, RMMSD: $sr^2$ = .02) we found an increase in the $sr^2$ scores when CR and RMSSD were entered conjointly as predictors of SE, as compared to the regression analysis where they were entered alone, supporting the assumption of a mutual suppression (Martinez Gutierrez & Cribbie, 2021).

In model 2, the statistically significant prediction of both CR ($b$ = .52, $p$ < .001) and RMSSD ($b$ = .24, $p$ < .05) on self-esteem remained when including the interactions.

Both models had a significant explanatory power with $R^2$ = .26 ($p$ < .01) for model 1 and $R^2$ = .27 ($p$ < .01) for model 2. Although the percentage of the explained variance in SE increased by 1% when including the interaction between subjective and physiological measures of self-regulation the change was not significant ($\Delta R^2$ = .009, $p$ > .05).

As can be seen in table 4, RMSSD slightly changed the relation between ER strategies an SE in the predicted direction. These differences however were not significant.

**Table 4**

*Hierarchical Regression Analysis for Variables Predicting Global Self-Esteem*

| Predictor | *b* | *b* 95% CI [LL, UL] | $sr^2$ | Model Fit | Difference |
|---|---|---|---|---|---|
| **Model 1** | | | | | |
| (Intercept) | 3.94** | [3.85, 4.04] | | | |
| Log_RMSSD | 0.23* | [0.01, 0.44] | .02 | | |
| CR | 0.52** | [0.39, 0.65] | .25 | | |
| ES | -0.07 | [-0.17, 0.03] | .01 | | |
| | | | | $R^2$ = .257** 95% CI [.15,.35] | |
| **Model 2** | | | | | |
| (Intercept) | 3.94** | [3.84, 4.03] | | | |
| Log_RMSSD | 0.25* | [0.04, 0.47] | .02 | | |
| CR | 0.52** | [0.39, 0.65] | .25 | | |
| ES | -0.07 | [-0.17, 0.03] | .01 | | |
| Log_RMSSD*CR | -0.15 | [-0.47, 0.17] | .00 | | |
| Log_RMSSD*ES | 0.14 | [-0.06, 0.35] | .01 | | |
| | | | | $R^2$ = .266** 95% CI [.15,.35] | $\Delta R^2$ = .009 95% CI [-.01, .03] |

*Note.* *N* = 187; CR = Cognitive Reappraisal; ES = Expressive Supression; Log_RMSSD = log transformed root mean square of successive difference; Log_RMSSD:CR and Log_RMSSD:ES indicate the interaction between variables.

A significant *b*-weight indicates the semi-partial correlation are also significant. *b* represents unstandardized regression weights. $sr^2$ represents the semi-partial correlation squared. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively.

* $p < .05$. ** $p < .01$

CHAPTER 5

# Discussion

## 5.1. Interpretation of the Research Results

The purpose of this study was to investigate different strategies to regulate emotions, namely cognitive reappraisal and expressive suppression, and physiological measures of regulatory capacity during class as measured through cardiovascular indices and their relationship with global self-esteem in a sample of Portuguese TEIP 3rd and 4th graders. TEIP schools are located in areas that have been identified as a particularly challenging context due to heightened levels of poverty, social exclusion, violence and school detachment (Direção-Geral da Educação, n.d.; Pinho et al., 2022; Sampaio & Leite, 2021). Investigating the interaction between these protective factors in high-risk populations is highly relevant, as data from this specific cohort is limited. By using a new approach that measures regulatory capacity during normal class the present dissertation aims to add valuable new insight from a naturalistic setting.

In accordance with prior literature (Teixeira et al., 2015), we assumed that cognitive reappraisal (CR), as an emotion regulation strategy, would be associated with higher levels of self-esteem (SE) (H1). Expressive Suppression (ES), on the other hand, was expected to show a negative relation with SE (H2). HRV as a measure of real-life regulatory capacity (Thayer & Lane, 2000) and embodied safety (Porges, 2022) was thought to moderate these relationships with a stronger association between CR and SE being expected for individuals with low levels of HRV (H3). For the relationship between ES and SE on the other hand we expected to find a buffering effect of HRV (H4).

In line with our first hypothesis, we found that CR was a significant predictor of SE. Similar results were found by Teixeira et al. (2015) who reported that CR correlated positively with self-esteem in Portuguese adolescents. Those results are also in line with a large body of research indicating the beneficial concomitant effects of CR on general psychological functioning (Hu et al., 2014). It supports the idea that ascendant focused emotion regulation strategies result in more successful emotion regulation as they require less resources of the organism as compared to response focused strategies that need to handle with full blown emotions (Suri & Gross, 2016).

Contrary to our prediction that ES would be negatively associated with SE we found no significant relation between those variables. This result is especially surprising, given that a previous validation study of the emotion regulation questionnaire for Portuguese children and adolescence found a significant negative relation between SE and ES (Teixeira et al., 2015), supporting the widespread observation that ES is a less adaptive strategy (Gross & Cassidy, 2019). Nevertheless, various factors might contribute to explaining our different results, such as those related to the specific characteristics of the sample. One of those factors is age. While the afore mentioned study investigated emotion regulation in 9th to 12th graders, our study examined the responses among 3rd and 4th graders. Research results for this age group have been mixed (Gross & Cassidy, 2019, 2024), including findings that show that children's ability to suppress especially negative emotions can also be related to higher social competence (Cole & Jacobs, 2018). The social benefits of ES might counterbalance its negative consequences for the self in younger population that are more dependent on social care. Culture is another environmental factor that has been used to explain regulatory success of different strategies. In cultures that have been labelled as being more interdependent, expressive suppression enacts societal norms of collective harmony and individual containment and might thus support societal affiliation and well-being (Mesquita et al., 2014; Tammilehto, 2024). Within the Portuguese culture that has both independent and interdependent characteristics (De Cristofaro et al., 2022), the negative bias of expressive suppression that is especially strong in individualistic populations might be less present. However, ES was negatively associated with self-esteem in the Portuguese validations study of the ERQ-CA (Teixeira et al., 2015) which weakens culture based explanation. Of special interest are research findings that identified ES as a beneficial strategy in some specific contexts including aversive environments (Yeh et al., 2017). In an aversive environment the individual might suffer the experience of not being cherished which may impact the motivation of expressing and sharing internal states. It thus might be less harmful for the self to suppress emotions, at least in the short run.

Also surprisingly, we found a significant positive relation between the two emotion regulation strategies suggesting that children who strongly use one strategy also report to strongly use the other strategy. Those results might be interpreted considering the specific age group and the developmental trajectory of emotion regulation. Due to the maturation process of the brain, especially the prefrontal cortex, children engage independently in cognitive reappraisal only with growing age (Willner et al., 2022). While continuously building up their repertoire of regulatory behaviour children who regulate more might still use different strategies exploring their different advantages.

Regarding our moderation hypothesis we did not find a significant interaction effect between vmHRV (indicating parasympathetic regulation) and CR (H3) or ES (H4) on SE. Although the interactions displayed the predicted direction, in which the positive association between CR and SE was stronger for individuals with low RMSSD, and the negative relation between ES and SE was weakened when RMSSD entered the interaction term, the effect of the interaction was not statistically significant. Similar results have been reported by Lande et al. (2023), who investigated the moderating effect of HRV in the relation between emotion regulation and general self-efficacy. In their small sample of high-school students (*N*=45) they found no significant interaction effect between HRV and ER. However, comparable studies in middle childhood are still missing and larger samples are required to reduce Type II errors, thereby providing more robust statistical conclusions.

Most interestingly is the result that HRV became a significant and positive predictor of self-esteem when entered in the regression analysis together with the use of CR as an emotion regulation strategy. It suggests that when the shared variance between CR and HRV is accounted for, the positive relationship between HRV and self-esteem becomes significant. This suppression effect might be interpreted in light of research results that found that CR decreased HRV during stress while at the same time facilitating a quick recovery to baseline levels after stress (Jentsch & Wolf, 2020). Students with high scores for CR as a trait to regulate their emotions are more likely to use this strategy within the classroom setting. The possible reappraisal induced changes in HRV could thus have biased the results regarding the relationship between HRV and SE in our sample.

The weak but significant negative correlation of CAR scores with ES are also interesting as they confirm that two-dimensional models enrich psychophysiological research (Menashri Sinai et al., 2024). Our exploratory analysis suggests that children who suppress more would tend towards a coinhibited profile of autonomic functioning as indicated through low activity of both, PNS and SNS. Regarding the Adaptive Calibration Model (Del Giudice et al., 2011) profiles of autonomic responsivity to environmental challenges develop in close relation with the biosocial factors of the individual's life history. Following that rational it has been observed that some children exposed to heightened levels of stress show autonomic patterns that have been described as buffered or unemotional and reflect a lower responsivity to stressors, theorized as a protective factor within the aversive environment (El-Sheikh & Erath, 2011; Zeytinoglu et al., 2022). The correlation of physiological coinhibition and suppression of emotion expression might thus be understood as an attempt to cope with overly stressful environmental conditions.

## 5.2. Limitations

Several limitations should be acknowledged when interpreting the research results.

First of all, in our study we recorded cardiac data in a real life setting with little control over parameters that might possibly influence cardiac output. This limits the comparability of data and increases the probability of type II errors. As described above, HRV mirrors a multifaceted interplay of mechanisms the organism applies to respond to allostatic load. The variety in stimuli and cognitive activities a naturalistic setting entails makes the detection of individual differences in HRV difficult and might require a larger sample size. Additionally, it might be possible that HRV as indexed through RMSSD might be a too simplistic measure. Applying a more holistic approach to indexing autonomic functioning (e.g., through two-dimensional and cross-system models) might result in better explanatory power.

Another related question concerns the decision whether to consider the gathered HRV data a trait or state. Since we did not measure ANS reactivity and recovery as compared to baseline values we could consider our data to entail a trait like nature. However, as Martens et al. (2008) have highlighted this might not be accurate and dispositional autonomic functioning might be better captured by either repeated measurement at various time points or by evaluating fluctuations and changes of HRV considering alternate conditions. HRV in our context is measured as the complex response of the organism to the totality of environmental factors that operate in the classroom context. It remains concealed if those results represent a generalizable mode of the individual to meet environmental demands.

It needs to be highlighted that the calculation of the CAB and CAR scores from the children's data has been done in an exploratory fashion in this study, after consulting its suitability with the researchers who developed the Kubios software. Caution is needed when interpreting these results as the indexes for CAR and CAB are based on Kubios generated PNS and SNS scores that have been normalized by Kubios using adult samples. Prior studies that evaluated autonomic functioning based on CAR and CAB indexes have usually analysed PEP scores as indexes of SNS activity and RSA indexes for PNS activity (Rahal et al., 2023). Some studies also evaluated cross-system autonomic functioning using EDA scores instead of PEP to mirror SNS activity (Stone et al., 2020).

Concerning the psychological measures, it should be noted that the internal consistency analysis of the emotion suppression and self-esteem scales did not pass the level of .70 that is considered a reliable threshold in educational studies, although some scholars find an alpha value of .65 still acceptable (Taber, 2018). Interpretations of the study results might be misleading, and the chances of type II errors increase as it is not clear if the scales scores can be considered a solid representation of the underlying constructs. This concern is especially valid for the global self-esteem scale that is just being validated for the study population within the scope of the MR-RCT. Furthermore, it should be acknowledged that self-esteem questionnaires tend to bear the risk of distorted results due to the possibility of desirability biases in the participants responses (Heatherton & Wyland, 2003). In fact, half of the students reported self-esteem scores of 4 or 5 points on the 1 to 5 Likert-scale. Adding social-desirability scales might help to understand if participants responses are biased and account for possible distortions in the data.

Finally, it needs to be mentioned that the data derived from a narrow study population. Participants stem from a specific age and neighbourhood cohort. While limiting generalizability this data allows for valuable insight into the specific developmental phase which is late middle childhood, more particularly the period prior to the transition to secondary school and the commencement of adolescence. In addition it provides information about children that grow up in an environment that has been considered by the Directorate-General for Education to bear specific challenges based on the heightened levels of poverty, social exclusion, violence, and school detachment. However, the assumptions regarding the specific milieu features are based on external, generalized evaluations and have not been assessed within this study.

## 5.3. Further Research Directions

School is a place where children usually spend great parts of their wake time. It is thought to be a place where academic and social learning occurs to provide the individual as well as the group with the resources considered to enable a self-determined life and social progress. Understanding how children feel and behave within this specific environment is crucial for imagining and reshaping educational landscapes to not only serve the goals of future societies but to meet children's basic needs and rights in the present and provide meaningful support. Future research questions that arise from the experiences and insights gained during the current study, aim at informing decision making within the educational context.

Considering the aforementioned limitation, one area for further investigation could be the study of contextual factors such as personal goals, cultural values, and social context (English et al., 2017; Lindsey, 2020; Wilms et al., 2020; Yang & Wang, 2019) in determining the selection, implementation, and success of specific ER strategies within the context of school. Together with the investigation of developmental differences in the adaptive use of emotion regulation strategies this could help to identify significant time windows for realizing meaningful interventions.

New unobtrusive measurement tools allow to investigate physiological signals in larger samples simultaneously. As those tools can capture several body signals at the same time, this supports the further development of cross-system models for autonomic functioning. Measuring autonomic functioning in groups can shed light on synchronisation and reciprocity mechanisms and their impact on interpersonal regulation. Research within naturalistic settings can foster our understanding of contextual factors and dynamic changes in regulatory processes.

In a similar vein longitudinal studies with experimental designs are needed to better disentangle the relationships between different systems and their directionalities examining (neuro-) physiological outcomes, cognitive processes, and psychological phenomena.

The ongoing longitudinal RCT MindRegulation should provide additional information about the relationship between the variables studied in this dissertation as it allows us to see how these relationships evolve over time and assess the long-term effects of the intervention.

Finally, various scholars have paralleled ANS measures, especially vmHRV with perceptions of safety (Duarte & Pinto-Gouveia, 2017; Porges, 2022; Schwerdtfeger & Rominger, 2024). However, research in the educational context is rare which is surprising considering the well-established links between safety perception and learning (Lacoe, 2020). As indicated through the comparison of the two last HBSC reports (HBSC, n.d) on Portuguese adolescents' health the perception of safety at school in Portuguese students decreased from 80.3% in 2018 to 76.7% in 2022. This is not surprising considering the observation that 21st century children are found to grow up in a world characterized by great uncertainties posed e.g., by the experiences of the corona pandemic and climate change (Conceição, 2022). How individuals process and react to cues of uncertainty is critical for their behavioural responses and psychological functioning (Porges, 2022). More study designs that combine physiological and subjective measures of safety would be needed to evaluate the conceptual power of HRV and two-dimensional models of ANS functioning as indicators of embodied safety. Factors that contribute to safety learning and tolerance to uncertainty need to be systematically researched. This would be especially important for understanding the impact of perceived safeness on school distance and learning difficulties and might help to design educational spaces where workers and learners feel secure to learn and explore.

# Conclusion

The functioning of our autonomous nervous system is essential for our well-being and health as it contributes to the adequate allocation of energy throughout the body. It can be considered one of the main communication pathways between the central nervous system and important body organs. By communicating the changing energy demands it is a key player in the maintenance of homeostatic balance. Emotions are central to such regulation. They are embedded in autonomic processes and represent the integration of various internal and external stimuli that inform goal directed decision making and behaviour. Regulating emotions in a flexible matter relates to adaptiveness and well-being as the success of different emotion regulation strategies depends on a variety of contextual factors. The experience of being able to meet those contextual demands is associated with a state of safety that fosters exploration, learning and social engagement. It promotes feelings of competence and social affiliation that nurture our self-esteem which in turn serves as a buffer against potential threats and helps us navigate through life. The investigation of interaction patterns between those protective factors is highly relevant as it helps promoting health and resilience in children.

The goal of the presented study was to understand if the interaction between autonomic markers of regulation and embodied safety (HRV) and two specific emotion regulation strategies, expressive suppression and cognitive reappraisal could better predict differences in global self-esteem as those factors in isolation in primary school children in Lisbon. By combining the students' subjective reports on their emotion regulation with physiological measures of regulatory capacity during normal school classes, we used a novel approach that delivers new insights from a naturalistic context. Our findings indicate that cognitive reappraisal has a strong, independent effect on self-esteem, which appears consistent across children with different levels of autonomic regulation. This suggests that the effectiveness of cognitive reappraisal in enhancing self-esteem does not depend on physiological functioning as measured by HRV. However, the fact that both cognitive reappraisal and HRV are predictors of self-esteem underscores the importance of this indicator when combined with more frequent use of reappraisal strategies. This outcome does not extend to expressive suppression, which remained unrelated with self-esteem or HRV. Thus, overall, our findings highlight the distinct roles these emotional regulation strategies play, demonstrating that reappraisal contributes positively to self-esteem, and higher HRV paired with reappraisal adds predictive value to self-esteem. More research across naturalistic settings is needed that combines different measures of regulatory processes in order to better understand the contextual dynamics of those processes. Larger sample sizes might be necessary to detect individual differences in real-life autonomic functioning, where possibilities to control confounding variables are limited.

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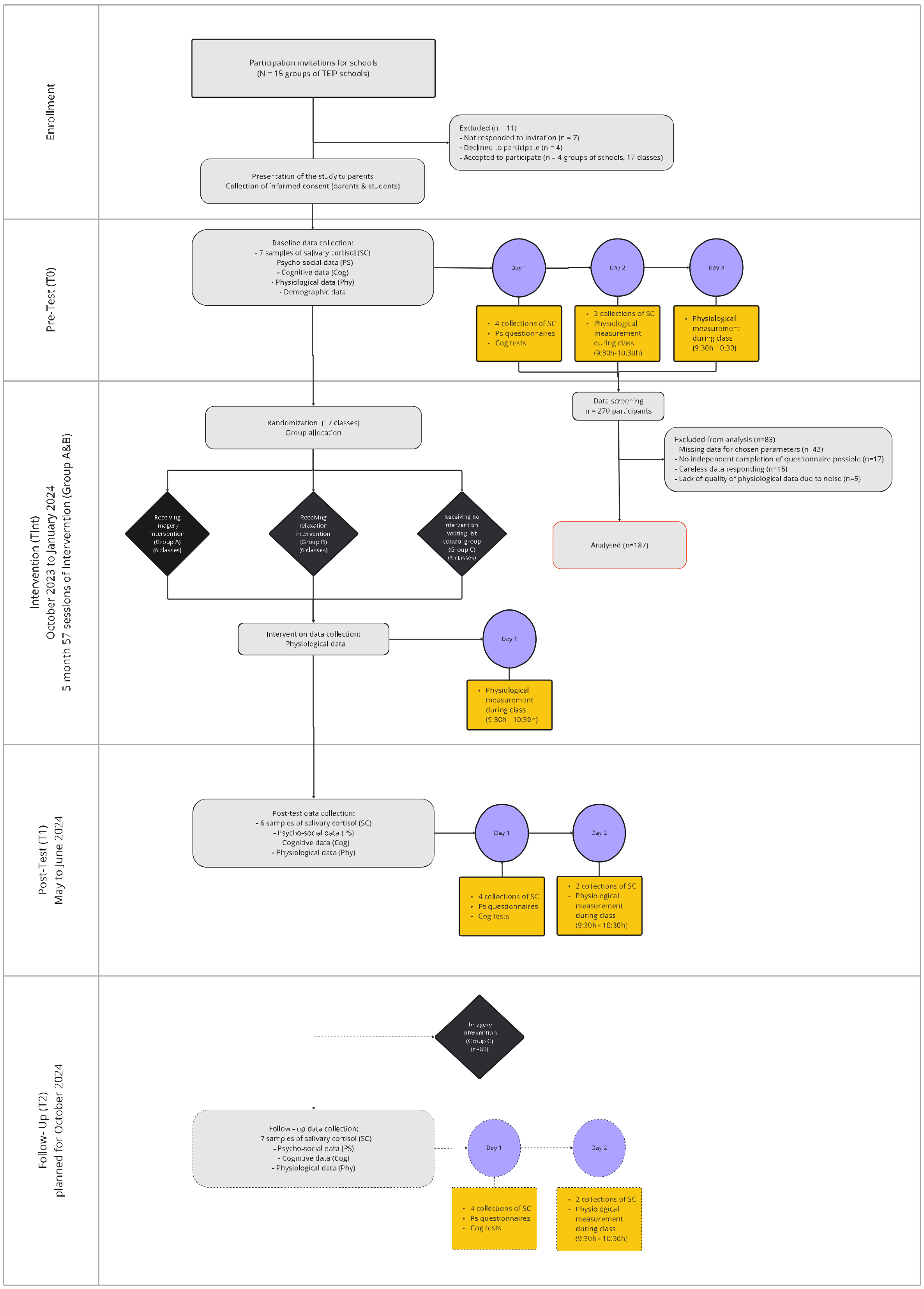
# Appendix

**Table 1**

*Overview of the MindRegulation Research Design*



*Note.* The figure shows the design of the Randomized Control Trial (RCT) within which this study is embedded. The aim of the RCT is to evaluate the impact of a guided imagery program (MindRegulation) on several developmental parameters in 3rd and 4th graders of TEIP schools located in and around the municipal area of Lisbon (Galinha et al., 2024). Classes have been randomly allocated to one of three possible conditions using the IBM Statistic randomization tool: A) the experimental group receiving the MindRegulation intervention consisting of relaxation and guided imagery B) the alternative condition receiving only relaxation intervention and C) the waiting list control group that will be involved in regular school activities and only perform in the MindRegulation intervention after the post-test data collection. Data is being collected at four data points: prior to the intervention (T0), during the interventions period (Tint), immediately after the intervention period (T1) and at the follow up (T2). Researcher collecting the data at T0 were blind towards group allocation. For the purpose of the presented study and due to temporal restrictions only baseline data (T0) will be analysed.