THE ROLE OF MINDFULNESS AND CARDIOVASCULAR REACTIVITY IN ECONOMIC RISK TAKING BEHAVIOR

by

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We all make financial decisions every day, weighing the probabilities of risk and reward in numerous contexts. These decisions occur in ostensibly stressful contexts. One potential mitigator of this stress is mindfulness. Mindfulness is the awareness that emerges through paying attention on purpose and non-judgmentally to the unfolding of experience moment by moment. The trait of mindfulness has been linked to reducing risk taking behavior in health contexts by increasing emotional control and regulating the body's stress response. Mindfulness as a state can be induced in participants with short term guided breathing interventions designed to elicit a calming response in the listener. However, little research has been done on the role of mindfulness interventions on economic risk taking. Furthermore, autonomic processes have been linked to cognition and decision-making, and mindfulness has been shown to alter these systems as well. This study attempts to investigate the intersection of these varied effects of mindfulness. Therefore, this experiment examined two main questions: First, how physiological measures of autonomic function in participants aged 18-35 (n=162) responded to a short-term mindfulness intervention. And second, how well these physiological changes predicted economic risk-taking behavior during the participant's completion of the **Columbia Card Task** (CCT), a computerized economic risk-taking assessment. We expected to find that the mindfulness intervention would decrease cardiac stress during the task, and that these changes would explain behavioral differences in risk taking. We found that group of participants randomly assigned to a mindfulness meditation intervention had an increase in high frequency heart rate variability during the task compared to participants randomly assigned to an audiobook control. In addition, risk taking during the task was moderated by the relationship between condition assignment and heart rate reactivity relative to ground. However, no physiological variables mediated the relationship between mindfulness and risk taking.

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Introduction

Financial decisions

We all make financial decisions each day, and we are affected by the decisions of others. Understanding how people arrive at the choices they make is important for understanding how to improve the outcomes of these decisions. Of particular interest in this project are decisions in which the probabilities of risk and reward are weighed. Individuals can complete “back of the envelope” calculations, but for the most part, the human ability to conceptualize probability is ineffective (Kahneman & Taversky, 1972). Trying to predict the future is difficult for people to do, and making the wrong decision can often have disastrous consequences: a stockbroker can lose millions of dollars on a single misplaced investment. Moreover, this decision-making may occur in stressful contexts (Coates & Gurnell, 2017). Therefore, our bodies may react much in the same way during these decision-making process as they would to imminent danger (O’Creevy et al., 2012). For instance, heart rate may increase, the skin may begin to produce sweat, and energy mobilizing hormones may be released into the bloodstream, potentially influencing the way we think.

Mindfulness

One potential mitigator of our physiological responses to an uncertain future is mindfulness meditation (Boyle, Stanton, Ganz, Crespi & Bower, 2017). Mindfulness as a trait is defined as “the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment.” (Kabat-Zinn, 2003, p. 145). More recently, an induced state of mindfulness via focused breathing exercises and meditation has garnered much attention for its effects on health and state of mind (Ludwig & Kabat-Zinn, 2008; Keng, Smoski, & Robins, 2011). Adapted from Buddhist tradition, mindfulness meditation interventions have been shown to reduce stress and anxiety, lessen the burden of learning disabilities, improve cognitive abilities under stressful conditions, and reduce subjective experiences of pain (Zeidan 2010a, Kabat-Zinn et al., 2007).

A large body of research documents the efficacy of mindfulness-based interventions in the treatment of a number of health-related disorders, including anxiety (Hofmann, Sawyer, Witt, & Oh, 2010; Roemer, Orsillo, & Salters-Pedneault, 2008) and depression (Hofmann, Sawyer, Witt, & Oh, 2010; Teasdale et al., 2000). There has also been growing evidence to demonstrate its efficacy with recreational and health-related risky decision-making behaviors, such as substance abuse (Bowen et al., 2006) and eating disorders (Tapper et al., 2009). However, the effects of mindfulness meditation interventions on financial risk taking behaviors have received less attention (*cf* see Lakey et al. 2007 for effects with dispositional mindfulness).

Given that mindfulness meditation is an emotion regulation technique (Brown et al., 2007), we posit that it may alter risky decision-making via affective decision-making processes (Hafenbrack et al., 2014; Kiken & Shook, 2011; Brown et al., 2003; Creswell, 2017; Hülsheger, Alberts, Feinholdt, & Lang, 2013). On the other hand, mindfulness interventions are also breathing exercises that involve focusing on internal bodily processes, and therefore may function via influencing our cardiovascular physiology (Bernardi et. Al., 2000). However, the effects of the underlying cardiovascular systems that react during mindfulness interventions in financial decision-making contexts are yet to be fully understood.

Therefore, to address this gap in the literature, this study aims to test: the effects of a mindfulness intervention on cardiovascular reactivity during the intervention and financial decision-making context (Question 1); and the subsequent utility of the mindfulness-induced physiological changes in predicting financial decisions during a financial risk-taking task (Question 2). As an additional exploratory analysis, we examined whether the relationship between trait-based physiological changes relative to zero (also designated as ground) and economic risk taking was conditionally moderated.

Question 1: What are the effects of a mindfulness intervention on cardiovascular reactivity during the intervention and in a later financial decision making context?

There is evidence involving mindfulness meditation in the regulation of a variety of cardiovascular changes in the body during stressful contexts (Creswell et. al. 2017; De Vibe et. al., 2017). Integral in many mindfulness meditation programs is the practice of sitting with the back straight, taking slow measured breaths. Many studies have found that these sorts of meditation programs in particular can influence a spectrum of cardiovascular variables (Landau et. al. 2017; Pargaonkar et. al., 2015). Prominent above other relaxation exercises, mindfulness meditation can affect the way the heart responds to stress over time (cardiac reactivity) (Ditto, Eclache, & Godman, 2006). These cardiovascular factors will be discussed in depth later. Evidence suggests that mindfulness interventions can help individuals effectively process stressful situations. They have also been seen to have immediate, short term physiological effects, such as on the measures of blood pressure and heart rate (Zeidan et. al. 2010b). However, the state of evidence does not suggest that mindfulness interventions clearly trend towards activating the **parasympathetic** (PNS) or **sympathetic nervous system**

(SNS). These two subsystems regulate heart rate, the PNS by slowing the heart down and the SNS by increasing heart rate. Some evidence suggests that both are upregulated by a mindfulness intervention, which would seemingly lead to a net zero effect on the stress state of the cardiovascular system (Ditto, Eclache, & Godman, 2006). Other studies have found a reduction in blood pressure reactivity as a result of mindfulness meditation interventions (Steffen & Larson, 2015). Notably, many physiology publications use small sample sizes in their studies (Ahmad et al., 2015; Kamarck, Manuck & Jennings, 1990). Given the lack of sufficient literature examining the inconsistencies in findings, we use a statistically well-powered sample test the effects of mindfulness meditation on cardiovascular reactivity before, during and after the intervention.

In addition to physiological changes, mindfulness meditation has been shown to reduce some kinds of risk taking behaviors. In particular, it has been shown effective in reducing addictive behavior among relapsing drug users (Vallejo and Amaro, 2009). Additionally, individuals who tend towards mindfulness as a result of their personality also make better gambling decisions than those who are less mindful (Lakey et. al., 2007). A finding such as this shows the correlational understanding of mindfulness that exists in the literature. Furthermore, recently published evidence has suggested that mindfulness can help to dampen the cardiac stress responses to a psychological stressor, such as viewing a violent video (Brzozowski, Gillespie, Dixon, & Mitchell, 2018). While the exact psychological mechanism through which mindfulness appears to impact decision-making is unclear, it does seem that mindfulness is involved in rectifying dysregulated reward seeking behaviors (Garland, 2016).

It follows from the above evidence that financial risk taking patterns could be altered by mindfulness interventions through a physiological mechanism. Therefore, in this study we explore how mindfulness can impact physiology during economic risk taking and how the cardiovascular system can help to explain any behavioral changes as a result of the intervention. While it has been demonstrated that short-term mindfulness interventions may have immediate effects, the sustaining downstream effects of the intervention on physiology across a decision-making context and during subsequent recovery have yet to be examined. This study examines changes across a 1.5-hour period, beginning with a baseline measurement, through the mindfulness intervention (or control audiobook) and completion of an economic risk taking task, and ending with a recovery period. Differences in cardiovascular response were compared across conditions, to allow for a comparison of the mindfulness intervention against an active control. This allows for a greater understanding of the persistence of the physiological changes induced by the mindfulness intervention, helping to expand the understanding of cardiac changes induced by a short term intervention. In doing so, this study attempts to paint a holistic picture of the cardiac response to nervous system regulation. This study examined the effects of mindfulness intervention on: sympathetic responses, parasympathetic responses and heart rate responses study, particularly the risk-taking task.

Autonomic Nervous System

There are two competing subsystems that dictate heart rate in human beings. The sympathetic nervous system allows for the mobilization of energy resources in response to stressful stimuli (Cannon, W. B., 1929). Higher sympathetic activity will increase the heart rate. This is accomplished through various endocrine mechanisms that break down stored sugars and fats, and upregulate the dispersal of oxygenated blood throughout the body. The parasympathetic nervous system helps facilitate the body's return to homeostasis after a stressful event (Gabella, 2001). One of the ways this is accomplished is through the vagus nerve. The vagus nerve runs from the brainstem to the heart, and allows for autonomic regulation of heart rate by the brain. Vagal stimulation of the heart slows down heart rate.

To test the effects of the mindfulness manipulation on cardiovascular responses to the experiment, we analyzed temporal changes in sympathetic and parasympathetic responses that were measured using the cardiac measures of **Pre Ejection Period** (PEP) and **Heart Rate Variability** (HRV) respectively (measures discussed in methods). These were measured across the four epochs in our study- baseline, reactivity to the intervention, changes during the task, and recovery after the task.

The Heart

The heart moves deoxygenated blood into the lungs and oxygenated blood into the arteries of the body. There are four major areas of the heart that will be focused on for the purpose of this thesis (Figure 1). There are two **ventricles** and two **atria**. The atria are the areas of the heart that receive blood, while the ventricles are the areas of the heart that squeeze this blood out of the heart. During each heartbeat, the atria first fill with blood from outside the heart. They send this blood down to the ventricles, which then contract to squeeze the blood into the target location.

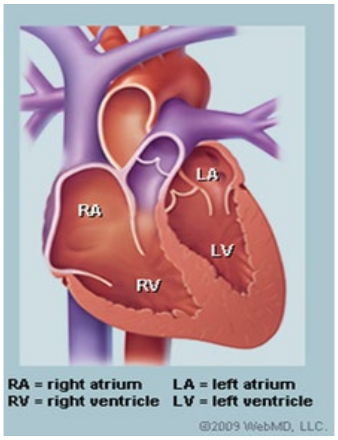


Figure 1. An illustration of the heart. (WebMD, llc)

The cardiovascular system is a lens through which we can understand the nature of human stress on a physiological level. Using these measures, we can understand the systems at play in physiological reactivity and whether they underlie higher order psychological processes. More specifically, we hypothesize that the participants assigned to the mindfulness training intervention, relative to control participants, will be able to upregulate their PNS and downregulate their SNS during the intervention and in response to the stress inducing financial decision-making context. We expect the meditation intervention to also result in a reduction of heart rate and blood pressure.

Question 2: How does physiological reactivity predict financial decisions during the task?

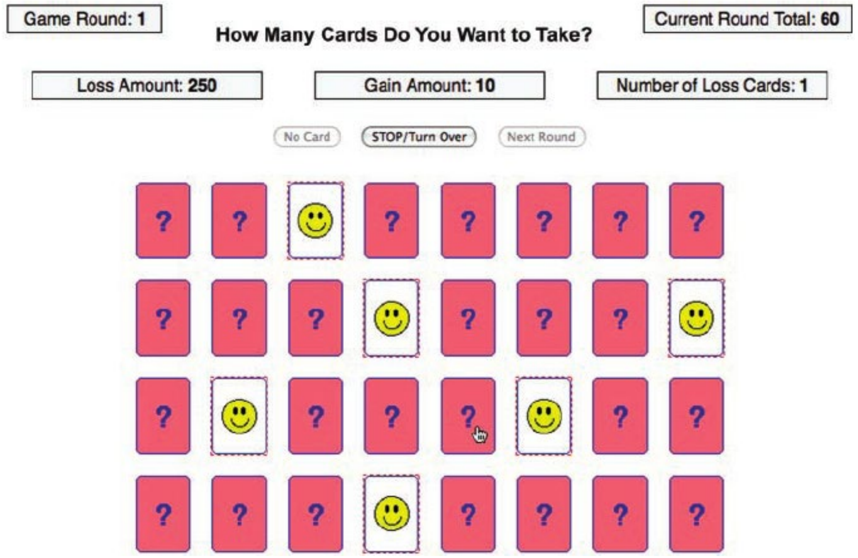
The other aim of this study was to examine how mindfulness-induced changes in cardiovascular physiology during the intervention and financial decision-making task predicted risky decisions. Using the hot (time pressured) version of the Columbia Card Task (CCT; Figner, Mackinlay, Wilkening, & Weber, 2009), we are able to quantify the amount and kind of risk a participant is willing to make.

Somatic Markers and Psychophysiology

The **somatic marker hypothesis** is a model that has been proposed to explain how these physiological signals can interact with higher order decision making processes (Bechara & Damasio, 2005). In this hypothesis, humans unconsciously respond to changes in their autonomic nervous system, altering the decisions they make based on the feedback they receive from their physiological response to a stimulus. This study examines the causal relationship between a mindfulness intervention and participants' physiological state, as well as the correlation that the intervention induced state has with the participants' economic decision making. Here, economic decision making will be modeled in the laboratory using the number of cards turned over in the CCT, a measure of risk. Any findings could illustrate a new utility for mindfulness meditation: use in making economic decisions. Institutional or other investors could potentially use mindfulness meditation as a tool to regulate their time-limited, affective decision making, allowing for better in the moment decision making and management of risk.

Columbia Card Task

A computerized task developed by the Columbia School of Business (Figner, Mackinlay, Wilkening, & Weber, 2009) has allowed for a balanced modeling of risk taking behavior in the lab. The rules of the game are as follows: in each round of the game, there are 32 cards that the participant can turn over. Most of these cards contribute a small amount of points, which translates to an overall increase in the participant's compensation. The other cards significantly reduce the amount of points that the participant earns in that round, which translates to an overall reduction in the participant's compensation. Picking one of these point-loss cards will also end the round. The participants run through a practice round and quiz to ensure they understand the task, and afterwards they complete 24 rounds of the game. In each round, three parameters change: the value of a "win" card, the value of a "loss" card, and the number of "loss" cards (Figure 2 illustrates a typical game setup).


Game Round: **1**

How Many Cards Do You Want to Take?

Current Round Total: **60**

Loss Amount: **250**

Gain Amount: **10**

Number of Loss Cards: **1**

Figure 2: A picture displaying a board that a participant might see during a round of the Columbia Card Task

There is a simple calculation to determine if turning cards over is the correct decision to make in a particular round. Many rounds, the probabilistically correct decision is to not turn over any cards and hit "stop" immediately. This is because the penalty one might receive from turning over the wrong card is so large that turning over even one card is more risk than the potential reward. If the probability and value of choosing a losing card is less than the probability and value of choosing a winning card then the correct path of action is to turn a card. The number of cards is considered an assessment of risk taking because as the participant turns more cards over, the likelihood of turning over a winning card decreases, and the likelihood of turning over a losing card increases. The amount of money they receive at the end of the study reflects their performance in 3 randomly selected rounds of the task. Participants completed the time pressure version of the task wherein, a timer at the top of the screen counted down from 18 seconds. After 18 seconds, no additional cards could be turned over in that trial, and the next trial began.

Previous research has investigated physiological reactivity during the CCT via skin conductance response to the card game in reference to a questionnaire and instructional set directly before and after the task (Figner & Murphy, 2011). This study found increased skin conductance, representing a stress response, relative to the periods before and after the game. Also, previous studies using samples of financial traders have shown that their financial decisions can induce changes in cardiovascular functioning (Lo & Repin, 2002; O'Creevy et. al., 2012).

These findings point to preliminary evidence of quantifiable bodily stress responses to participants undertaking financial decision-making, specifically using the hot version of the CCT. Moreover, it is likely the time pressure associated with each round of the CCT and the incentives associated with decision outcomes may elicit this cardiovascular response. As an additional stressor, the participants know they are being observed by the experimenter. Therefore, as the task appears to be physiologically stressful, and mindfulness meditation has been shown to mitigate physiological stress, we hypothesize that the mindfulness meditation will down regulate the SNS, reducing heart rate and blood pressure, and upregulate the PNS relative to control. We expected that these mindfulness meditation induced physiological states would predict risk taking behavior on the CCT. We expected the higher PNS activity to predict lower risk taking, and the lower SNS, BP and heart rate activity would also predict lower risk taking, providing an explanatory mechanism between meditation and reductions in risk taking behaviors in other contexts.

Methods

Participants

Data were collected from 161 participants (% 55.3 Female), who were recruited through the University's online human subjects pool and with flier and email postings. These participants were compensated $10 with a chance to earn a bonus of up to $4 based on their performance on a financial decision-making task. Average age of participants was 20.59 (SD = 2.76).

Procedure

On arriving at the lab, participants read and provided informed consent. After consent, participants were seated in the study room where they were connected to electrodes to measure **electrocardiography** (ECG) and **impedance cardiography** (ICG) measures across the duration of the study (see below for more information). During baseline cardiovascular measurement, participants completed a set of questions that assessed their psychological traits (not reported here). Participants were then randomly assigned to a mindfulness condition or an active control audio recording condition. After the participant completed listening to the mindfulness manipulation or control condition recording, participants completed a post-manipulation questionnaire and blood pressure measurements were taken. Following this, participants completed an economic risk-taking task, the CCT. Finally participants completed a post-task questionnaire to indicate affective and psychological states experienced during the risk-taking task (see Figure 3 for study timeline).

Cardiovascular measurement

In this study we measured: (i) Heart Rate (HR), (ii) Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP), (iii) Pre Ejection Period (PEP), and (iv) High Frequency Heart Rate Variability (HFHRV).

Using the Biopac MP150 (BioPac Systems, Inc; Goleta, CA) cardiovascular data collection system with Bionomadix wireless units, cardiovascular data was collected from the participants across the duration of the protocol (approximately 90 minutes). These non-invasive measures are recorded by placing electrodes on the skin of a patient or participant. ECG electrodes monitor heart activity by detecting small changes in the electrical properties of the skin when the heart beats, caused by the electrical signals from the contraction of heart muscle. We recorded ECG using a three-lead setup. Similarly, we recorded ICG using an eight lead ICG setup (see Figure 4 below for (L) ECG and (R) ICG electrode placement). Impedance cardiography works by placing at least four electrodes on the participant's body. One pair to transmit current, and the other to record changes in the impedance of that signal through the torso and thoracic cavity. In Figure 4 below, eight electrodes are being used. In this figure (R), the uppermost and lowermost horizontal pairs transmit current, while the two middle pairs of electrodes measure the change in impedance of that signal through the torso, measurable because of the constant current, and changing amount of blood in the torso.

Blood pressure

There are two factors involved in a typical blood pressure reading. The first factor is systolic pressure. **Systolic pressure (SBP)** is a measure of the pressure of blood vessels as the heart is beating. This number should always be larger than diastolic blood pressure. **Diastolic pressure (DBP),** which is a measure of blood vessel pressure when the heart is at rest. The upper healthy limit of systolic blood pressure is 120 mm Hg (mm Hg is a measure of pressure) and the upper healthy limit of diastolic pressure is 80 mm Hg (Whelton et. al., 2017). Blood pressure can be used as a measure of stress, since elevation of blood pressure is indicative of the body's sympathetic nervous system response (Blascovich et. al., 2001, Carrol et. al. 2001). To measure blood pressure, we used both systolic and diastolic blood pressures, recorded with an Omron Blood Pressure Monitor (Omron Inc., Kyoto, Japan). The Omron brand of monitor is a valid measure of blood pressure utilizing the brachial artery (Association for the Advancement of Medical Instrumentation, 1993; O'Brien et al., 1993; O'Brien et al., 2001). The monitor obtains SBP and DBP values using the oscillometric technique, using an automated cuff inflating and deflating repeatedly over the brachial artery to obtain a reading. The output reading was determined from an average of three readings taken over the course of two minutes. A period of 15 seconds separated each reading. Four blood pressure measurements were interspersed throughout the entirety of the study, between the epochs used for continuous cardiovascular measures (Figure 3).

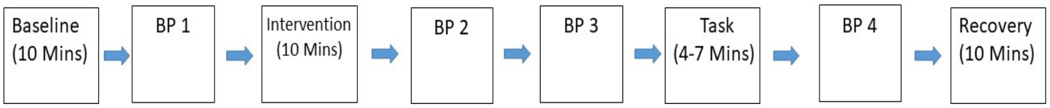


Figure 3. Study Timeline. BP = Blood pressure measurement.

Landmarks in Continuous Cardiography Waveforms

There are several important landmarks in the ECG and ICG waveforms. Starting at the beginning of the heartbeat on the ECG waveform is the P point (Figure 4). This P point of the ECG wave indicates an initial depolarization of the atria, moving blood into the ventricles. The Q point demarcates the beginning of ventricular depolarization, moving blood into the rest of the body. The R spike is the large characteristic, upwards change in voltage in the middle of the waves. This spike corresponds to the depolarization of the ventricles, and occurs just before the ejection of the blood from the heart into the target tissues.

Cardiography Measures

Using ECG, a variety of important physiological measurements can be taken. Specifically, the person’s heart rate, which is the duration in time from one R spike to the next, can be measured with ECG. ECG also allows measurement of heart rate variability (HRV), which is the relative change in the timing of heart beats within a given period. The high-frequency component of the HRV (or HF HRV) can be calculated, which is thought to be a relatively clean signal of vagally-mediated parasympathetic activity (Thayer & Lane, 2000). HF HRV has previously been associated with autonomic and affective regulation (Thayer & Siegle, 2002) as well as executive function and cognition (Hansen et. al. 2004), such that higher HFHRV is associated with improved executive function and emotional control.

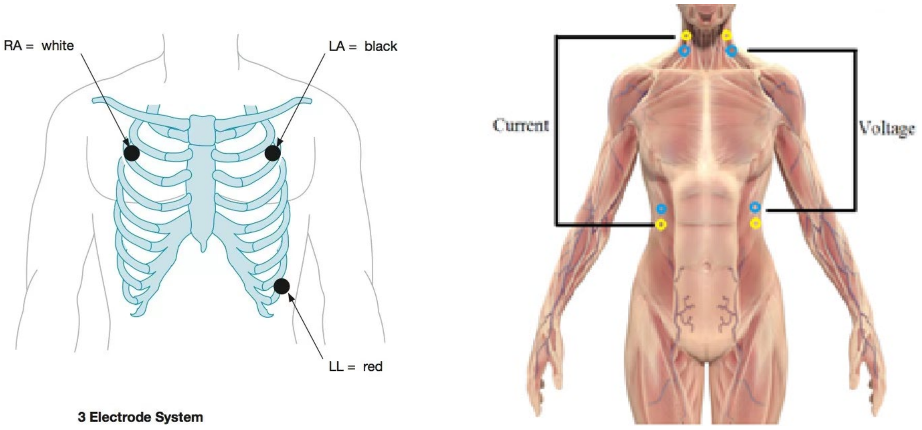


Figure 4. ECG (Left; Cadogan, A. *3-electrode system*) and ICG (Right) set up. (medicalgraphics.de)

A metric of cardiovascular function determined via ECG and ICG together is pre-ejection period (PEP), which is a measure of sympathetic nervous activity. This is the amount of time between the Q wave (Figure 5) and the initial ejection of blood by the ventricles. This initial ejection begins with the opening of the aortic valve. In impedance cardiography, the aortic valve opening is coded as the B point, an empirically determined time between R point and peak of the ICG waveform of a given cycle (Lozano et al., 2007). Therefore, PEP is the distance in time from Q to B (Figure 4 for these landmarks). This period of the cardiac cycle is especially interesting to psychologists because this particular metric has been tied to catecholamines (such as epinephrine) produced as part of the sympathetic stress response. Higher levels of catecholamines – and higher sympathetic activity – shorten the PEP (Newlin 1979).

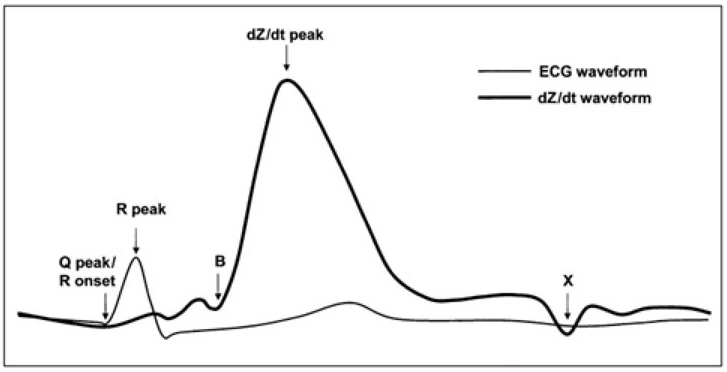


Figure 5. Electrocardiography and Impedance Cardiography waveform. (Lozano et. al., 2007)

Mindfulness manipulation

After participants provided the initial baseline measurement, they were randomly assigned to either the mindfulness intervention or control condition for the audio recording portion of the experiment (N = 161, 78 control, 83 experimental). Both the control and mindfulness recordings were 10 minutes in length. The recordings were administered via headphones in individual testing rooms. The mindfulness recording was a focused breathing exercise that was presented as an attention training exercise (Alberts & Thewissen, 2011), and the active control was an affectively neutral excerpt from the book *Lord of the Rings: A Fellowship of the Ring* on audiobook (see appendix for transcript), also presented as an attention training exercise. Experimenters who assigned participants to either condition were blind to the condition assignment. As highlighted above - cardiovascular reactivity was measured over the course of the 10-minute recording.

Columbia Card Task

After the mindfulness intervention, participants completed an economic risk taking task- the “hot version” of the CCT (Figner & Weber, 2011; Figner, Mackinlay, Wilkening & Weber, 2009). In the task, 32 digital cards are displayed in front of the participant, and they must decide how many to turn over that round. Most of the cards are “win” cards, and correspond to a small increase in the participant’s points for that round. One to three cards each round is a “loss” card and corresponds to a significant decrease in the amount of points earned in the round. The exact point amount per card changes from round to round. Drawing a “loss” card also ends the round.

Participants complete 24 rounds of play, separated into three blocks. Each round is completed in 18 seconds, which is communicated to the participant with a timer at the top of the page. The round is over at the end of these 18 seconds, and the next round begins.

Before completing the CCT, the participants completed a practice round of the task, to ensure that they understood the task and could navigate the task interface. As a second check, they also completed a quiz to demonstrate their understanding of the rules of the task and basic arithmetic. Before the task, the participants were informed that their performance on the task would affect the amount of money they would receive for their time in the study, ranging from 10 to 14 USD. Text on-screen reminded the participants to think back to their audio file from earlier, and tracked affective changes. The participant completed the CCT while alone in a room, but to increase the social evaluative aspect of the task, their screen was set up in front of them to be monitored by the researcher from outside. At the conclusion of the task, three rounds were selected at random to determine participant payout. Risk-taking is measured by calculating the average number of cards turned over per trial (Figner, Mackinlay, Wilkening & Weber, 2009). In this study, the hot version of the CCT was programmed in our lab using MATLAB.

Data Analysis for physiological measurement

Physiological measurement was obtained across four epochs during the study - Baseline, Intervention, Task, and Recovery. The baseline epoch lasted 10 minutes from the participant sitting in the chair to complete the questionnaire. The intervention epoch lasted 10 minutes after the beginning of the audio file (*Lord of the Rings* recording for control and the mindfulness intervention for experimental). The task epoch lasted the duration of the CCT and began with the participant's first click on the screen, ending with their last. This epoch ranged from 4-10 minutes (Mean = 6.88, SD = 1.50), and was dependent on the participant's speed and length of the trials. Finally, the recovery epoch lasted 10 minutes.

These four epochs were combined into two reactivity scores using Pruessner and colleagues' (2003) method. One score – known as AUCi (Area Under the Curve - with respect to increase) – subtracts out baseline and therefore represents a reactivity measure. The other score - representing overall cardiac arousal is known as AUCg (Area Under the Curve -with respect to ground, Figure 6). AUCg scores are a summation of the epochs, according to the formula

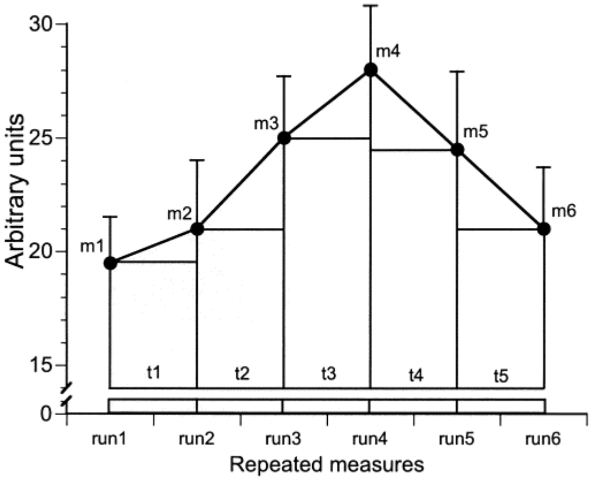


Figure 6: AUCg ilustration.

Where m_1 is the first epoch, and m_n corresponds to each subsequent epoch, approximating the area under the curve of physiological reactivity. AUCi (Figure 7) is identical, except for the removal of the area between ground and the first measure (baseline) for all time points, in this case the baseline measure is subtracted three times.

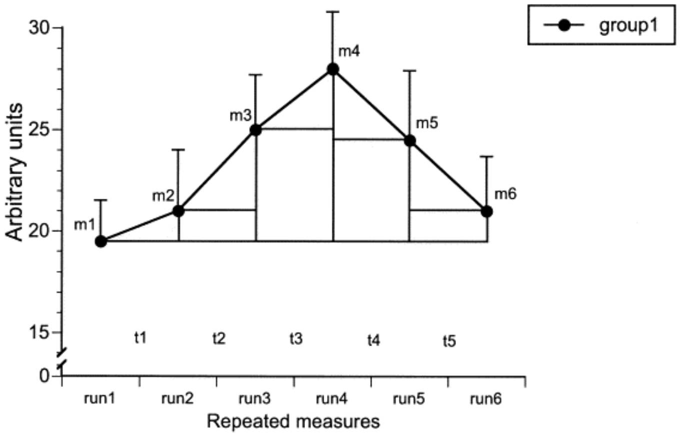


Figure 7: AUCi illustration.

Using ACQknowledge 4.1, we used a semi-automatic procedure to determine the R peak in the ECG waveform (Figure 5 for visual depiction of waveform). Data was segmented into epochs of interest, cleaned, and the built in Pre Ejection Period scoring tool was used to determine the landmarks on the ECG and ICG waves.

The R-R intervals were measured within each epoch of interest. The change in voltage from the B point to the C point (the maximum of the dZ/dt waveform) was used to determine the Z-max of the impedance waveform -- i.e., the peak of a cycle's dZ/dt representative of the maximal blood ejection -- from which the B-point of the dz/dt wave was determined using the Lozano et al. (2007) method. From this data, the HR, HRV, and PEP of the participants was recorded.

Cardiovascular time points and landmarks were extracted from the raw ACQknowledge data into a text file using an open source Python library, "BioRead." The package "RHRV" (Garcia, Otero, Vila & Lado, 2012) was utilized to determine HF HRV via an autoregressive model that estimated the relative power of the high frequency component (0.15-0.4 Hz) of the HRV waveform (a clean index of PNS activity (Thayer & Lane, 2000; Berntson et. al., 1997)).

Statistical Analysis

Preceding statistical analysis, the datasets were winsorized such that any data points more than three standard deviations away from the grand mean were set to equal the datapoint collected in the set that was closest to three standard deviations. This lead to changes in 3 PEP scores and 4 HRV scores, as well as 3 SBP and 4 DBP scores.

Intervention Physiological Effects: Change over time (Question 1)

To analyze the overall changes in physiological responses to the mindfulness intervention, 2 (Control vs. Mindfulness) x 4 (Epochs) repeated measures GLM were used. Several of these models violated sphericity assumptions, and Greenhouse-Geisser corrections were applied to rectify this. The epoch scores were calculated by averaging the minute-by-minute values of each measure. For example, baseline PEP was calculated by averaging the PEP during minutes 0-10 of the participant's baseline recording. The task epoch was calculated based on when the participants began clicking and finished clicking during the CCT.

Physiological Effects and Resulting Behavior During the CCT (Question 2)

To test the effects of physiological changes on risk taking behavior during the CCT, we ran mediation analyses using the PROCESS macro (v 2.16.3), Model 4 template in SPSS (v22., IBM Corp). In this model, we tested a mediation model with intervention condition as the independent variable, HR, PEP, HRV, DBP and SBP, as AUCi reactivity scores, as mediators, and risk taking behavior as the dependent variable.

Exploratory question

To explore the effects of overall cardiac arousal (as a measure of trait-level reactivity) on risk taking behavior, we ran moderation analyses using the PROCESS macro (v 2.16.3), Model 1 template in SPSS (v22., IBM Corp). Here, we used AUCg scores for HR, PEP, HRV, DBP and SBP to predict risk taking on the CCT by condition. Given prior unpublished evidence that individual difference factors, such as-neuroticism, may indeed moderate the effect of mindfulness meditation on risk taking (Mehta et al., unpublished; Prasad, 2018). These findings suggest that the mindfulness intervention may be beneficial for those with certain traits. We operationalized cardiac reactivity relative to zero (or "ground") as a trait-like measure to explore the connection between cardiac reactivity relative to ground and risk taking.

Transparency in reporting

This study is a subset of a larger study in which psychological and endocrine measures were collected (Prasad, 2018). Participants completed questionnaires that allowed them to describe their psychological state during the intervention phase of the experiment, these included the Positive And Negative Affect Schedule (PANAS), two risk-taking and gambling assessments, biological and demographics information. Saliva samples were collected to measure endocrine responses to the mindfulness intervention and decision-making task. These questionnaires and saliva samples were collected to investigate other research questions of interest, and are not reported here. Questionnaires were taken by participants during baseline, after the intervention and after the task, and saliva samples were collected simultaneously.

Results

Tables of SDs and Means:

Below we report descriptive statistics of the different physiological variables during each of the epochs of interest.

Table 1

Means and Standard Deviations for Continuous Cardiovascular Variables

	Baseline	Intervention	Task	Recovery
PEP	127.73 (9.08)	125.59 (8.31)	127.10 (9.44)	127.63 (8.97)
HRV	0.208 (0.103)	0.229 (0.123)	0.219 (0.116)	0.207 (0.102)
HR	77.05 (12.07)	74.24 (11.27)	73.58 (11.11)	72.13 (10.23)

Table 2

Means and Standard Deviations for Blood Pressure Measurements

	Baseline	Pre-intervention	Post-intervention/Pre-task	Post-Task
DBP	69.37 (7.84)	68.40 (7.73)	71.68 (9.24)	70.40 (7.62)
SBP	106.34 (10.77)	103.65 (10.36)	107.38 (11.26)	104.33 (10.47)

Question 1: What are the effects of a mindfulness intervention on cardiovascular reactivity during the intervention and in a later financial decision-making context?

Parasympathetic and sympathetic reactivity

As noted previously, the parasympathetic and sympathetic nervous systems both regulate the cardiovascular system, but in opposite directions. The SNS aids in physiological reactivity to stressors, while the PNS helps the body return to or maintain homeostasis. We can operationalize SNS activity with PEP and PNS activity with HFHRV. In the following analyses, we examined the role of mindfulness in altering the reactivity of these systems from baseline to intervention, through the economic decision-making task and upon return to recovery.

Parasympathetic response: First, we tested the effects of the mindfulness manipulation on the parasympathetic nervous system by using a repeated measures ANOVA of HF HRV across all epochs and with condition as a between subjects factor. We expected to see enhanced PNS reactivity in the experimental condition compared to the control condition. These analyses revealed a significant interaction between time and condition ($F(2.459, 327.027) = 4.631$ $p = .006$, $\eta_p = .034$). Visual inspection of the interaction indicated that while we did not see any differences in the effects of the intervention on HRV during the intervention epoch, HRV increased in the participants in the intervention condition relative to the control condition during the task epoch.

To investigate the temporal specificity of the time x condition interaction, we conducted follow up analyses using independent samples t tests on HFHRV across each epoch, with condition as a between subjects factor. At baseline and during the intervention, we found no differences in HRV (Baseline: $t(139) = -0.890$, $p = .375$; Intervention: $t(138) =0.522$, $p = .603$). During the task epoch, we observed a significant difference between the control and experimental conditions, confirming what appeared to be true from a qualitative analysis of the repeated measures ANOVA outputs (Task: $t(135) = -2.098$, $p = .036$; Levene's test for equality of variances was significant (p $=.002$), equal variances were not assumed). This finding supports our hypothesis that the experimental condition increased HFHRV activity compared to the control condition (see Table 1 for Ms and SDs). This finding supports our hypothesis that experimentally assigned participants would show increased maintenance of PNS activity levels relative to control through the CCT.

Finally, as we would expect, HFHRV returned to comparable levels across both conditions after the completion of the task during the recovery epoch (Recovery: $t(134)$ $= -0.870$, $p = .870$). This finding suggests that the mindfulness intervention may have provided participants with greater parasympathetic control relative to control, allowing the participants to maintain their PNS response that they demonstrated during the intervention, and more effectively deal with the potentially stressful nature of the decision-making task.

Moreover, we also found a main effect for time in the repeated-measures ANOVA ($F(2.459, 327.027) = 3.784$ $p = .016$, $\eta_p = .028$). Repeated measures contrasts revealed that from baseline to intervention; participants showed increased HFHRV in the intervention epoch across both conditions compared to baseline (Repeated measures contrasts: **Baseline to Intervention:** $F(1,134) = 7.806$, $p = .006$). However, there were no differences in the other epochs of the study (**Intervention to Task:** $F(1,134) = 1.369$, $p = .244$ **Task to Recovery:** $F(1,134) = 2.780$, $p = .098$) See Table 1 for Means and SDs of HFHRV across epochs. The significant differences in HFHRV from baseline to the intervention epoch may highlight an up-regulation of the PNS due to the intervention, across both conditions.

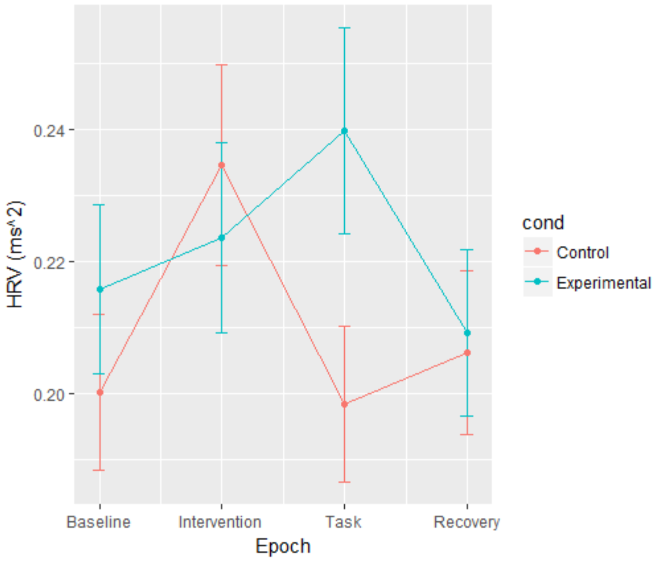


Figure 8. Repeated measures ANOVA for HFHRV during baseline, mindfulness training, task, and recovery. Error bars represent standard error.

Sympathetic response: Next, we examined the role of the intervention on changes in PEP across all four epochs of the study. Specifically, we expected to see reduced sympathetic activation (i.e., longer PEP) in the intervention and task epochs relative to the control condition. To investigate this, we ran a mixed model repeated measures ANOVA with time as a within subjects factor and with condition as a between subjects factor. We found no significant effect for the interaction between time and condition ($F(3, 402) = 1.232$ $p = .298$, $\eta_p = .009$), thereby failing to support our hypothesis that the experimental condition would alter SNS reactivity to the experiment. However, we did find a main effect for time ($F(3, 405) = 14.753$ $p < .0005$, $\eta_p = .099$). The general trend between the two conditions was very similar, with a reduction in PEP during the intervention epoch (**Baseline to Intervention:** $F(1,135) = 43.164$, $p < .0005$) and an increase to task (**Intervention to Task:** $F(1,135) = 15.503$, $p < .0005$). However, the lengthening of PEP was sustained from the task epoch to recovery (**Task to Recovery:** $F(1,135) = 2.210$, $p = .139$). See Table 1 for means and direction of effect.

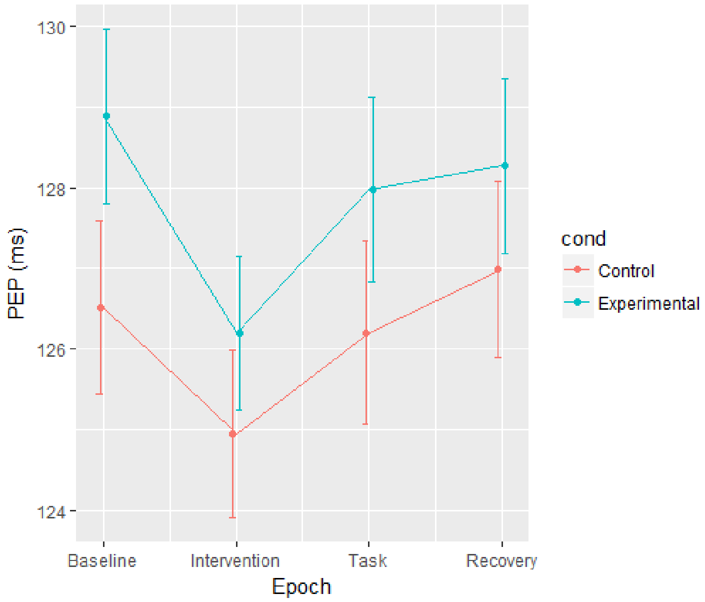


Figure 9. Repeated measures ANOVA for PEP during baseline, mindfulness intervention, task, and recovery. Error bars represent standard error.

We found the shortening during the intervention epoch unexpected, as that period of time was hypothesized to dampen the SNS response. It is possible the shortened PEP during this epoch was due to the engaging nature of the intervention and the active control (a passive control, such as a silent 10 minutes, would be less engaging). The meditation intervention required the full attention of the participant, and the active control still required the participant to focus on the arc of a story. Also intriguing is the lengthening of PEP into the task, which has been shown to be stressful. This could be a result of increased SNS activity during the intervention returning to baseline (see discussion for SNS and meditation findings).

Cardiac Reactivity

To help triangulate the findings of the autonomic subsystems, we tested for differences in heart rate and blood pressure by condition.

Blood Pressure: We used the four blood pressure measurements taken at baseline, post intervention, pre task and post task. Of note, blood pressure measurements were captured at specific instances of the study and therefore do not fully align with continuous or epoch based cardiovascular data. We hypothesized that the mindfulness intervention would lower blood pressure after the intervention and before and after the task. We also expected to find lowered blood pressure in these epochs for experimentally assigned participants relative to control. To test the effect of the intervention on both systolic and diastolic blood pressure across the entire study, we ran mixed model repeated measures ANOVAs (Figure 10) with time as a within subjects factor and condition as a between subjects factor.

We found no significant time x condition interaction for SBP through a repeated measures ANOVA across all epochs with condition as a between subjects factor ($F(2.638, 400.990) = 0.132$ $p = .932$, $\eta_p = .001$). We found a main effect for time for SBP ($F(3, 459) = 19.989$ $p < .000$, $\eta_p = .116$). Repeated measures contrasts revealed that SBP decreased from baseline to after the intervention and control (**Baseline to Post Intervention:** $F(1,153) = 34.523$, $p <.0005$), increased from after the intervention in anticipation of the task (**Intervention to Pre Task:** $F(1,153) = 43.610$, $p < .0005$), and then decreased again directly after the completion of the task **(Pre Task to Post Task:** $F(1,153) = 30.986$, $p < .0005$).

We also found no significant time x condition interaction for DBP through a repeated measures ANOVA across all epochs with condition as a between subjects factor ($F(2.773, 421.501) = 1.941$ $p = .127$, $\eta_p = .013$). We found a main effect for time for DBP ($F(3, 459) = 16.493$ $p < .000$, $\eta_p = .097$). We found that these changes were significant across all epochs (**Baseline to Post Intervention:** $F(1,153) = 6.079$, $p = .015$ **Intervention to Pre Task:** $F(1,153) = 34.356$, $p < .0005$ **Pre Task to Post Task:** $F(1,153) = 4.441$, $p = .037$). Changes followed the same pattern as SBP, described above. Table 2 displays means and SDs for these data.

In both sets of blood pressure measurements, our hypothesis that the intervention would allow for experimentally assigned participants to maintain a lower blood pressure through the study relative to the control condition was not supported. However, we did find time dependent changes with decreases in blood pressure after the intervention and increases directly before the task. This suggests that the intervention and control both reduced BP in a non-discriminant way across both conditions. Moreover, participants demonstrated subsequent increases in BP from after the intervention to just before participants began the task. It is also important to note that participants completed three practice trials and a quiz pertaining to task instructions that may have also increased BP prior to the task. The quiz was completed under direct observation of a research assistant. Therefore, because the third BP measurement was taken just prior to the 24 rounds of the task it is likely that the blood pressure change at that time represents an anticipatory response, preparing the body for the stress of the CCT. Alternatively, it could represent a social stress response in reaction to the evaluation of a math task. Nonetheless, the lack of difference between conditions suggests the mindfulness intervention was not successful in differentially regulating blood pressure.

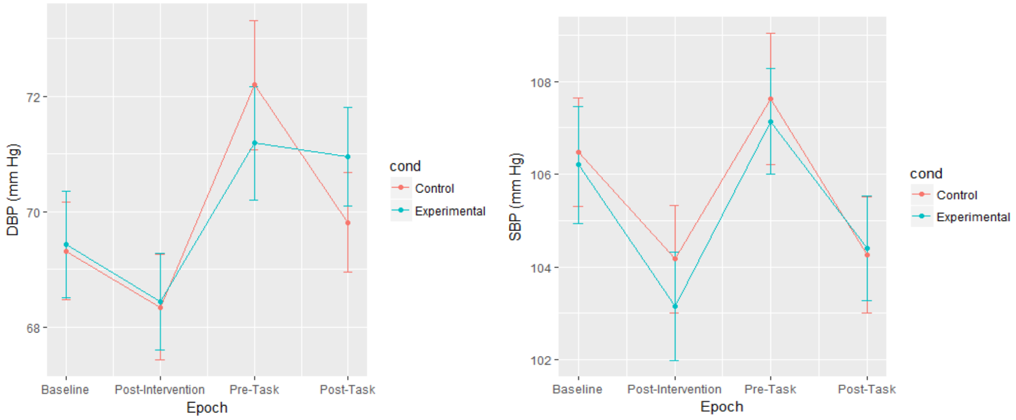


Figure 10. Systolic Blood Pressure (L) and Diastolic Blood Pressure (R) across the entire study. Error bars represent standard error.

Heart Rate: As a final measure, we hypothesized that the mindfulness assignment would allow participants to exhibit a lower heart rate during the intervention and task epochs. To examine if the mindfulness manipulation altered heart rate, a mixed model repeated measures ANOVA was conducted with time as a within subjects factor and condition as a between subjects factor. We found no significant effect for the interaction between time and condition ($F(2.554, 344.804) = 1.501$ $p = .218$, $\eta_p = .011$; see Figure 11), thereby not providing support to our hypothesis that individuals in the mindfulness intervention condition would show reduced heart rate during the intervention and task epochs relative to those in the control condition.

We did find a main effect for time ($F(3, 408) = 47.979$ $p < .0005$, $\eta_p = .261$). We found these differences to be driven mainly by the baseline-intervention differences and the task-recovery differences (**Baseline to Intervention:** $F(1,136) = 99.075$, $p < .0005$ **Intervention to Task:** $F(1,136) = 0.933$, $p = .336$ **Task to Recovery:** $F(1,136) = 9.419$, $p = .003$). See table 1 for means and direction of effect. As shown in Figure

11, we found a decrease in heart rate across all epochs. This could be due to the sedentary nature of the study, as participants walked into lab but were seated from the beginning of the experiment until the end. These changes over time also may reflect the interplay between our autonomic nervous systems, as we see increased activation of both the SNS and PNS, it is not clear which direction is dominating control of heart rate. The overall decline suggests stronger PNS activation, particularly from baseline to intervention, that which is consistent with the significant increase in HFHRV from baseline to intervention. The increase in SNS activity during this same period does not preclude the PNS from having an effect on overall heart rate, as the magnitudes of each are not directly comparable. Significant increases in both does not mean there was no net effect, as the increase in one system could be more powerful.

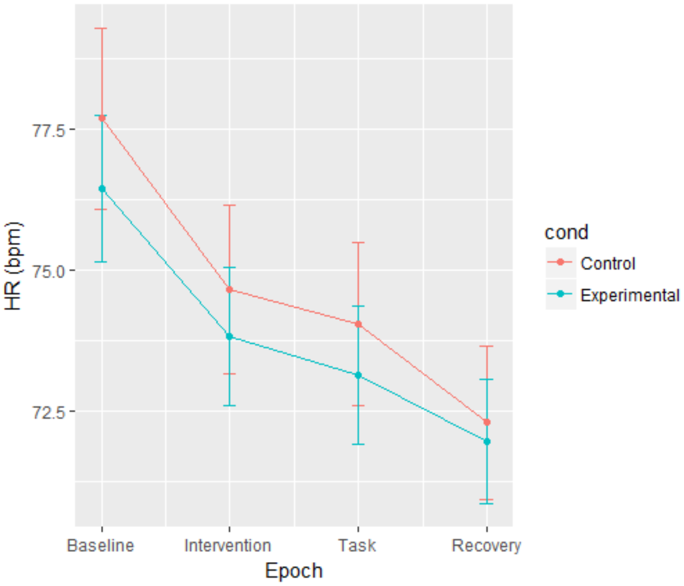


Figure 11. Repeated measures ANOVA for HR during baseline, mindfulness training intervention, task, and recovery. Error bars represent standard error.

Question 2: How does the physiological reactivity of participants throughout the study predict economic risk-taking?

For the following analyses, we used Area Under the Curve with respect to increase (AUCi) scores to measure cardiovascular reactivity to the intervention. These analyses examined the extent to which changes in physiological reactivity as a result of the manipulation predicted behavioral differences in risk-taking. It is important to note that because we found that the mindfulness manipulation increased risk-taking in the CCT ($t(156) = -1.864$, $p = .064$, Prasad, 2018), we expected to find inconsistent mediation via the pathway of cardiovascular reactivity. More specifically, given that the direct path between intervention and risk-taking was positive, we predicted that cardiovascular reactivity would act as a suppressor of this positive effect of mindfulness on risk-taking by reversing the direction of the mindfulness and risk-taking relationship. We utilized the PROCESS macro Model 4 for SPSS, whose mediation analysis uses bootstrap, bias corrected effects to analyze possible mediators (Hayes, 2013).

Parasympathetic Response: The parasympathetic response was operationalized using HFHRV. We hypothesized that the participants assigned to the mindfulness condition would exhibit higher levels of HFHRV reactivity (more PNS activity) relative to control, and higher levels of HFHRV as a result of the mindfulness intervention would in turn predict lowered risk taking. Contrary to our prediction, we did not find a significant mediation of condition predicting risk-taking behaviors via HFHRV reactivity (PROCESS Model 4:$b =$ -0.0137 $SE = 0.0564$, *95% CI*: [-0.2028, 0.0539]). This analysis suggests that mindfulness induced HFHRV reactivity changes do not underlie economic risk taking behavior.

Despite the repeated-measures findings of mindfulness intervention's effects on HF HRV, we found no main effect of condition on HFHRV AUCi scores (*t*(133) = 0.472, *p* = .638), which resulted in a weak mediation effect. To further investigate the mediation, we repeated the analysis with the HFHRV for the task epoch, which was significant between conditions (*t*(135) = -2.098, *p* = .036). This allows us to see in greater fidelity in where the mediation breaks down. However, in this analysis, we still did not see mediation of risk taking by condition and physiology. (*b* = 0.0299 *SE* = 0.0945, *95% CI*: [-0.1340, 0.2625]). This finding suggests that the physiological and behavioral pathways of this experiment are independent. Even when we see significant differences across condition for physiology during the task, we do not necessarily see those changes match up with a significant change in risk taking behavior.

Sympathetic Response: As PEP is a measure of sympathetic activation and mindfulness interventions are known to reduce SNS activity and reduce health related risk taking, we predicted that the experimentally assigned participants would exhibit a lengthening of PEP relative to control (meaning reduced sympathetic response), and these same participants would exhibit lowered risk taking. No significant results were found for a PROCESS Model 4 mediation analysis predicting risk taking with PEP and condition (*b* = 0.0351 *SE* = 0.0604, *95% CI*: [-0.0518, 0.2030]) This analysis suggests that mindfulness induced SNS reactivity changes do not underlie economic risk-taking behavior.

Blood Pressure: We expected to see blood pressure mediate the relationship between risk taking and condition. As mindfulness interventions can be thought of as stress reducing, and higher BP is associated with greater levels of cardiac stress, we hypothesized BP to be lower in the experimental condition and that this lower BP would correlate to less risk taking. A PROCESS Model 4 mediation analysis was conducted with both systolic and diastolic blood pressures, with no significant results. This did not support our hypothesis, and suggests that blood pressure does not mediate the relationship between experimental condition and risk-taking behavior. (**DBP**: *b* = -0.007, *SE* = 0.0481, *95% CI*: [-0.1450, 0.0706]; **SBP**: *b* = 0.0125, *SE* = 0.0618, *95% CI:* [-0.0914, 0.1710]) This finding suggests that mindfulness induced blood pressure reactivity changes do not underlie economic risk-taking behavior.

Heart-rate: Finally, we hypothesized that experimentally manipulated changes would lead to lower heart rate in the experimental condition, and this would correlate to less risk taking, as perhaps the mindfulness would introduce better control of the stress response. To test this possibility, we ran a mediation analysis, determining how well the condition-induced changes in physiological reactivity predicted risk taking behavior by using a PROCESS model 4 analysis (*b* = -0.0021 *SE* = 0.0536, *95% CI*: [-0.1316, 0.0975]). This analysis suggests that mindfulness induced heart rate reactivity changes do not underlie economic risk-taking behavior.

Taken together, these findings suggest that the physiological reactivity as a result of the experimental manipulation did not predict economic risk taking on the CCT. That is, we do not see that condition induced changes in cardiovascular reactivity help to explain the marginal differences between conditions for risk taking on the CCT.

Exploratory question: How do metrics of trait-based physiological changes relative to ground moderate the effect of condition on economic risk taking?

As an exploratory research question, we also examined the extent to which trait based differences in resting physiology may moderate the effects of the mindfulness intervention on risk-taking. Given prior unpublished evidence that individual difference factors, such as- neuroticism, may indeed moderate the effect of mindfulness meditation on risk taking (Mehta et al., unpublished; Prasad, 2018). These findings suggest that the mindfulness intervention may be beneficial for those with higher levels of trait neuroticism. More specifically, for individuals in the mindfulness condition those with higher levels of neuroticism would show lower risk-taking behaviors, however for those in the control condition the opposite pattern of effects was found. We argue that individual differences in cardiac reactivity may also moderate the relationship between mindfulness and risk-taking. Neuroticism is one measure of emotional regulation, and we expect to find trait based cardiovascular reactivity to play a similar role in risk taking. We predicted that for those assigned to the mindfulness intervention, individuals with reduced SNS and cardiac reactivity, and higher levels of PNS activity would show lower levels of risk-taking. This may be because the mindfulness intervention may equip participants to refrain from making risky decisions on the CCT. We do not expect to see a strong effect in the control condition.

Unlike an AUCi score, which removes all baseline measurements from the analyses, to measure trait-based physiological reactivity we used Area Under the Curve (ground) or AUCg scores. The reason why we used this measure was because it takes into account baseline differences in cardiovascular reactivity and therefore includes in the analysis the participants’ cardiovascular state as they enter the laboratory, as well as their overall pattern throughout the duration of the experiment.

HFHRV: No significant results were found for a PROCESS Model 1 analysis testing the interaction between condition parasympathetic nervous system activity (i.e., HFHRV) predicting risk taking. $\Delta R^2 = .0090$, $B = -1.4589$, *95%CI*: [-4.0781, 1.1603] $F(1, 130) = 1.2144$, $p = .2725$. This did not support our hypothesis, and suggests that trait based changes in PNS activity did not moderate the effects of an intervention on risk taking behavior.

PEP: No significant results were found for a PROCESS model 1 moderation analysis testing the interaction between condition and sympathetic nervous system activity (PEP) $\Delta R^2 = .0014$, $B = -0.0064$, *95%CI*: [-0.0359, -0.0231] $F(1, 131) = 0.1855$, $p = .6674$. This did not support our hypothesis, and suggests that trait based changes in PEP do not moderate the relationship between condition and risk taking behavior.

Blood Pressure: A PROCESS model 1 analysis was conducted with measures of both systolic and diastolic blood pressure reactivity that revealed no significant results. This suggests that blood pressure does not moderate the relationship between experimental condition and risk taking behavior. **SBP**: $\Delta R^2 = .0015$, $B = 0.0060$, *95%CI*: [-0.0182, 0.0301] $F(1, 149) = 0.2388$, $p = .6258$ **DBP**: $\Delta R^2 = .0015$, $B = -0.0080$, *95%CI*: [-0.0411, -0.0251] $F(1, 149) = 0.2272$, $p = .6343$. This did not support our hypothesis, and suggests that trait based changes in BP do not moderate the relationship between condition and risk-taking behavior.

Heart-rate: Finally, using PROCESS Model 1, we ran a moderation analysis with condition and heart rate reactivity predicting risk taking behavior ($\Delta R^2 = .0425$, $B = -0.0299$, *95%CI*: [-0.0540, -0.0059] $F(1, 133) = 6.0630$, $p = .0151$). We found that

AUCg scores of heart rate moderated the interaction between risk taking behavior and condition.

An analysis of simple slopes for heart rate indicated in the experimental condition there was a negative relationship between HR reactivity and risk-taking (Experimental: b = -0.0227, t(133) = -2.4018, p = .0177, *95% CIs*: [−0.0414, -0.0040]), however in the control condition this negative effect was suppressed (Control: b = 0.0073, t(133) = 0.9276, p = .3451, *95% CIs*: [−0.0079, 0.0224]). The statistically significant interaction term indicates that these slopes differed from each other (See Figure 12). This finding suggests that for those in the intervention condition, higher levels of HR predicted taking fewer risks, while those in the control condition did not show this relationship. As a confirmatory analysis that this effect is driven by baseline heart rate, we repeated the model with AUCi scores, which do not account for baseline. We found a null result (ΔR^2 = .0081, B = 0.0457, *95%CI*: [-0.0403, -0.1317] F(1, 133) = 1.1044, p = .2952), suggesting that it is not heart rate reactivity alone, but rather heart rate reactivity relative to ground drives the differences between conditions.

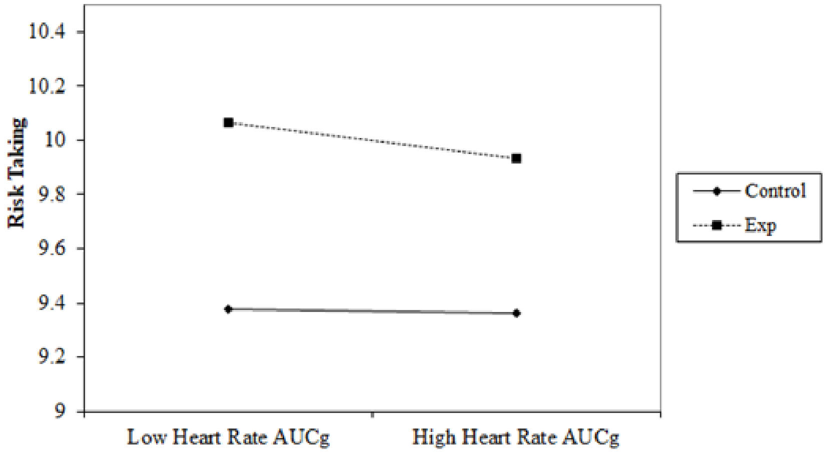


Figure 12: Illustration of Heart rate reactivity x condition moderating risk taking on the CCT. Note truncation of y-axis for purpose of illustrating effect.

Discussion

In the present study we sought to examine the ways that a mindfulness intervention could alter a participant's physiology. We also investigated how a mindfulness induced physiological profile predicted risk taking on the CCT, a potentially stressful financial decision making task. In this study we found that a mindfulness intervention increases participant PNS activity during the CCT relative to a positive control. We found null effects for a condition x time interaction on the measures of HR, DBP, SBP and PEP. We also found that the effects of condition on risk taking behavior on the CCT were not mediated by reactivity measures (AUCi) for any of the cardiovascular measures.

Interpretation and Implications of the Effects of a Mindfulness Intervention on Cardiovascular Activity

The present study illustrates that mindfulness interventions can increase PNS activity relative to a positive control. These results were consistent with previous findings regarding mindfulness meditation interventions and heart rate variability (Burg, Wolf & Michalak, 2012, Krygier et. al., 2013). Specifically, experimentally assigned participants showed increased HFHRV during the task epoch compared to those in the control condition. Previous research has found peri-intervention changes to HFHRV (Krygier et. al. 2013), but few have explored the time-delayed effects of an intervention during a financial decision-making task. These results are the first to demonstrate the time-delayed effects of a mindfulness meditation intervention on physiological activity during a financial decision-making task.

One possible interpretation of this data is that the mindfulness intervention allowed participants to successfully deal with the challenging task by using the techniques they were introduced to during the mindfulness audio recording. They were reminded to refer back to the intervention during the task, so the mindfulness intervention would have been a point of focus for them as they completed the rounds of the CCT. This requires future research to examine other possible mechanisms to explain our effects. Affective changes underlying the differences in PNS activity between conditions could be one potential mechanism. Perhaps the mindfulness meditation intervention provides the participants a sense of having enough resources to deal with the challenging task. Perhaps the task itself is perceived as less of a challenge. Differing levels of participant engagement with the intervention could also help to explain the changes we found.

The PNS findings point towards mindfulness meditation as a way of achieving higher levels of vagal tone. This illustrates that we have some level of conscious control over what is essentially an autonomic nervous process. We examine this in a financial risk taking context, but being able to regulate the PNS in any many contexts allows for improved emotional recognition, social cognition and working memory (Thayer & Brosschot, 2005; Thayer & Sternberg, 2010; Quintana et. al., 2012; Giuilano, Gatzke-Kopp, Roos & Skowron, 2017). All three of these could in theory underlie a change in economic risk taking.

It is likely that this effect reaches beyond financial decision making, and can be applied to an array of stressors, as illustrated by other studies showing mindfulness' ability to exhibit greater control over cardiac reactivity during stressors like scenes of violence (Brzozowski, Gillespie, Dixon, & Mitchell, 2018) or marital conflict (Kimmes et. al., 2017). Additionally, the CCT in this study served a dual role as a social stressor, potentially illustrating that this increase in PNS activity could work for social stresses as well as financial. This meditation exercise could be utilized to purposefully speed up a person's return to cardiac homeostasis in a variety of circumstances. This infers that mindfulness meditation could be used as a coping mechanism to ensure that decision makers are able to more effectively "de stress" prior to a stress inducing task. The damaging effects of overactivation of the SNS have been well documented (Dobie et. al., 2004; Pearlin, Schieman, Fazio & Meersman, 2005; Wiebe & McCallum, 1986), and this study shows that mindfulness meditation represents a way to mitigate the activity of the SNS by increasing vagal regulation of the heart.

It is curious that we found effects for HFHRV during the task but did not see corresponding changes in PEP, SBP, DBP or HR. This is an area of future research that could help explain what we found in this study. These results suggest that participants can independently regulate their PNS without changing SNS activity or net cardiac stress. Future research should investigate these results to see if the specific upregulation we found is reproducible. Activation of the SNS has many benefits: it allows for energy mobilization and effective coping in the face of a stressor.

To some extent, we found convergence of the measures across the study. We saw an increase in PNS and SNS activity from baseline to intervention, and an overall reduction in heart rate. We saw a conditional effect from intervention to task for PNS activity, with overall reduced SNS activity, and a drop in heart rate, as would be expected. There were no glaring inconsistencies across measures. The most confounding finding is that SNS activity was higher in participants during the intervention than during the task, which seems to infer that listening to an audio file increases SNS activity more than risking money. This is not entirely inconsistent or unexpected, however, as previous studies have found an increase in SNS activity during meditation (Ditto, Eclache, & Godman, 2006; Kubota et al, 2001).

Cardiovascular Changes and Their Implications for Behavior

We examined the downstream effects of physiological changes during the mindfulness intervention on risk-taking. Although we found direct effects of experimental condition on risk-taking behavior, we did not find that changes in physiological variables mediated the relationship between condition assignment and risk taking. This suggests that mindfulness meditation may modulate the body's stress systems and behaviors via distinct pathways. The physiological effects and risk taking effects of mindfulness appear to be unique and non-additive, that is, participants who are taking more risks as a result of the condition assignment are not those participants reacting physiologically to the intervention. The mindfulness meditation intervention alters both, but the mechanisms are not linked. Future work involving selective activation of the SNS and PNS, perhaps utilizing pharmacological agents, could help reproduce the lack of causality between physiology and behavior in this context.

In an exploratory analysis, we found that participants who were experimentally assigned to the mindfulness condition and had higher heart rate behaved in a less risk taking manner compared to control - assigned participants, who did not exhibit a strong relationship between physiology and risk taking. This study links mindfulness interventions, high heart rate reactivity relative to ground, and reduced risk taking behavior on the CCT. Our followup analysis using AUCi illustrates that this effect is driven by baseline, rather than the changes across the study.

This evidence suggests that there is a negative relationship between heart rate reactivity relative to ground and financial risk taking in the mindfulness condition. The fact that this was only found for heart rate could be because the only physiological factor that is important for the decision making task is the participant's overall heart rate, and the PNS and SNS subcomponents do not necessarily reflect that. Perhaps mindfully assigned participants with high baseline heart rates can perceive their heart rate and implicitly use this to guide decision making, but cannot necessarily use PEP, HRV or BP as a somatic marker in the same way.

This effect can then be thought of as analogous to a trait effect: participants who show up to the study with higher heart rates *and* are assigned to the experimental condition take fewer risks. Perhaps the intervention proves effective in lowering risk taking only for those individuals who are already in a state of arousal when they arrive at the study. Participants who are not exhibiting higher heart rate when they show up do not exhibit the same behavioral changes of mindfulness meditation. Perhaps these participants are less receptive to utilizing the intervention during the stressful task, and the intervention cannot effectively alter their behavior. These findings are preliminary and will require more thorough investigation to understand fully.

Limitations and Future Directions

Follow up research could explore issues we found with the cardiovascular measures. Heart rate decreased throughout the study, suggesting that we saw an effect from the participants taking a seat after having walked into lab. Future research could include a sedentary period during which participants sit or lay in a supine position to help normalize differences between participants from walking to lab, and to help prevent the sort of linear effect observed here.

Furthermore, the financial decision making task utilized in this study failed to increase SNS or increase heart rate from baseline, suggesting that perhaps any physiological effects of the task on the SNS are not robust enough to be examined using current methods. For analyses with blood pressure, measurements closest to each epoch were used. More specifically, first BP measurement corresponds to baseline, second to post-intervention, third to pre-task, and final post-task). It is of note that these do not have a 1:1 relationship with the continuous cardiovascular data, and continuous BP data could help elucidate some of the seemingly contradictory changes seen during the study. Future research should utilize continuous blood pressure measurement to allow for better coordination among the various cardiac measures. Additionally, more precise measures of SNS activity such as studying microvascular reactivity (Maver, Strucl, & Acceto, 2004) could allow for a better understanding of the effects of this system on behavior.

Glossary

Atrium - Area of the heart. Receives blood from veins. Sends blood to ventricle.

Columbia Card Task – Computerized financial risk taking task.

Diastolic Pressure - Blood pressure measured while the heart is at rest.

Heart Rate – Heart beats per minute. A measure of net cardiac stress.

Heart Rate Variability – Variability in inter-beat time lengths – controlled primarily by the vagus nerve.

Impedance - Resistance as applied to alternating current circuits. Can be used as a measure of cardiac output with the approximation of the human torso as a cylinder.

Parasympathetic Nervous System – The "rest and digest" system that brings the body back to homeostasis

Pre Ejection Period - Amount of time between the beginning of ventricular depolarization and ejection of blood from the heart.

Somatic Marker Hypothesis – A model of decision making positing that the decisions we make are in part driven by responses to acute autonomic changes.

Sympathetic Nervous Response – The "fight or flight" response, mediated by epinephrine.

Systolic Pressure - Blood pressure measured while the heart is beating.

Ventricle - Area of the heart. Receives blood from atrium. Sends blood to elsewhere in the body upon contraction.

Appendix

LOTR Script

When Mr. Bilbo Baggins of Bag End announced that he would shortly be celebrating his eleventy-first birthday with a party of special magnificence, there was much talk and excitement in Hobbiton.

Bilbo was very rich and very peculiar, and had been the wonder of the Shire for sixty years, ever since his remarkable disappearance and unexpected return. The riches he had brought back from his travels had now become a local legend, and it was popularly believed, whatever the old folk might say, that the Hill at Bag End was full of tunnels stuffed with treasure. And if that was not enough for fame, there was also his prolonged vigour to marvel at. Time wore on, but it seemed to have little effect on Mr. Baggins. At ninety he was much the same as at fifty. At ninety-nine they began to call him *well*-preserved, but *unchanged* would have been nearer the mark. There were some that shook their heads and thought this was too much of a good thing; it seemed unfair that anyone should possess (apparently) perpetual youth as well as (reputedly) inexhaustible wealth.

‘It will have to be paid for,’ they said. ‘It isn’t natural, and trouble will come of it!’

But so far trouble had not come; and as Mr. Baggins was generous with his money, most people were willing to forgive him his oddities and his good fortune. He remained on visiting terms with his relatives (except, of course, the Sackville-Bagginses), and he had many devoted admirers among the hobbits of poor and unimportant families. But he had no close friends, until some of his younger cousins began to grow up.

The eldest of these, and Bilbo's favourite, was young Frodo Baggins. When Bilbo was ninety-nine, he adopted Frodo as his heir, and brought him to live at Bag End; and the hopes of the Sackville-Bagginses were finally dashed. Bilbo and Frodo happened to have the same birthday, September 22nd. 'You had better come and live here, Frodo my lad,' said Bilbo one day; 'and then we can celebrate our birthday-parties comfortably together.' At that time Frodo was still in his *tweens,* as the hobbits called the irresponsible twenties between childhood and coming of age at thirty-three.

Twelve more years passed. Each year the Bagginses had given very lively combined birthday-parties at Bag End; but now it was understood that something quite exceptional was being planned for that autumn. Bilbo was going to be *eleventy-one,* 111, a rather curious number and a very respectable age for a hobbit (the Old Took himself had only reached 130); and Frodo was going to be *thirty-three,* 33) an important number: the date of his 'coming of age'.

Tongues began to wag in Hobbiton and Bywater; and rumour of the coming event travelled all over the Shire. The history and character of Mr. Bilbo Baggins became once again the chief topic of conversation; and the older folk suddenly found their reminiscences in welcome demand.

No one had a more attentive audience than old Ham Gamgee, commonly known as the Gaffer. He held forth at *The Ivy Bush*, a small inn on the Bywater road; and he spoke with some authority, for he had tended the garden at Bag End for forty years, and had helped old Holman in the same job before that. Now that he was himself growing old and stiff in the joints, the job was mainly carried on by his youngest son, Sam Gamgee.

Both father and son were on very friendly terms with Bilbo and Frodo. They lived on the Hill itself, in Number 3 Bagshot Row just below Bag End.

‘A very nice well-spoken gentlehobbit is Mr. Bilbo, as I’ve always said,’ the Gaffer declared. With perfect truth: for Bilbo was very polite to him, calling him ‘Master Hamfast’, and consulting him constantly upon the growing of vegetables - in the matter of ‘roots’, especially potatoes, the Gaffer was recognized as the leading authority by all in the neighbourhood (including himself).

‘But what about this Frodo that lives with him?’ asked Old Noakes of Bywater. ‘Baggins is his name, but he’s more than half a Brandybuck, they say. It beats me why any Baggins of Hobbiton should go looking for a wife away there in Buckland, where folks are so queer.’

‘And no wonder they’re queer,’ put in Daddy Twofoot (the Gaffer’s next-door neighbour), ‘if they live on the wrong side of the Brandywine River, and right agin the Old Forest. That’s a dark bad place, if half the tales be true.’

‘You’re right, Dad!’ said the Gaffer. ‘Not that the Brandybucks of Buck-land live *in* the Old Forest; but they’re a queer breed, seemingly. They fool about with boats on that big river - and that isn’t natural. Small wonder that trouble came of it, I say. But be that as it may, Mr. Frodo is as nice a young hobbit as you could wish to meet. Very much like Mr. Bilbo, and in more than looks. After all his father was a Baggins. A decent respectable hobbit was Mr. Drogo Baggins; there was never much to tell of him, till he was drownded.’

‘Drownded?’ said several voices. They had heard this and other darker rumours before, of course; but hobbits have a passion for family history, and they were ready to hear it again. ‘Well, so they say,’ said the Gaffer. ‘You see: Mr. Drogo, he married poor Miss Primula Brandybuck. She was our Mr. Bilbo’s first cousin on the mother’s side (her mother being the youngest of the Old Took’s daughters); and Mr. Drogo was his second cousin. So Mr. Frodo is his first *and* second cousin, once removed either way, as the saying is, if you follow me. And Mr. Drogo was staying at Brandy Hall with his father-in-law, old Master Gorbadoc, as he often did after his marriage (him being partial to his vittles, and old Gorbadoc keeping a mighty generous table); and he went out *boating* on the Brandywine River; and he and his wife were drownded, and poor Mr. Frodo only a child and all. ‘

‘I’ve heard they went on the water after dinner in the moonlight,’ said Old Noakes; ‘and it was Drogo’s weight as sunk the boat.’

‘And *I* heard she pushed him in, and he pulled her in after him,’ said Sandyman, the Hobbiton miller.

‘You shouldn’t listen to all you hear, Sandyman,’ said the Gaffer, who did not much like the miller. ‘There isn’t no call to go talking of pushing and pulling. Boats are quite tricky enough for those that sit still without looking further for the cause of trouble. Anyway: there was this Mr. Frodo left an orphan and stranded, as you might say, among those queer Bucklanders, being brought up anyhow in Brandy Hall. A regular warren, by all accounts. Old Master Gorbadoc never had fewer than a couple of hundred relations in the place. Mr. Bilbo never did a kinder deed than when he brought the lad back to live among decent folk.

‘But I reckon it was a nasty shock for those Sackville-Bagginses. They thought they were going to get Bag End, that time when he went off and was thought to be dead.

And then he comes back and orders them off; and he goes on living and living, and never looking a day older, bless him! And suddenly he produces an heir, and has all the papers made out proper. The Sackville-Bagginses won't never see the inside of Bag End now, or it is to be hoped not.'

'There's a tidy bit of money tucked away up there, I hear tell,' said a stranger, a visitor on business from Michel Delving in the Westfarthing. 'All the top of your hill is full of tunnels packed with chests of gold and silver, *and* jools, by what I've heard. '

'Then you've heard more than I can speak to,' answered the Gaffer. I know nothing about *jools.* Mr. Bilbo is free with his money, and there seems no lack of it; but I know of no tunnel-making. I saw Mr. Bilbo when he came back, a matter of sixty years ago, when I was a lad. I'd not long come prentice to old Holman (him being my dad's cousin), but he had me up at Bag End helping him to keep folks from trampling and trapessing all over the garden while the sale was on. And in the middle of it all Mr. Bilbo comes up the Hill with a pony and some mighty big bags and a couple of chests. I don't doubt they were mostly full of treasure he had picked up in foreign parts, where there be mountains of gold, they say; but there wasn't enough to fill tunnels.

Mindfulness Intervention (Alberts and Thewissen, 2011)

In order to induce a mindful state, participants in the mindfulness, participants were instructed for approximately 12 min to focus their attention on their breathing and as much as possible on the present moment. Moreover, when intrusive thoughts arose, they were asked to notice them, accept them without judging them and subsequently direct their attention back to the breathing.

Correlation Matricies of Physiological Variables and Risk Taking

Table 3. Pearson Correlations Between Baseline Physiological Variables and Risk Taking on the CCT.

	Risk Taking	PEP	HRV	HR
Risk Taking	1	.138	.003	-.068
PEP	.138	1	-.072	.151
HRV	.003	-.072	1	-.342**
HR	-.068	.151	-.342**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4. Pearson Correlations Between Intervention Physiological Variables and Risk Taking on the CCT.

	Risk Taking	PEP	HRV	HR
Risk Taking	1	.084	.054	-.079
PEP	.084	1	.028	.059
HRV	.054	.028	1	-.243**
HR	-.079	.059	-.243**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5. Pearson Correlations Between Task Physiological Variables and Risk Taking on the CCT.

	Risk Taking	PEP	HRV	HR
Risk Taking	1	.120	.063	-.084
PEP	.120	1	-.045	.086
HRV	.063	-.045	1	-.170*
HR	-.084	.086	-.170*	1

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6. Pearson Correlations Between Recovery Physiological Variables and Risk Taking on the CCT.

	Risk Taking	PEP	HRV	HR
Risk Taking	1	.167	-.023	-.026
PEP	.167	1	-.092	.094
HRV	-.023	-.092	1	-.266**
HR	-.026	.094	-.266**	1

**. Correlation is significant at the 0.01 level (2-tailed).

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