Journal of Articles in Support of the Null Hypothesis
Vol. 23, No. 1

www.jasnh.com

Testing Conventional Theories of Self-Regulation: Heart-Rate Variability and Mental Imagery

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The present experiment was performed to test the hypotheses that self-regulation and mental imagery positively correlate and that mental imagery mediates the correlation of resting heart-rate variability and self-regulation. While a positive correlation between mental imagery and self-regulation was found, its magnitude is not congruent with many conventional theories. No relationship was detected between resting heart-rate variability and self-regulation, and therefore no mediatory role was possible for mental imagery.

Keywords: mental imagery, self-regulation, heart-rate variability, HRV, Self-Regulation Questionnaire, Plymouth Sensory Imagery Questionnaire, SRQ, Psi-Q

Introduction

Self-regulation may be understood as proficiency in goal-directed behavior (Carey et al., 2004). Various theories have attempted to explain its origin and identify methods with which individuals may become more self-regulating, often proposing a connection between it and mental imagery, the "experience of sensory information without a direct external stimulus" (Pearson et al., 2015, p. 590). For example, Carver and Scheier's (1981) Control Theory (CT) holds that human beings self-regulate via the parallel experience of imagined, potential states of being and sensed, actual states of being. According to CT, the discrepancy between these perceptions forms a "negative feedback loop" that drives self-regulated action (Carver & Scheier, 1981).

Another example is provided by Mihaly Csikszentmihalyi's theory of flow (1990), which identifies mental imagery as a central tool for the individual's "control over mental processes" (p. 120). He recognizes two consequences of mental imagery: emotional order (mental images can compensate for unpleasant actualities) and planning (mental images can be used to prepare actions), and he states that these skills are lost to those who do not develop mental imagery (Csikszentmihalyi, 1990). Jerome Singer (1976) resonates with Csikszentmihalyi's claims and adds that mental imagery serves to sustain motivation. Furthermore, several other authors of classic works have taken it as obvious that mental imagery is fundamental to goal-directed behavior (van der Kolk, 2014; Jaynes, 1976).

While no experiment has so far tested directly whether a correlation exists between the traits self-regulation and vividness of mental imagery, several have investigated the self-regulatory effects of the experience of mental imagery. Taylor et al (1998) found that mental simulation of task performance increases goal achievement, and elsewhere engagement in task-related mental imagery has been found to increase physical exercise (Ackermann et al., 2022) and the psychological integration of exercise plans (Duncan et al., 2012). In short, there has accumulated a great amount of empirical evidence that engagement in mental imagery can serve self-regulation (Kosteli et al., 2018; Skottnik & Linden, 2019).

Heart-rate variability (HRV), a measure of change in heart rate (HR), is another construct that has been widely proposed to correlate positively with self-regulation. HR changes rapidly in response to both physiological processes like breathing, a phenomenon called respiratory sinus arrhythmia (RSA; Quigley et al., 2024) and perceived stimuli, and two predominant theories link these changes in HR to self-regulation. Polyvagal theory (PVT) holds that the complex regulation of HR has permitted mammalian social behavior and that autonomic state, reflected in HRV, is therefore an adaptive response to the perceived environment. PVT holds that HRV changes in mammals autonomically according to the perception of threat and safety, which correspond respectively to low HRV and high HRV (Porges, 2025). Neurovisceral integration theory likewise finds the regulation of HR fundamental to self-regulation, but it holds that this occurs according to the ability of top-down processes (processes organized by hierarchically higher regions of the brain, such as the prefrontal cortex) to respond adaptively to ongoing experience (Thayer & Koenig, 2025). In both theories, higher HRV corresponds to higher self-regulation.

NIT and PVT both emphasize vagally mediated HRV (the dynamism of parasympathetic influence upon heart rate; vmHRV). vmHRV has been experimentally found to predict self-regulatory capacity (Crameri et al., 2021), and improvement in either has been associated with improvement in the other (Smith et al., 2020). Even when vmHRV is increased via electrical stimulation, self-regulation has been found to increase (Laborde et al., 2023). More broadly, both NIT and PVT predict that HRV positively correlates with self-regulation, and several experiments have directly found such a correlation (Zahn et al., 2016; Holzman & Bridgett, 2017). HRV has been found to predict self-regulation (Mccraty & Shaffer, 2015; Mather & Thayer, 2018), even bidirectionally (Thayer et al., 2009).

While HRV is highly state dependent, prior investigations of its relationship as a trait with self-regulation have measured it at physiological rest and found positive correlations (Segerstrom & Nes, 2007; Reynard et al., 2011), which the present experiment sought to replicate and explain. Though many measures of HRV exist, especially the standard deviation of all normal heart periods (Quigley et al., 2024), these original correlations were found using the root-mean square of successive differences (RMSSD), which is easily calculated and less influenced by RSA than more complex measures (Quigley et al., 2024), making it ideal for the calculation of resting HRV. For these reasons, RMSSD was presently employed.

To measure the vividness of mental imagery, the Plymouth Sensory Imagery Questionnaire (Psi-Q; Andrade et al., 2014) was employed. It covers all modalities of sensation, unlike other self-report measures of mental imagery (Vividness of Visual Imagery Questionnaire: Marks, 1973; Bucknell Auditory Imagery Scale: Halpern, 2015), and it only contains currently common vocabulary, unlike the Questionnaire upon Mental Imagery (Betts, 1909; shortened: Sheehan, 1967), from which it drew most of its structure and content. In order to minimize the effort requested of participants, the Psi-Q was chosen for the present experiment.

Self-regulation likewise was measured via self-report. Brown et al. (1999) developed the Self-Regulation Questionnaire (SRQ) to discover whether self-report is adequate to measure self-regulation, something that has been since confirmed (Enkavi et al., 2019). In 2004, Carey et al. found 31 items of the original 63-item SRQ that fit within a single factor and named it the SSRQ (Carey et al., 2004; validation: Hustad et al., 2009), which was here employed for its brevity and minimal difficulty of completion.

Self-regulation was hypothesized to correlate positively with mental imagery, which was hypothesized to mediate self-regulation's correlation with resting HRV, and the present experiment was performed to test these hypotheses.

Method

Participants

The present experiment involved 136 participants (N = 136) who were recruited from an introductory psychology course at a large Midwestern university and given course credit for their participation. Ninety-six participants identified themselves as female, while the remaining 40 participants identified themselves as male. One hundred and one participants identified themselves as white, and 20 participants identified themselves as non-white. Fifteen participants identified themselves as both white and at least one other race. Participants' ages ranged from 18 to 38 (M = 19.51, SD = 2.98).

Apparatus and Stimuli

An electrocardiogram was used to record HR via a BIOPAC System MP30 amplifier (Saha et al., 2013). Participants placed disposable leads (Medicotest Blue Sensor, N-00-S) onto their own ankles and right wrists, and five minutes of HR data were collected from each participant while resting. Since 30-second HR intervals have been found to be adequate for the calculation of RMSSD (Baek et al., 2015), the RMSSD of the final 30 seconds of the five-minute recordings, the period during which participants would be most deeply at rest, were isolated, and the intervals between normal heart beats were measured with BIOPAC peak identification. These raw interval values were then processed into RMSSD via Excel, and the resultant values were converted into milliseconds. Two HR files contained ectopic heart beats, and these heart beats were entirely excluded, with only their presence being recorded in the variable beats per minute (BPM). Two files of HR data were excluded from the analysis due to equipment error having rendered the identification of heart beats within them impossible. No RMSSD data were physiologically impossible, and therefore all were base-ten logarithmically transformed to calculate the variable Resting Heart-Rate Variability (Resting HRV) for the sake of parametric analysis.

To assess mental imagery, the Psi-Q's visual and auditory subscales were used (Andrade et al., 2014). Each subscale contains prompts to imagine five different experiences and asks participants to rate the vividness of each image. Responses were made on a slider intensity scale that ranged from 0 ("no image at all") to 10 ("image as clear and vivid as real life"), and these values were averaged. For the sake of parametric analysis, these average Psi-Q values were reflected around their maximum, transformed via square root, then re-reflected to calculate the variable Mental Imagery (MI).

The SSRQ was employed to assess self-regulation (Carey et al., 2004), and responses to it were made on a slider intensity scale that ranged from 0 ("strongly disagree") to 5 ("strongly agree"). Responses to the reverse-worded items were reverse coded before calculating average scores, which constitute the variable Self-Regulation (SR).

In addition to the Psi-Q and the SSRQ, participants were asked demographic questions. The informed consent form was administered on paper. The demographic questions, Psi-Q, and SSRQ were presented via Qualtrics (Ginsberg, 2011).

Procedure

Before the start of the experiment, its procedure was reviewed by the institutional review board of the author's university and was approved (IRB-FY2024-384).

Participants met with the experimenter in the psychology building of their university and were given a verbal summary of the procedure. In one of two adjacent rooms, they then read the informed consent form and, if they had given their informed consent to participate, sat in a comfortable chair near the door and attached three disposable electrodes to themselves (one to each ankle and one to the right wrist). They were asked to relax, stay as still as possible, and close their eyes until a timer's alarm sounded.

After the alarm sounded, participants removed the electrodes from their bodies and were handed a number token before moving to the next-door room, where they sat in front of a computer onto which the Qualtrics questionnaire had been loaded. After the experimenter encouraged them to ask him any questions they might have, participants completed the questionnaire. The items of the SSRQ and demographic questionnaire were presented in random order, and the order of the questionnaires was also randomized.

Finally, participants were thanked for their participation.

Results

Transformations and Assumption Checks

All data analyses were conducted in JASP 0.19.1 and Excel.

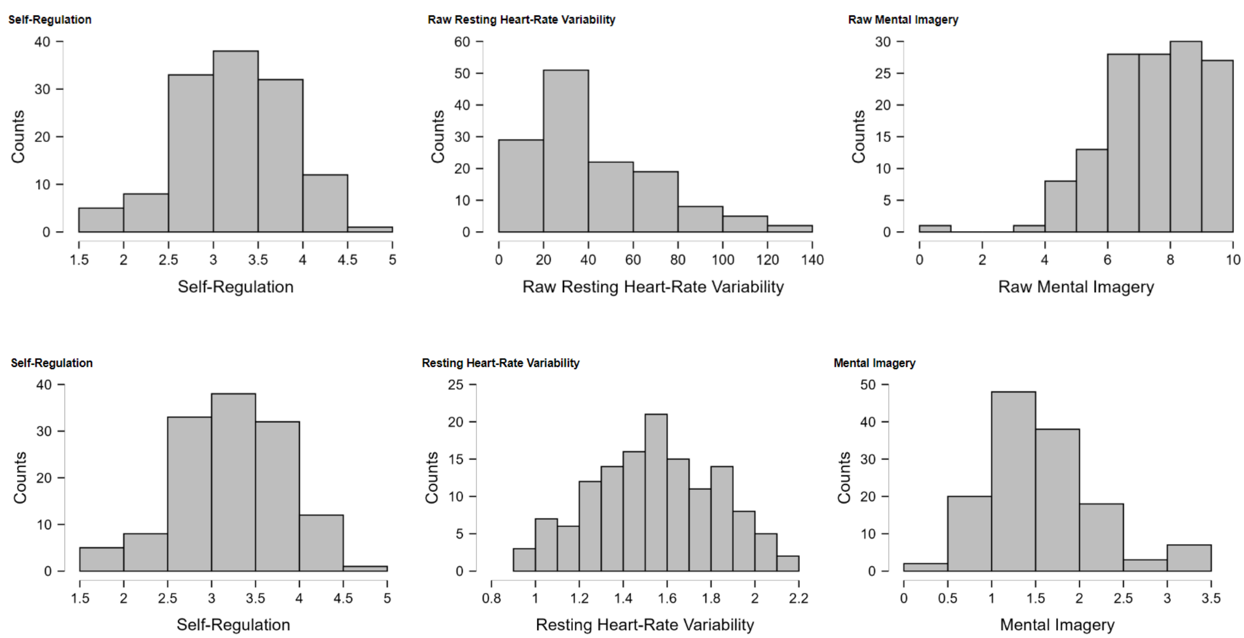

Figure 1. Histograms of Self-Regulation, Resting Heart-Rate Variability, and Mental Imagery before and after transformation.

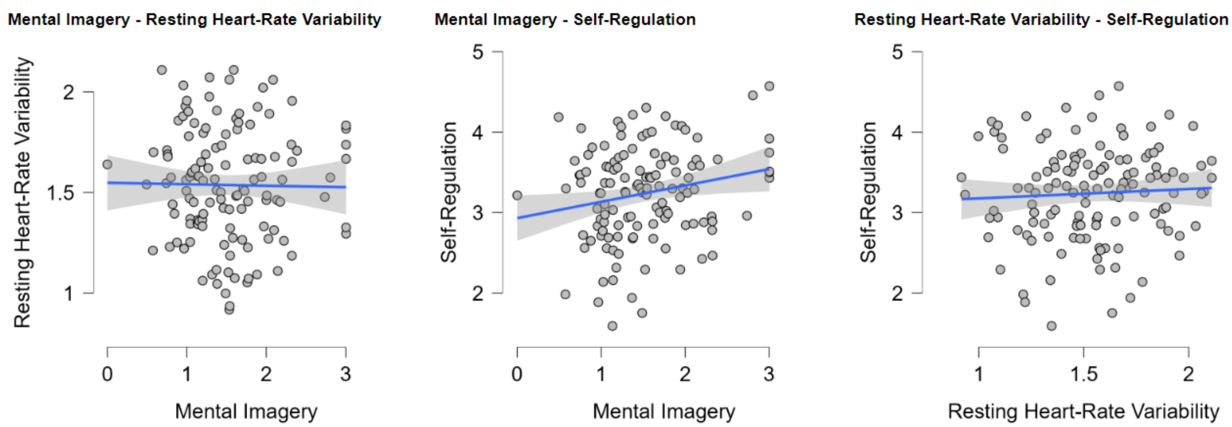

Figure 2. Scatter plots of the correlations among Mental Imagery, Self-Regulation, and Resting Heart-Rate Variability with the 95% confidence interval shaded.

Visual inspection of the raw variables' histograms indicates that SR was normally distributed but neither the raw Psi-Q data (Raw Mental Imagery) nor the raw HRV data (Raw Resting Heart-Rate Variability) were (see Figure 1). Transformations succeeded in normalizing MI and Resting HRV, bringing the skewness and kurtosis of each variable into normal range (respectively: -0.34 and -0.01 for SR, -0.07 and -0.65 for Resting HRV, and 0.616 and -0.32 for MI). The *p*-values of a series of Shapiro-Wilk tests confirmed the normality of SR (p = .400) and Resting HRV (p = .246) but not that of MI (p < .001).

Visual inspection of Figure 2 indicates that all relationships between SR, MI, and Resting HRV are linear and yields little evidence of multicollinearity or heteroscedasticity.

Scale Analyses

The present SSRQ data (M = 3.24, SD = 0.59, n = 129) are internally consistent (unstandardized Cronbach's a = .90), with only the deletion of item 13 increasing this consistency. Item 13 is also the only item that had a low item-rest correlation (r < .30).

Responses to the Psi-Q (M = 7.57, SD = 1.27, n = 136) were also internally consistent (unstandardized Cronbach's a = .87), and the deletion of any item would not have improved this consistency. Its item-rest correlations ranged between .41 and .70.

See Table 1 for descriptive statistics of all outcome variables, split by sex.

Hypothesis Testing

In order to test the hypothesis that mental imagery and self-regulation positively correlate, a zero-order correlation analysis was conducted between SR and MI. Its results were significant, r(127) = .21, p = .019, 95% CI [.04, .37].

In order to test the hypothesis that mental imagery mediates the correlation of resting heart-rate variability and self-regulation, a mediation analysis was conducted with Resting HRV entered as the predictor, MI entered as the mediator, and SR entered as the outcome. The indirect effect was not statistically significant (ab = −.02, p = .629, 95% CI [-.10, .06]). The total effect was negligible and had a *p*-value greater than .500 (c = .11, p = .572, 95% CI [−.26, .47]).

Sensitivity Checks

To ascertain the robustness of the correlation between MI and SR, a series of sensitivity checks were performed.

First, the influence of seven extreme responses (with raw values of 10) was investigated. They were deleted from MI, further normalizing its distribution (skewness = 0.23, kurtosis = 0.01, Shapiro-Wilk *p*-value = .458), and r was again calculated between MI and SR, r(121) = .12, p = .206. A winsorized correlation was then run between SR and MI, r(127) = .19, p = .033.

Second, Spearman's rho was calculated between Raw Mental

Table 1. Descriptive statistics for all outcome variables, split by sex.

	Resting Heart-Rate Variability		Self-Regulation		Mental Imagery		Raw Resting Heart-Rate Variability		Raw Mental Imagery		Heart Beats per Minute	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Valid	94	40	90	39	96	40	94	40	96	40	94	40
Missing	2	0	6	1	0	0	2	0	0	0	2	0
Mean	1.539	1.553	3.167	3.397	1.533	1.556	43.064	41.652	7.491	7.519	78.936	74.900
Std. Deviation	0.295	0.245	0.610	0.496	0.593	0.629	28.717	24.489	1.610	1.657	13.756	12.673
Skewness	−0.064	−0.012	−0.262	−0.242	0.627	0.609	1.102	1.454	−0.802	−0.311	0.047	0.321
Std. Error of Skewness	0.249	0.374	0.254	0.378	0.246	0.374	0.249	0.374	0.246	0.374	0.249	0.374
Kurtosis	−0.797	−0.198	−0.127	0.109	0.603	−0.124	0.687	2.359	1.652	−0.827	−0.353	−0.347
Std. Error of Kurtosis	0.493	0.733	0.503	0.741	0.488	0.733	0.493	0.733	0.488	0.733	0.493	0.733
Shapiro-Wilk	0.982	0.983	0.989	0.992	0.957	0.957	0.895	0.872	0.956	0.961	0.991	0.976
P-value of Shapiro-Wilk	0.229	0.805	0.675	0.990	0.003	0.131	< .001	< .001	0.003	0.182	0.784	0.558
Minimum	0.917	1.072	1.589	2.138	0.000	0.493	8.263	11.792	0.981	3.701	46.000	50.000
Maximum	2.110	2.061	4.573	4.457	3.003	3.003	128.722	115.016	10.000	10.000	114.000	104.000

Imagery and SR, $\rho(127) = .17$, $p = .049$, indicating the correlation's level of robustness against the violation of normality.

Third, a scatterplot with a smooth regression line was generated (see Figure 3).

Finally, a zero-order correlation was calculated between Resting HRV and SR as a sanity check for the mediation analysis. Its result was not significant, $r(125) = .06$, $p = .532$, 95% CI [−.01, .23].

Discussion

The present experiment aimed to explain the well documented correlation of self-regulation and resting HRV (Segerstrom & Nes, 2007; Reynard et al., 2011) and test the conventionally theorized correlation of self-regulation and mental imagery (Singer, 1976; Carver & Scheier, 1981; Csikszentmihalyi, 1990). Because the analysis failed to detect a correlation between self-regulation and resting HRV, it failed to explain these variables' relationship. On the other hand, limited support for a positive correlation between self-regulation and mental imagery was found.

The present data yield important information about the SSRQ and Psi-Q. Both had high levels of internal consistency and were not collinear, indicating that each measured a different, specific construct. While responses to the SSRQ were normally distributed, those to the Psi-Q were negatively skewed, with the greatest concentration of responses to each of its items being between eight and ten, meaning that participants overwhelmingly reported their mental images to be as vivid, or nearly as vivid, as sensory perception. That this is valid seems unlikely. Both distributions are concurrent with those found in the scales' development studies (SSRQ: Carey et al., 2004; Psi-Q: Andrade et al., 2014).

Responses to the SSRQ positively correlated with responses to the Psi-Q. Despite being presented in random order, participants were most likely to view these questionnaires in immediate sequence, and the least likely scenario, in which the SSRQ and Psi-Q were separated, still very nearly had them in immediate sequence, possibly influencing their correlation. The significant, positive correlation between MI and SR, therefore, may be an effect of order.

Nonetheless, theoretical explanations can be offered. For example, mental imagery may enrich perception with otherwise absent, goal-related objects. Thus, it may increase the intensity and duration of a goal's direction of behavior. As has been found in the case of emotion regulation (Andries et al., 2024), however, imagery vividness' service of self-regulation may depend upon attention control, the ability to direct and maintain attention upon goal-related objects.

For the most part, the reported sensitivity checks serve to confirm the robustness of MI and SR's correlation. It appears that extreme responses to the Psi-Q fueled the correlation, but nothing certifies that they are outliers and should be excluded. After winsorization, the correlation largely remained intact, and the 95% confidence interval bands (see Figure 3) are consistent throughout the upper half of the correlation. The extreme responses do not therefore seem to be aberrant but rather appear to reinforce the positive trend already present. Finally, the correlation's robustness against the violation of normality uncovered by non-parametric analysis indicates that the diminution of MI's normality caused by the extreme responses does not radically challenge the correlation's validity.

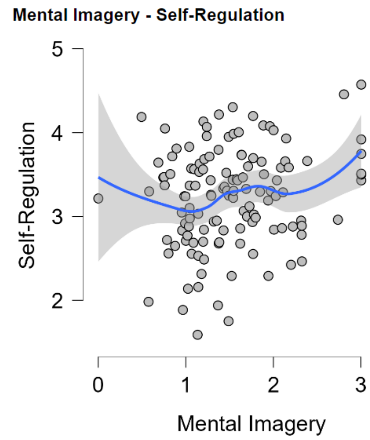

Figure 3. Scatterplot of Mental Imagery and Self-Regulation with a smooth regression line and 95% confidence intervals shaded.

The correlation of Resting HRV and SR was non-significant and negligible, consistent with Resting HRV's lack of predictive power in the mediation analysis. No mediation is possible for a relationship that has not been detected.

The present method has many noteworthy limitations, and any interpretation of its results should consider its imperfection. While 30-second periods of HR data have been found to be adequate for the calculation of RMSSD (Baek et al., 2015), the present use of them differs from previous correlations, which involved longer periods of HR data (Segerstrom & Nes, 2007; Reynard et al., 2011), and this may explain the present failure to replicate them. During these periods, furthermore, it was assumed that participants were in a resting state, but no attempt was made to confirm this. In addition, no covariates were controlled for in the calculation of the present correlations, and it is possible that important variables such as body-mass index, sex, and age weakened them and should have been controlled. Respiration especially affects HR (Quigley et al., 2024), yet it was neither measured nor controlled, and its effect upon the present failure to correlate resting HRV and self-regulation is not known.

Many directions appear fruitful for future research. Firstly, the development of a physiological measure of mental imagery would allow for its measurement without reliance upon self-report. In addition, episodic memory appears to be a form of mental imagery. Episodic recall and the construction of false memories might correlate positively with mental imagery. Finally, post-traumatic stress disorder (PTSD) may also positively correlate with mental imagery, and individual differences in mental imagery may help to explain individual differences in the development and constitution of PTSD.

The present experiment yielded no evidence that self-regulation correlates with resting HRV, even though such a correlation has been well documented (Segerstrom & Nes, 2007; Reynard et al., 2011) and numerous findings have supported a correlation between HRV and self-regulation (Thayer et al., 2009; Mccraty

& Shaffer, 2015; Mather & Thayer, 2018; Thayer & Koenig, 2025). Some studies, however, have failed to find such correlations (McIntyre & Sloan, 2025). Li et al (2024), for example, found no cross-sectional evidence that vmHRV correlates with rumination, an activity contrary to self-regulation, and a research team led by the same author later found no longitudinal evidence that vmHRV correlates with depressive symptoms and work stress, constructs closely related to self-regulation (Li et al., 2025).

While conclusions drawn from the present study are limited by its imperfection, it is not alone in failing to detect a correlation between resting HRV and self-regulation. Recently, Sinichi et al. (2025) found no evidence in a sample drawn from Colombia, Nepal, and South Africa that resting HRV correlates with a number of constructs that are closely associated with self-regulation (emotional regulation, inhibitory control, delay discounting, anxiety, and depression) and some evidence that it positively correlates with maladaptive externalizing behavior. By specifically measuring self-regulation and testing its correlation with resting HRV in an American sample, the present analysis reinforces these null results and contributes to the investigation into whether there exists a correlation between HRV and self-regulation.

On the other hand, SR and MI did correlate in the direction anticipated by several conventional theories (Carver & Scheier, 1981; Csikszentmihalyi, 1990), but their correlation's low effect size is not congruent with a fundamental role of mental imagery in self-regulation.

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Received: 11.7.2025
Revised: 2.28.2026
Accepted: 3.2.2026