

**Title:**

**Good decision-making is associated with an adaptive cardiovascular response to social competitive stress.**

**Running title:** Decision-making and stress

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## ABSTRACT

Competition elicits different psychological and cardiovascular responses depending on a person's skills. Decision-making has been considered a distal factor that influences competition, but there are no studies analyzing this relationship. Our objective was to analyze whether decision-making affects the response to competition. Specifically, we aimed to test whether good performers on a decision-making test, the Iowa Gambling Task (IGT), showed an adaptive cardiovascular response to competition. In all, 116 participants (44 women) performed the IGT and were classified into Good or Poor decision-makers. Subsequently, they were exposed to a stress task in two different conditions: a face-to-face Competition (Winners/Losers) or a Control condition, while an electrocardiogram was recorded. In the Competition group, Good decision-makers increased their High Frequency (HF/HRV) levels during the task, compared to Poor decision-makers. The Competition group showed a lower heart rate variability (HRV) stress pattern (High LF and low HF) than the Control group. Moreover, in the group of Losers, Good decision-makers had a decline in Low Frequency (LF) during the task and faster recovery than Poor decision-makers. In conclusion, Good decision-makers have a more adaptive stress response and higher levels of mental effort, based on total HRV interpretation. Decision-making skills could be a factor in a more adaptive cardiovascular response to competition.

**Keywords:** Heart rate variability, Decision-making, Iowa gambling task, Coping, Competition, Stress.

## 1 Introduction

2        Researchers have investigated the effects of stress on subsequent decision-  
3 making, finding deleterious or beneficial effects depending on the characteristics of the  
4 task and the situation (Starcke & Brand, 2012). However, little is known about how  
5 decision-making skills affect stress responses. Good performance on executive function  
6 (EF) tasks, such as decision-making, could be a resilience factor in coping with stress  
7 (Thayer & Lane, 2009; Williams, Suchy, & Rau, 2009). Decision-making is a complex  
8 cognitive function that involves learning processes, previous experience, and sensitivity  
9 to feedback (Bechara, 2004). The Iowa Gambling Task (IGT) is one of the most widely  
10 used computerized tasks to assess decision-making (Bechara, Damasio, Damasio, &  
11 Anderson, 1994; Bechara, 2004). People have to choose among four decks that give a  
12 virtual monetary reward or punishment. Two decks have disadvantageous consequences  
13 (short-term high gains, but greater long-term punishment), whereas the other two have  
14 favorable consequences (with low gains, but smaller long-term losses), thus rewarding  
15 conservative decision-making. To our knowledge, only one study (Santos-Ruiz et al.,  
16 2012) investigated the effect of decision-making on coping with a social stress situation.  
17 These authors divided participants into good or poor decision makers depending on  
18 their performance on the IGT. They found that good IGT performers displayed lower  
19 cortisol increases in response to social stress than poor performers; that is, the better the  
20 decision-making skills, the more adaptive the physiological stress response (Santos-  
21 Ruiz et al., 2012).

22        Therefore, stress and decision-making would have a reciprocal relationship. In  
23 this regard, competition is a real-life social stressor that elicits psychobiological  
24 responses (Salvador & Costa, 2009). In their Coping Competition Model, Salvador and  
25 Costa (2009) pointed out that psychobiological responses to competition can be best

1 explained as part of a coping response. Thus, a core factor of competition is appraisal,  
2 which begins before competition and is influenced by distant factors such as previous  
3 experience or generic abilities (eg. cognitive, psychomotor, or social skills). In this  
4 context, decision-making can be considered a distal variable, and good performance on  
5 the IGT has been found to depend on the capacity to use contextual feedback and act in  
6 consequence, adapting the choices (Brand, Labudda, & Markowitsch, 2006). Therefore,  
7 good decision-making is a personal resource that would help people to cope adaptively  
8 with stress situations (Bechara, Damasio, & Damasio, 2000; Santos-Ruiz et al., 2012).

9 A balanced autonomic reactivity (high Sympathetic nervous system -SNS-  
10 activity and low Parasympathetic nervous system -PNS- tone) and quick recovery to  
11 previous levels have been considered an adaptive physiological response to stress  
12 (Thayer & Lane, 2009; Williams et al., 2009). It is worth noting that impaired EF,  
13 including decision-making, are related to smaller increases in heart rate (HR) under  
14 stress and slower recovery after stress (Lin, Heffner, Mapstone, Chen, & Porsteinsson,  
15 2014; Roiland, Lin, Phelan, & Chapman, 2015). In fact, HR is partially controlled by  
16 the same brain region as decision-making, the pre-frontal cortex (Starcke & Brand,  
17 2012). According to the neurovisceral integration model, heart rate variability (HRV)  
18 could be a good measure of cognitive regulation under stress (Thayer, Ahs, Fredrikson,  
19 Sollers, & Wager, 2012). Particularly, High frequency (HF) HRV is considered a  
20 marker of good self-control (Duschek, Wörsching, & Reyes Del Paso, 2013; Thayer &  
21 Lane, 2009; Zahn et al., 2016), whereas reduced levels of Low frequency (LF) would be  
22 a marker of mental load (Mukherjee, Yadav, Yung, Zajdel, & Oken, 2011). Finally,  
23 higher levels of the sum of the three HRV band frequencies ( $HRV_{tot}$ ) are related to  
24 greater autonomous nervous system (ANS) flexibility in modulating cardiac activity  
25 during changing situations (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Therefore,

good decision-making skills would imply a better cardiovascular balance during stress and quick recovery after the stressful situation (Williams et al., 2009). In laboratory competitive situations, using ‘the letters squares’ task or social group negotiations, these cardiovascular patterns for competition were found in both sexes; winners showed increases in heart rate (HR) and Systolic Blood Pressure (SBP) from basal levels during the task and faster recovery, whereas losers had decreases or smaller increases in HR and SBP (Costa & Salvador, 2012; Ricarte, Salvador, Costa, Torres, & Subirats, 2001). More specifically, similar patterns were found, with a predominance of SNS (increases in electrodermal activity) and PNS withdrawal (HF reduction) during a laboratory competition, and a quicker recovery in winners than in losers and control groups (Abad-Tortosa, Alacreu-Crespo, Costa, Salvador, & Serrano, 2017).

Our main objective was to analyze how decision-making skills (assessed with IGT) influence the subjective and cardiovascular response to a laboratory competition, ‘the letters squares’ task. We hypothesized that: (a) decision-making skills would modulate the subjective assessment of competition; and (b) good decision-makers would show higher  $HRV_{tot}$  during the competition (Santos-Ruiz et al., 2012; Williams et al., 2009), with a higher SNS response during competition and faster recovery with PNS dominance after competition.

## Material and methods

### *Participants*

The total sample was composed of 116 university students (Women: N = 44) from different departments at the University of Valencia and University Miguel Hernandez (Spain). These participants were screened from a larger (n=220) sample of volunteers, using a questionnaire that included the following exclusion criteria: having cardiovascular, endocrine, neurological or psychiatric disease; smoking 5 or more cigarettes per day; consuming drugs; doing more than 10 hours of physical exercise per

week; or experiencing a stressful life event in the past month. Selected participants were asked to maintain their normal food intake and sleep patterns and avoid strenuous physical exercise and drinking alcohol 24 hours before the experiment. Moreover, they were instructed to avoid stimulant beverages or smoking two hours before the experimental session.

The 116 participants were randomly distributed into two groups: Competition group (N = 86; 43 couples) and Control group (N = 30; 15 couples). Additionally, the Competition group was divided into winners and losers, depending on the outcome obtained on the task: Winners (N = 43; 29 men, 14 women; age, Mean  $\pm$  Standard Error of the Mean (SEM) = 21.92  $\pm$  0.48 years), Losers (N = 43; 29 men, 14 women; age, Mean  $\pm$  SEM = 21.61  $\pm$  0.46 years), and Controls (N = 30; 14 men, 16 women; age, Mean  $\pm$  SEM = 21.45  $\pm$  0.56 years). From this sample, four men (one from the Control group and three from Winners) were eliminated due to ECG irregularities. Thus, the final sample was composed of 112 participants. Previously, all the participants had performed the IGT, whose outcome was used as a criterion to additionally differentiate between Good and Poor Deciders, as explained below.

The study was approved by the Ethics Research Committee of the University of Valencia in accordance with the ethical standards of the 1964 Declaration of Helsinki.

### ***Procedure***

All sessions were carried out between 15:30 pm and 20:00 pm, and procedures (Figure 1) lasted 1 hour and 30 minutes. Participants arrived at the laboratory in same-sex dyads and were placed in different rooms where the experimenter explained the general procedure (without referring to competition) before the participants signed the informed consent. Weight and height were measured, and participants were instructed to put on an HR monitor. Next, participants rested for 10 minutes in order to become

1 habituated to the situation (Baseline). Then, they performed the standard computerized  
2 IGT (Bechara et al., 1994; Bechara, 2008) to assess whether they were good or poor  
3 decision-makers.

4 After performing the IGT, participants moved to the interaction room, where the  
5 competitive/control task took place, and a same-sex experimenter invited them to sit  
6 face-to-face at a table. Then, the experimenter read the competitive/control task  
7 instructions. For the competition group, the instructions emphasized that they were  
8 going to compete for an economic reward. In the case of the control group, the task was  
9 merely explained, without mentioning competition or rewards. Instructions were read in  
10 order to maintain the same experimental condition. This period lasted approximately 10  
11 minutes.

12 Next, participants performed the paper-and-pencil task for approximately 18  
13 minutes (Task). Finally, participants waited 10 minutes (Post-task). During this period,  
14 they all answered questions about the competitive/control task, and the women  
15 answered some questions about the characteristics of their menstrual cycles.

16 *Insert here Figure 1*

### 17 ***Decision-making skills***

18 To measure decision-making skills, we used the standard version of the Iowa  
19 Gambling Task (IGT: Bechara et al., 1994; Bechara 2008). This computerized task  
20 simulates the usual components of daily decision-making under conditions of  
21 uncertainty and risk. The participants received the instruction to win as much money as  
22 possible starting from 2000 € of virtual money. They had to choose between four decks.  
23 Decks A and B are disadvantageous because they provide immediate high gains but  
24 great future losses (long-term loss). The other two decks (Decks C and D) are  
25 advantageous because they provide immediate smaller gains, but smaller future losses  
26 (long-term gain). Participants had to choose 100 times, and after each pick, the

computer showed feedback, that is, the amount of money earned or lost. The result of the IGT was the IG index, assessed using the number of advantageous decks selected minus the number of disadvantageous decks selected ( $CD - AB$ ), in blocks of 20 trials. Total IG values (100 trials) greater than zero imply a predominance of advantageous decisions (good decider), whereas negative values are related to disadvantageous decisions (poor decider). Thus, the IG values were computed, and participants were assigned to Good decider or Poor decider groups based on their performance on the IGT. If they had a total IG value equal to or greater than 0, they were assigned to the Good deciders group, and if they had a total IG below 0, they were assigned to the Poor deciders group (Santos-Ruiz et al., 2012). Participants were not aware of this distribution.

#### ***Competitive/control task***

The competitive task was 'the letters squares' task (Cordero, Seisdedos, González & De la Cruz, 1990), a paper-and-pencil cognitive task that measures perception and attention. Each participant received 90 matrixes of 16 letters (4 x 4) and another page of 50 matrixes if necessary. Participants had to find the repeated letter in a line or column.

The original task was modified by dividing it into five trials lasting 2.5 minutes each (Costa & Salvador, 2012). In order to increase competitiveness, the competition group was informed that they were going to compete for a prize consisting of 5 € of real money for the winner (the higher accumulated matrix score). After each competition trial, the experimenter who corrected the schedules gave feedback about who was winning and who was losing. The feedback sentences were standardized for all participants ('A is winning, go on; B is losing, try harder, you can win). At the end, the

1 experimenter informed them about their total scores and gave the economic reward to  
2 the winner. Therefore, in each dyad, the winner performed better than the loser.

3 The control group (also participating in dyads) was instructed to complete the  
4 task with the same instructions as the competition group, but without referring to  
5 competition (the word competition was changed to task). Participants were not informed  
6 about an economic reward and did not receive any feedback after each trial; moreover,  
7 they had no knowledge about the performance of the other person.

8 The assignment to the Competitive or Control group was random.

### 9 ***Competitive/control task evaluation***

10 After the interaction, participants completed a 5-item scale to characterize the  
11 competitive task. They rated perceived effort, frustration, performance, stress, and  
12 difficulty on a Likert scale (0 – 100), based on previous studies (Carrillo et al., 2001;  
13 Costa & Salvador, 2012). In the control group, the word “competition” was replaced by  
14 “task”.

### 15 ***Cardiovascular measures***

16 Cardiovascular levels were recorded with the Polar®RS800cx watch (Polar CIC,  
17 USA), which consists of a chest belt for the detection and transmission of heartbeats and  
18 a Polar watch for data storage (sampling frequency of R-R intervals of 1000 Hz),  
19 previously validated (Williams et al., 2016). Data were analyzed using the HRV  
20 software Kubios Analysis (Biomedical Signal Analysis Group, University of Kuopio,  
21 Finland; Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014). Means  
22 were analyzed every 5 minutes from Baseline, Task, and Post-Task, following the  
23 recommendations of the Task Force (1996), from the middle of the recorded periods.  
24 Automatic Kubios artefacts were fixed with the appropriate degree of correction. Scores

from missing values were computed with the method of row and column means when the participant had only one missing period (20% of the total).

We computed the R–R interval (ms) time series. Power spectral analyses of HRV were calculated by means of Fast Fourier Transformation (FFT) using Kubios to extract frequency domain measures. Spectral power density was expressed in absolute units ( $\text{ms}^2/\text{hz}$ ). We computed the High frequency (HF) band (between 0.15 to 0.40 Hz), which reflects respiratory sinus arrhythmia (RSA) and can be used as an index of parasympathetic control; the Low frequency (LF) band (between 0.04 to 0.15 Hz.), which is an index of the baroreflex function and can be interpreted as both sympathetic and parasympathetic control (Berntson et al., 2007); and the Very low frequency (VLF) band (between 0.003 to 0.04 Hz.). The total HRV power ( $\text{HRV}_{\text{tot}}$ ) was assessed with the sum of the frequency bands (Liao, Carnethon, Evans, Cascio, & Heiss, 2002; Svensson et al., 2016). In order to highlight the effects of HF, we calculated the normalized units on this band. Previous studies criticize the use of normalized units because, in the estimation of these indexes, only LF and HF are used in the denominator (Reyes del Paso et al. 2013), and they recommend including VLF in the estimation of these indexes ( $\text{HF}/\text{HRV}$ ). Finally, we calculated the hertz where HF were collected ( $\text{HF}_{\text{hz}}$ ), which is an index of the respiratory rate. However, following some authors' suggestions (Denver, Reed, & Porges, 2007), the respiratory rate was not controlled in the computation of the HRV variables.

### ***Data reduction and statistical analyses***

We calculated outliers using the 3 standard deviations method for variables measured one time and the Mahalanobis distances method  $p < 0.001$  criterion for variables measured two or more times. No outliers were found. Kolmogorov-Smirnoff was used to check normality.  $\text{HRV}_{\text{tot}}$ , VLF, LF, HF,  $\text{HF}_{\text{hz}}$ , perceived effort, frustration,

performance, stress, and difficulty did not have normal distributions and were normalized with the Log10 method (Field, 2009).

Participants randomly performed the competition or control task. The Competition group was divided into Winners or Losers depending on their performance on the competitive task. Additionally, using the total IGT scores, participants were distributed into Good decision-makers (0 or positive total IG) and Poor decision-makers (negative total IG) during the data analysis process, based on Santos-Ruiz et al. (2012). Preliminary analyses were performed to check the homogeneity of the groups. We performed three-way ANOVAs with 'Outcome', 'Decision', and 'Sex' as independent variables, and BMI and Baseline HRV as dependent variables. Chi-square analyses of 'Outcome' (Winners/Losers/Control) and 'Sex' (Men/Women) and 'Decision' (Good/Poor) were performed. Moreover, ANOVAs were performed with the 'menstrual cycle phase' classification (Yildirim, Kabakci, Akgul, Tokgozoglu, & Oto, 2002).

To identify the psychological evaluation of the task depending on the decision-making skills, we carried out one-way ANOVAs, with 'Decision' as the independent variable and the task evaluation variables as dependent variables. In order to study whether decision-making skills were related to the outcome, chi-square analyses were conducted with 'Outcome' and 'Decision'. Moreover, Pearson correlations were carried out with total IG and the performance on the 'letters squares' test.

Next, we calculated the Reactivity (Task – Baseline) and Recovery (Post-task – Task) indexes for the HRV variables. A two-way ANCOVA was performed, with 'Outcome' and 'Decision' as independent factors, using BMI as covariate and these indexes (Reactivity and Recovery) as dependent variables. *Post hoc* tests were performed with simple contrasts using the Bonferroni correction. We only present the

results when the 'Decision' factor or the 'Decision  $\times$  Outcome' interaction was significant.

The alpha significance level was fixed at 0.05. Partial eta squared for ANCOVAs was reported as a measure of effect size.  $\beta$ -1 was reported as a measure of power. All statistical analyses were performed with the SPSS 20.0.

## Results

### *Preliminary analyses*

Participants were distributed into groups depending on their IGT performance (good or poor deciders) and the outcome of the competition (winners, losers, and control). The number of participants in each condition was the following: Good decision-makers (N = 61; Winners = 22, Losers = 21 and Control = 18) and Poor decision-makers (N = 51; Winners = 18, Losers = 22 and Control = 11).

No significant differences were found in the number of men and women based on the 'Outcome' ( $X^2 = 4.19, p < 0.12$ ) and 'Decision' ( $X^2 = 0.00, p < 0.99$ ) factors. Furthermore, the menstrual cycle phase was not significant ( $p$ 's  $> .05$ ), and age did not correlate significantly with the HRV variables ( $p$ 's  $> .05$ ).

The three-way ANOVA with 'Outcome', 'Decision', and 'Sex' as independent factors did not show significant effects of the 'Decision' and 'Outcome' factors ( $p$ 's  $> 0.05$ ). Only the 'Sex' factor showed significant effects for BMI ( $F_{1, 99} = 9.47, p < 0.01, \eta^2_p = .071, power = .86$ ), Baseline R-R ( $F_{1, 99} = 7.91, p < 0.01, \eta^2_p = .074, power = .79$ ), Baseline LF ( $F_{1, 99} = 5.06, p < 0.03, \eta^2_p = .049, power = .61$ ), and Baseline HF/HRV ( $F_{1, 99} = 4.49, p < 0.04, \eta^2_p = .044, power = .56$ ). Men had higher BMIs (Mean  $\pm$  SEM: Men =  $24.38 \pm 0.42$  kg/m<sup>2</sup> vs Women =  $22.32 \pm 0.52$  kg/m<sup>2</sup>), Baseline R-R (Mean  $\pm$  SEM:

Men =  $861.41 \pm 15.69$  vs Women =  $790.83 \pm 19.58$ ), and Baseline LF (Mean  $\pm$  SEM: Men =  $2153.99 \pm 153.93$  vs Women =  $1493.06 \pm 192.04$ ), but lower Baseline HF/HRV, than women (Mean  $\pm$  SEM: Men =  $.300 \pm .019$  vs Women =  $.364 \pm .024$ ).

We included BMI as covariate in the subsequent analyses.

### ***Decision-making skills and task evaluation***

Regarding the evaluation of the task, Good and Poor decision-makers only showed significant differences in Perceived effort ( $F_{1, 101} = 6.54, p < 0.01, \eta^2_p = 0.062, power = 0.72$ ). Good decision-makers perceived higher effort than Poor decision-makers. Mean  $\pm$  SEM for the psychological variables are presented in Table 1.

*Insert here Table 1*

Regarding the proportion of Good or Poor decision-makers in the 'Outcome' factor, the result was not significant ( $\chi^2 = 4.19, p = 0.12$ ). Moreover, no significant correlations were found between Total IG and the performance on the 'square letters' test ( $p's > .05$ ).

### ***Decision-making skills and HRV responses***

*R-R interval:*

For the R-R interval Reactivity and Recovery indexes, neither 'Decision' nor 'Decision  $\times$  Outcome' showed significant differences or interactions ( $p's > 0.05$ ; Fig. 2A).

*Total Heart Rate Variability Spectrum:*

For the HRV<sub>tot</sub> Reactivity index, we found a significant 'Decision  $\times$  Outcome' interaction ( $F_{2, 102} = 3.28, p < 0.04, \eta^2_p = 0.060, power = 0.61$ ; Fig. 2B). *Post-hoc* comparisons showed differences between losers; good-deciders who lost the competition had lower HRV<sub>tot</sub> Reactivity than poor-deciders who lost ( $F_{2, 102} = 5.55, p <$

0.02,  $\eta^2_p = 0.052$ ,  $power = 0.65$ ). Moreover, good-deciders who competed (Winners and Losers) had lower HRV<sub>tot</sub> Reactivity than Control group good-deciders ( $F_{2, 102} = 5.84$ ,  $p < 0.01$ ,  $\eta^2_p = 0.103$ ,  $power = 0.86$ ).

For the HRV<sub>tot</sub> Recovery index, we found the same 'Decision  $\times$  Outcome' interaction ( $F_{2, 101} = 3.64$ ,  $p < 0.03$ ,  $\eta^2_p = 0.067$ ,  $power = 0.66$ ; Fig. 2B), with Loser good-deciders showing higher HRV<sub>tot</sub> Recovery than Loser poor-deciders ( $F_{2, 101} = 4.25$ ,  $p < 0.04$ ,  $\eta^2_p = 0.040$ ,  $power = 0.53$ ). Furthermore, good deciders in the Competition group (Winners and Losers) had higher HRV<sub>tot</sub> Recovery than good-deciders in the Control group ( $F_{2, 101} = 6.24$ ,  $p < 0.01$ ,  $\eta^2_p = 0.110$ ,  $power = 0.89$ ).

*Insert here Figure 2*

#### *Very Low Frequency:*

For VLF power, no significant effects were found ( $p$ 's  $> 0.05$ ; Fig. 3A).

#### *Low Frequency:*

In the case of LF Reactivity, a significant 'Decision  $\times$  Outcome' interaction was found ( $F_{2, 102} = 3.68$ ,  $p < 0.03$ ,  $\eta^2_p = 0.067$ ,  $power = 0.67$ ; Fig. 3B). In Losers, good-deciders had lower LF Reactivity than poor-deciders ( $F_{2, 102} = 4.51$ ,  $p < 0.04$ ,  $\eta^2_p = 0.042$ ,  $power = 0.56$ ). Furthermore, good-deciders (both Winners and Losers) had lower LF Reactivity than good-deciders in the Control group ( $F_{2, 102} = 8.62$ ,  $p < 0.001$ ,  $\eta^2_p = 0.145$ ,  $power = 0.96$ ).

For the LF Recovery index, the same 'Decision  $\times$  Outcome' interaction was significant ( $F_{2, 101} = 3.68$ ,  $p < 0.03$ ,  $\eta^2_p = 0.068$ ,  $power = 0.67$ ; Fig. 3B). In the group of Losers, good-deciders had higher LF Recovery than poor-deciders ( $F_{2, 101} = 3.83$ ,  $p < 0.05$ ,  $\eta^2_p = 0.037$ ,  $power = 0.49$ ). Good-deciders (both Winners and Losers) had higher

1 LF Recovery than good-deciders in the Control group ( $F_{2, 101} = 7.47, p < 0.001, \eta^2_p =$   
2  $0.129, power = 0.94$ ).

### 3 *High Frequency:*

4 Regarding the HF Reactivity index, no significant effects were found ( $p$ 's  $>$   
5  $0.05$ ; Fig. 3C). However, for HF Recovery, there was a significant 'Decision  $\times$   
6 Outcome' interaction ( $F_{2, 101} = 3.35, p < 0.04, \eta^2_p = 0.062, power = 0.62$ ; Fig. 3C). *Post-*  
7 *hoc* comparisons showed that good-deciders who lost had higher HF Recovery than  
8 good-deciders in the Control group ( $F_{2, 101} = 3.36, p < 0.03, \eta^2_p = 0.067, power = 0.66$ ).

9 For the HF<sub>hz</sub> respiratory index, no significant effects were found ( $p$ 's  $> 0.05$ ; Fig.  
10 2C).

11 Finally, for the HF/HRV Reactivity index, a significant 'Decision  $\times$  Outcome'  
12 interaction was found ( $F_{2, 102} = 3.32, p < 0.04, \eta^2_p = 0.061, power = 0.62$ ; Fig. 3D).  
13 Good-deciders who won the competition had higher Reactivity than poor-deciders ( $F_{2,$   
14  $102 = 8.10, p < 0.01, \eta^2_p = 0.074, power = 0.81$ ). Moreover, among the Losers, good-  
15 deciders had higher HF/HRV Reactivity than poor-deciders ( $F_{2, 102} = 3.81, p < 0.05, \eta^2_p$   
16  $= 0.036, power = 0.49$ ). Furthermore, the group of good-deciders who competed  
17 (Winners and Losers) had higher HF/HRV Reactivity than the Control group ( $F_{2, 102} =$   
18  $5.80, p < 0.01, \eta^2_p = 0.102, power = 0.86$ ).

19 Analyzing the index of HF/HRV Recovery, a 'Decision  $\times$  Outcome' interaction  
20 was found ( $F_{2, 101} = 3.71, p < 0.03, \eta^2_p = 0.068, power = 0.67$ ; Fig. 3D). *Post-hoc*  
21 comparisons showed, for Winners, lower HF/HRV Recovery in good-deciders than in  
22 poor-deciders ( $F_{2, 101} = 7.54, p < 0.01, \eta^2_p = 0.069, power = 0.78$ ). In good-deciders,  
23 lower HF/HRV Recovery was found for Winners than for the Control group ( $F_{2, 101} =$   
24  $3.19, p < 0.05, \eta^2_p = 0.059, power = 0.60$ ).

*Insert here Figure 3*

### **Discussion**

The present study reveals that the performance on a decision-making task (IGT) influences the situational appraisal and cardiovascular response to competition. Results show that good-deciders perceived greater effort than poor-deciders. Moreover, good-deciders had a withdrawal from their vagal influences during the Competition (lower HF/HRV and HRV reactivity), and subsequently recovered quickly, compared to the Control group. Our investigation points out that the HRV response is affected by the interactions among decision-making, the task characteristics (competitive vs non-competitive), and the outcome.

From an evolutionary point of view, the most adaptive way of coping with stress is to increase SNS activation and experience PNS deactivation, in order to achieve an autonomic balance that allows the best “fight or flight” response (Harrison et al., 2001; Manuck, 1994; Orbist, 1981). In a competition, this autonomic balance could lead to an increase in the probability of winning (Salvador & Costa, 2009), although it would depend on the type of task involved. In terms of autonomic balance, good-deciders who competed had this autonomic balance, showing lower  $HRV_{tot}$  and LF reactivity and higher recovery than the control group; in other words, the better the IGT performance, the lower the LF reactivity and the faster the recovery. We hypothesized that good-deciders would show higher  $HRV_{tot}$ , that is, an adaptive response to stress, but our data did not actually support this. Thus, to interpret this result, it should be kept in mind that LF reductions in good-deciders during the task affected the  $HRV_{tot}$  scores (Fig. 2B and 3B). This decrease in good-deciders can represent higher levels of mental effort during

the task (Mukherjee et al., 2011), coinciding with the higher levels of psychological perceived effort. These results suggest that good-deciders could have better LF band adaptability than poor-deciders. Thus, these influences of LF do not necessary imply that lower levels of  $HRV_{tot}$  during a task are related to lower adaptability, but that people increase their mental effort during the task in order more adaptively perform the task. Therefore, LF reductions could reduce  $HRV_{tot}$ , reflecting the person's effort to increase control. This cardiovascular response in good-deciders agrees with Obrist's (1981) postulations that the most demanding tasks induce greater beta-adrenergic stimulation with a higher sympathetic response (Richter, Friedrich, & Gendolla, 2008). Therefore, the pattern of CV reactivity in good decision-makers seems more adaptive in a competitive situation.

With regard to the CV response of poor-deciders, our data show that their response is similar to that of the Control participants. A recent investigation shows that people with higher levels of mental stress have high levels of LF and low levels of HF (von Rosenberg et al., 2017). Our data show that poor-deciders and the Control group had a mental stress response during and after the task that is consistent with the von Rosenberg et al. (2017) study (Fig. 3B and 3C). Therefore, poor-deciders probably interpreted the situation as threatening, regardless of whether it was competitive or not. In fact, our data show an approximation to this pattern in good-deciders during the task (Fig. 3B and 3C), which is consistent with an appraisal on a social stress task.

An important contribution of our study is that it shows the interaction between decision-making and the outcome of competition. The group of winning Good-deciders had better vagal control during (higher HF/ $HRV$  reactivity) and after competition (lower HF/ $HRV$  recovery) than Poor-deciders. The association between higher  $HRV_{tot}$  and higher adaptability comes from HF band associations with PNS activation and pre-

frontal activity (Lane, Reiman, Ahern, & Thayer, 2001; Lane et al., 2009) and better EF performance (Hansen, Johnsen, & Thayer, 2003). The parasympathetic branch is known to induce the speediest changes in the heart, and this branch is controlled by inhibitory input from prefrontal areas to the central amygdala (Thayer et al., 2012). In fact, neurobiological correlates of decision-making (like the IGT) also lie in pre-frontal areas (Starcke & Brand, 2012). Our results indicate that having good decision-making abilities may help to improve the inhibitory connection, which would be reflected in higher PNS activation during a stressor and higher HF indexes as a result. In our data, when we control the HF component, considering all the  $HRV_{tot}$  components (HF/HRV), good-deciders who win have more HF than poor-deciders who win. Therefore, the higher vagal control in good-deciders could probably facilitate winning the competition.

Losers showed a different CV response. Loser poor-deciders had higher  $HRV_{tot}$  and LF reactivity, but lower HF/HRV reactivity. Loser poor-deciders probably show SNS over-activation on PNS, which would be related to less emotional control (HF/HRV diminution) and less effort when facing the stressful situation (higher LF). This kind of CV response in poor-deciders could lead to a greater likelihood of losing the competition (Salvador & Costa, 2009).

Regarding CV recovery after competition, regardless of the outcome, our results showed that good-deciders had higher HF/HRV reactivity and slower recovery (in winners), which means higher PNS activation, unlike the control group. In this regard, after competition, good decision-makers may show more PNS activation and more SNS withdrawal than poor decision-makers. Faster recovery to basal levels is considered an adaptive stress response (Chida & Steptoe, 2010). This recovery pattern is healthier than permanent activation of the SNS (Brosschot, Gerin, & Thayer, 2006; Chida & Steptoe, 2010; Schwartz et al., 2003; Williams et al., 2009). Previous literature showed that

1 better EF could predict this healthier cardiovascular recovery in elderly people (Lin et  
2 al., 2014; Roiland et al., 2015). Our results are similar for young people and include  
3 decision-making skills as another predictor. Moreover, the cardiovascular response in  
4 good-deciders is usually associated with better cortisol recovery (Johnsen, Hansen,  
5 Murison, Eid, & Thayer, 2012), as reported in Santos-Ruiz et al. (2012), and thus with a  
6 healthier stress response.

7         Given these findings, it is worth noting that the IGT is a decision-making task  
8 that rewards conservative decisions (Bechara et al., 1994). Therefore, in our study,  
9 good-deciders avoided disadvantageous decisions. However, other decision tasks  
10 reward risky behavior. Thus, depending on the situation, it is better to make more  
11 conservative decisions rather than risky decisions, or *vice versa*. This pattern of  
12 cardiovascular response could be mediated by the more conservative behavior of our  
13 participants, although, for example, in adolescents, high risk behaviors are  
14 cardiovascular protective (Liang et al., 1995). Moreover, higher HF levels were related  
15 to less conservative behaviors in adults (Ramírez, Ortega, & Reyes Del Paso, 2015).  
16 Depending on the rules of the competition, sometimes it is better to behave more  
17 conservatively and sometimes in a riskier way. During our competition, participants  
18 were able to adapt their behavior depending on the feedback given. Therefore, our  
19 results indicate that good decision-making is related to the CV pattern, due to the  
20 capacity for adaptation in uncertain situations. Good decision-makers have the capacity  
21 to experience less uncertainty under social stress (a situation with an uncertain result),  
22 which implies less cortisol increase (Coates & Herbert, 2008; Santos-Ruiz et al., 2012).  
23 In this regard, higher HF activity is related to optimal activation of the neural pathways,  
24 leading to more flexible behaviors in changing environments (Laborde, Raab, &  
25 Kinrade, 2014).

1           This study has some limitations, such as the moderate effect sizes in some  
2 analyses, and it would be interesting to increase the sample size. Moreover, the  
3 exclusion criteria and our sample population also limit the generalization of the results  
4 to other health samples or to a clinical situation. It would be interesting to study  
5 decision-making skills in clinical populations such as chronic patients or patients with  
6 CV or metabolic illness in future studies. Finally, there are some limitations in the  
7 interpretation of the HRV frequency domain as SNS or PNS activation indexes  
8 (Goldstein, Benth, Park, & Sharabi, 2011; Reyes et al., 2013). Future studies would  
9 benefit from the inclusion of other psychological variables, such as coping styles  
10 (Folkman, Lazarus, Gruen, & DeLongis, 1986) or mood response, in order to have more  
11 information about how decision-making could be a factor in coping with competition.

## 12 **Conclusion**

13           In conclusion, this study shows that participants with better performance on the  
14 IGT have a cardiovascular reactivity pattern that could be adaptive in coping with  
15 competition. By contrast, poor-deciders could have a worse cardiovascular response  
16 when coping with the competitive stressor. Moreover, participants who win the  
17 competition with better decision-making skills seem to have better vagal control and  
18 quicker recovery. In the case of losers, being a poor-decider involves higher  
19 cardiovascular reactivity, which could imply worse emotional control in the competitive  
20 situation. Therefore, this study contributes to understanding how decision-making helps  
21 people to cope with a social stressor such as competition, and it opens up new lines of  
22 investigation into the stress coping paradigm.

## 23 **Acknowledgements**

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## Declaration of interest

The authors declare that there are no current or potential conflicts of interest.

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## References

- Abad-Tortosa, D., Alacreu-Crespo, A., Costa, R., Salvador, A., & Serrano, M. Á. (2017). Sex differences in autonomic response and situational appraisal of a competitive situation in young adults. *Biological Psychology*, 126, 61-70. <http://doi.org/10.1016/j.biopsycho.2017.04.008>
- Bechara, A. (2004). The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition*, 55(1), 30-40. <http://doi.org/10.1016/j.bandc.2003.04.001>
- Bechara, a, Damasio, a R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, 50, 7-15. [http://doi.org/10.1016/0010-0277\(94\)90018-3](http://doi.org/10.1016/0010-0277(94)90018-3)
- Bechara, a, Damasio, H., & Damasio, a R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex (New York, N.Y. : 1991)*, 10(3), 295-307. <http://doi.org/10.1093/cercor/10.3.295>
- Berntson, G. G., Quigley, K. S., Lozano, D., Cacioppo, J. T., & Tassinari, L. G. (2007). Cardiovascular psychophysiology. *Handbook of Psychophysiology (3rd Ed.)*, 182-210. Retrieved from <http://resources.library.brandeis.edu/login?url=http://search.ebscohost.com/>

login.aspx?direct=true&db=psych&AN=2007-08652-008&site=ehost-  
live&scope=site

Brand, M., Labudda, K., & Markowitsch, H. J. (2006). Neuropsychological  
correlates of decision-making in ambiguous and risky situations. *Neural  
Networks*, 19, 1266-1276. <http://doi.org/10.1016/j.neunet.2006.03.001>

Brosschot, J. F., Gerin, W., & Thayer, J. F. (2006). The perseverative cognition  
hypothesis: A review of worry, prolonged stress-related physiological  
activation, and health. *Journal of Psychosomatic Research*, 60(2), 113-124.  
<http://doi.org/10.1016/j.jpsychores.2005.06.074>

Carrillo, E., Moya-Albiol, L., Gonz lez-Bono, E., Salvador, A., Ricarte, J., &  
G mez-Amor, J. (2001). Gender differences in cardiovascular and  
electrodermal responses to public speaking task: The role of anxiety and  
mood states. *International Journal of Psychophysiology*, 42(3), 253-264.  
[http://doi.org/10.1016/S0167-8760\(01\)00147-7](http://doi.org/10.1016/S0167-8760(01)00147-7)

Chida, Y., & Steptoe, A. (2010). Greater cardiovascular responses to laboratory  
mental stress are associated with poor subsequent cardiovascular risk  
status: A meta-analysis of prospective evidence. *Hypertension*, 55(4),  
1026-1032. <http://doi.org/10.1161/HYPERTENSIONAHA.109.146621>

Coates, J. M., & Herbert, J. (2008). Endogenous steroids and financial risk  
taking on a London trading floor. *Proceedings of the National Academy of  
Sciences*, 105(16), 6167-72. <http://doi.org/10.1073/pnas.0704025105>

Costa, R., & Salvador, A. (2012). Associations between success and failure in a  
face-to-face competition and psychobiological parameters in young women.  
*Psychoneuroendocrinology*, 37, 1780-1790.

1 <http://doi.org/10.1016/j.psyneuen.2012.03.012>

2 Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in  
3 the quantification of respiratory sinus arrhythmia. *Biological Psychology*,  
4 74(2), 286-294. <http://doi.org/10.1016/j.biopsycho.2005.09.005>

5 Duschek, S., Wörsching, J., & Reyes Del Paso, G. A. (2013). Interactions  
6 between autonomic cardiovascular regulation and cortical activity: A CNV  
7 study. *Psychophysiology*, 50(4), 388-397.  
8 <http://doi.org/10.1111/psyp.12026>

9 Field, A. (2009). *Discovering statistics using SPSS. Discovering statistics using*  
10 *SPSS 2nd ed.*

11 Folkman, S., Lazarus, R. S., Gruen, R. J., & DeLongis, A. (1986). Appraisal,  
12 coping, health status, and psychological symptoms. *Journal of Personality*  
13 *and Social Psychology*, 50(3), 571-579. [http://doi.org/10.1037/0022-](http://doi.org/10.1037/0022-3514.50.3.571)  
14 [3514.50.3.571](http://doi.org/10.1037/0022-3514.50.3.571)

15 Goldstein, D. S., Benth, O., Park, M., & Sharabi, Y. (2011). Low-frequency  
16 power of heart rate variability is not a measure of cardiac sympathetic tone  
17 but may be a measure of modulation of cardiac autonomic outflows by  
18 baroreflexes, 1255-1261. <http://doi.org/10.1113/expphysiol.2010.056259>

19 Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on  
20 working memory and attention. *International Journal of Psychophysiology*,  
21 48(3), 263-274. [http://doi.org/10.1016/S0167-8760\(03\)00073-4](http://doi.org/10.1016/S0167-8760(03)00073-4)

22 Harrison, L. K., Denning, S., Easton, H. L., Hall, J. C., Burns, V. E., Ring, C., &  
23 Carroll, D. (2001). The effects of competition and competitiveness on

cardiovascular activity. *Psychophysiology*, 38(4), 601-606.

<http://doi.org/10.1111/1469-8986.3840601>

Johnsen, B. R. H., Hansen, A. L., Murison, R., Eid, J., & Thayer, J. F. (2012).

Heart rate variability and cortisol responses during attentional and working memory tasks in naval cadets. *International Maritime Health*, 63(4), 181-7.

Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/24595973>

Laborde, S., Raab, M., & Kinrade, N. P. (2014). Is the ability to keep your mind

sharp under pressure reflected in your heart? Evidence for the

neurophysiological bases of decision reinvestment. *Biological Psychology*,

100, 34-42. <http://doi.org/10.1016/j.biopsycho.2014.05.003>

Lane, R. D., McRae, K., Reiman, E. M., Chen, K., Ahern, G. L., & Thayer, J. F.

(2009). Neural correlates of heart rate variability during emotion.

*NeuroImage*, 44(1), 213-22.

<http://doi.org/10.1016/j.neuroimage.2008.07.056>

Lane, R. D., Reiman, E. M., Ahern, G. L., & Thayer, J. F. (2001). Activity in

medial prefrontal cortex correlates with vagal component of heart rate

variability during emotion. *Brain and Cognition*, 47, 97-100.

<http://doi.org/10.1006/brcg.2000.1275>

Liang, S. W., Jemerin, J. M., Tschann, J. M., Irwin Jr, C. E., Wara, D. W., &

Boyce, W. T. (1995). Life events, cardiovascular reactivity, and risk

behavior in adolescent boys. *Pediatrics*, 96(6), 1101-1105.

Liao, D., Carnethon, M., Evans, G. W., Cascio, W. E., & Heiss, G. (2002). Lower

Heart Rate Variability Is Associated With the Development of Coronary

Heart Disease in Individuals With Diabetes: The Atherosclerosis Risk in

Communities (ARIC) Study. *Diabetes*, 51(12), 3524-3531.

<http://doi.org/10.2337/diabetes.51.12.3524>

Lin, F., Heffner, K., Mapstone, M., Chen, D.-G. (Din), & Porsteisson, A. (2014).

Frequency of Mentally Stimulating Activities Modifies the Relationship

Between Cardiovascular Reactivity and Executive Function in Old Age. *The*

*American Journal of Geriatric Psychiatry*, 22(11), 1210-1221.

<http://doi.org/10.1016/j.jagp.2013.04.002>

Manuck, S. B. (1994). Cardiovascular Reactivity in Cardiovascular Disease:

“Once More Unto the Breach.” *International Journal of Behavioral Medicine*,

7(1), 4-31. [http://doi.org/10.1207/s15327558ijbm0101\\_2](http://doi.org/10.1207/s15327558ijbm0101_2)

Mukherjee, S., Yadav, R., Yung, I., Zajdel, D. P., & Oken, B. S. (2011). Clinical

Neurophysiology Sensitivity to mental effort and test - retest reliability of

heart rate variability measures in healthy seniors. *Clinical Neurophysiology*,

122(10), 2059-2066. <http://doi.org/10.1016/j.clinph.2011.02.032>

Ramírez, E., Ortega, A. R., & Reyes Del Paso, G. A. (2015). Anxiety, attention,  
and decision making: The moderating role of heart rate variability.

*International Journal of Psychophysiology*, 98(3), 490-496.

<http://doi.org/10.1016/j.ijpsycho.2015.10.007>

Reyes, G. A., Paso, D. E. L., Langewitz, W., Mulder, L. J. M., Roon, A. V. A. N.,

& Duschek, S. (2013). The utility of low frequency heart rate variability as

an index of sympathetic cardiac tone : A review with emphasis on a

reanalysis of previous studies, 50, 477-487.

<http://doi.org/10.1111/psyp.12027>

Ricarte, J., Salvador, a, Costa, R., Torres, M. J., & Subirats, M. (2001). Heart

Rate and Blood Pressure Responses to a Competitive Role-Playing Game.  
*Aggressive Behavior*, 27(June 1998), 351-359.  
<http://doi.org/10.1002/ab.1020>

Richter, M., Friedrich, A., & Gendolla, G. H. E. (2008). Task difficulty effects on  
cardiac activity. *Psychophysiology*, 45(5), 869-875.  
<http://doi.org/10.1111/j.1469-8986.2008.00688.x>

Roiland, R. A., Lin, F., Phelan, C., & Chapman, B. P. (2015). Stress Regulation  
as a Link between Executive Function and Pre-Frailty in Older Adults. *J  
Nutr Health Aging*, 19(8), 828-838. <http://doi.org/10.1007/s12603-015-0476-1>

Salvador, A., & Costa, R. (2009). Coping with competition: Neuroendocrine  
responses and cognitive variables. *Neuroscience and Biobehavioral  
Reviews*, 33, 160-170. <http://doi.org/10.1016/j.neubiorev.2008.09.005>

Santos-Ruiz, A., Garcia-Rios, M. C., Fernandez-Sanchez, J. C., Perez-Garcia,  
M., Muñoz-García, M. A., & Peralta-Ramirez, M. I. (2012). Can decision-  
making skills affect responses to psychological stress in healthy women?  
*Psychoneuroendocrinology*, 37, 1912-1921.  
<http://doi.org/10.1016/j.psyneuen.2012.04.002>

Schwartz, A. R., Gerin, W., Davidson, K. W., Pickering, T. G., Brosschot, J. F.,  
Thayer, J. F., ... Linden, W. (2003). Toward a causal model of  
cardiovascular responses to stress and the development of cardiovascular  
disease. *Psychosomatic Medicine*, 65(1), 22-35.  
<http://doi.org/10.1097/01.PSY.0000046075.79922.61>

Starcke, K., & Brand, M. (2012). Neuroscience and Biobehavioral Reviews

Decision making under stress: A selective review. *Neuroscience and Biobehavioral Reviews*, 36(4), 1228-1248.

<http://doi.org/10.1016/j.neubiorev.2012.02.003>

Svensson, M. K., Lindmark, S., Wiklund, U., Rask, P., Karlsson, M., Myrin, J., ... Eriksson, J. W. (2016). Alterations in heart rate variability during everyday life are linked to insulin resistance. A role of dominating sympathetic over parasympathetic nerve activity? *Cardiovascular Diabetology*, 15(1).

<http://doi.org/10.1186/s12933-016-0411-8>

Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. a, Ranta-Aho, P. O., & Karjalainen, P. a. (2014). Kubios HRV--heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, 113(1), 210-20. <http://doi.org/10.1016/j.cmpb.2013.07.024>

Thayer, J. F., Ahs, F., Fredrikson, M., Sollers III, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, 36(2), 747-756.

<http://doi.org/10.1016/j.neubiorev.2011.11.009>

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, 37(2), 141-153.

<http://doi.org/10.1007/s12160-009-9101-z>

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration.

1 *Neuroscience & Biobehavioral Reviews*, 33(2), 81-88.

2 <http://doi.org/10.1016/j.neubiorev.2008.08.004>

3 von Rosenberg, W., Chanwimalueang, T., Adjei, T., Jaffer, U., Goverdovsky, V.,  
4 & Mandic, D. P. (2017). Resolving ambiguities in the LF/HF ratio: LF-HF  
5 scatter plots for the categorization of mental and physical stress from HRV.  
6 *Frontiers in Physiology*, 8(JUN). <http://doi.org/10.3389/fphys.2017.00360>

7 Williams, D. P., Jarczok, M. N., Ellis, R. J., Hillecke, T. K., Thayer, J. F., &  
8 Koenig, J. (2016). Two-week test-retest reliability of the Polar<sup>®</sup> RS800CX  
9 <sup>™</sup> to record heart rate variability. *Clinical Physiology and Functional*  
10 *Imaging*, n/a-n/a. <http://doi.org/10.1111/cpf.12321>

11 Williams, P. G., Suchy, Y., & Rau, H. K. (2009). Individual Differences in  
12 Executive Functioning: Implications for Stress Regulation. *Annals of*  
13 *Behavioral Medicine*, 37(2), 126-140. [http://doi.org/10.1007/s12160-009-](http://doi.org/10.1007/s12160-009-9100-0)  
14 [9100-0](http://doi.org/10.1007/s12160-009-9100-0)

15 Yildirim, A., Kabakci, G., Akgul, E., Tokgozoglu, L., & Oto, A. (2002). Effects of  
16 menstrual cycle on cardiac autonomic innervation as assessed by heart  
17 rate variability. *Annals of Noninvasive Electrocardiology*, 7(1), 60-63.  
18 [http://doi.org/10.1016/S0735-1097\(02\)80922-6](http://doi.org/10.1016/S0735-1097(02)80922-6)

19 Zahn, D., Adams, J., Krohn, J., Wenzel, M., Mann, C. G., Gomille, L. K., ...  
20 Kubiak, T. (2016). Heart rate variability and self-control-A meta-analysis.  
21 *Biological Psychology*, 115, 9-26.  
22 <http://doi.org/10.1016/j.biopsycho.2015.12.007>

1   **Lay summary:**

2           This paper examines whether people who make good decisions have an adaptive  
3   cardiovascular response to a subsequent stressor. Our results indicate that good deciders  
4   have a more adjusted cardiovascular response to the stressor than bad deciders.  
5   Therefore, learning to make decisions would improve our ability to cope with stress  
6   and, consequently, reduce its harmful consequences.

7

Post Print

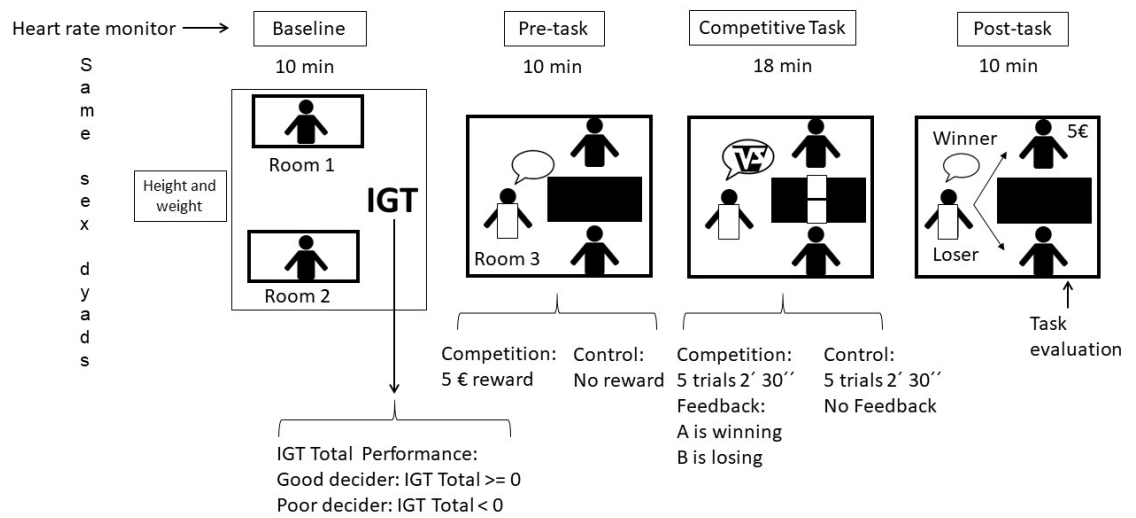


Figure 1: Summary of the study protocol.

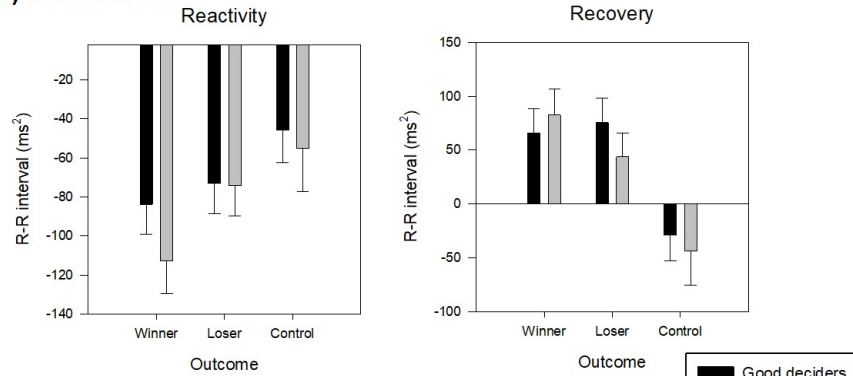
338x190mm (96 x 96 DPI)

1 Table 1: Mean  $\pm$  SEM of Total IG, Number of participants (N=), BMI, basal HRV indexes, IGT, Total 'Square letters' scores and Task perception of participants by Decision  
2 (Good/Poor) and Outcome (Winners/Losers/Control).  
3

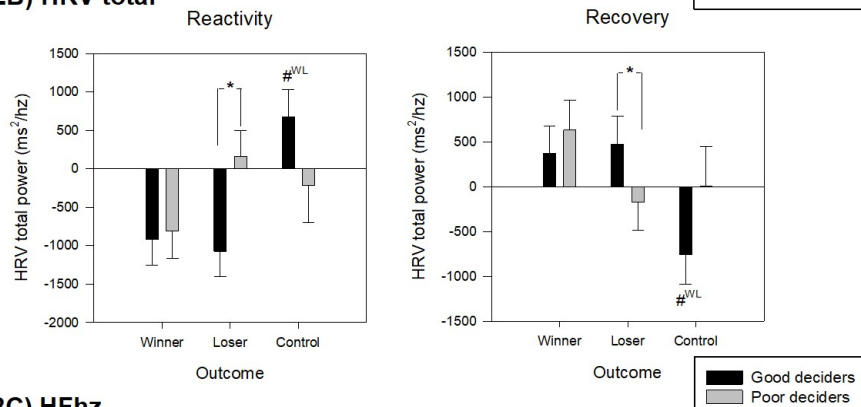
| Variable                    | Good Deciders      |                    |                    |                                  | Poor Deciders      |                    |                    |                                    |
|-----------------------------|--------------------|--------------------|--------------------|----------------------------------|--------------------|--------------------|--------------------|------------------------------------|
| Outcome                     | Winners            | Losers             | Control            | Total                            | Winners            | Losers             | Control            | Total                              |
| Participants                | N = 22             | N = 21             | N = 18             | N = 61                           | N = 18             | N = 22             | N = 11             | N = 51                             |
| <b>Preliminary</b>          |                    |                    |                    |                                  |                    |                    |                    |                                    |
| BMI (Kg/m)                  | 23.7 $\pm$ .67     | 24.5 $\pm$ .74     | 23.2 $\pm$ .79     | 23.8 $\pm$ .42                   | 23.5 $\pm$ .77     | 23.0 $\pm$ .68     | 23.7 $\pm$ 1.1     | 23.4 $\pm$ .49                     |
| R-R interval basal          | 820.9 $\pm$ 26.6   | 847.1 $\pm$ 27.2   | 814.7 $\pm$ 29.4   | 827.5 $\pm$ 16.0                 | 865.3 $\pm$ 29.4   | 876.2 $\pm$ 27.2   | 803.6 $\pm$ 37.6   | 848.4 $\pm$ 18.3                   |
| HRV <sub>tot</sub> basal    | 3054.8 $\pm$ 449.9 | 3619.5 $\pm$ 449.9 | 2750.8 $\pm$ 485.9 | 3141.7 $\pm$ 266.9               | 3837.6 $\pm$ 485.9 | 3536.9 $\pm$ 449.9 | 3017.2 $\pm$ 621.6 | 3463.9 $\pm$ 302.7                 |
| VLF basal                   | 181.4 $\pm$ 77.4   | 399.7 $\pm$ 77.4   | 243.4 $\pm$ 83.6   | 274.8 $\pm$ 45.9                 | 307.9 $\pm$ 83.6   | 296.8 $\pm$ 77.4   | 219.1 $\pm$ 106.9  | 274.6 $\pm$ 52.1                   |
| LF basal                    | 1824.6 $\pm$ 258.9 | 2111.9 $\pm$ 265.1 | 1326.8 $\pm$ 286.3 | 1754.4 $\pm$ 156.1               | 2253.0 $\pm$ 286.3 | 1912.7 $\pm$ 265.1 | 1842.5 $\pm$ 366.3 | 2002.7 $\pm$ 178.4                 |
| HF basal                    | 985.5 $\pm$ 206.0  | 1107.9 $\pm$ 210.8 | 1180.7 $\pm$ 227.7 | 1091.3 $\pm$ 124.2               | 1276.7 $\pm$ 227.7 | 1327.4 $\pm$ 210.8 | 955.6 $\pm$ 291.3  | 1186.6 $\pm$ 141.9                 |
| HF/HRV <sub>tot</sub> basal | .339 $\pm$ .033    | .303 $\pm$ .033    | .389 $\pm$ .036    | .344 $\pm$ .020                  | .338 $\pm$ .036    | .348 $\pm$ .033    | .301 $\pm$ .046    | .329 $\pm$ .022                    |
| HF <sub>hz</sub> basal      | .221 $\pm$ .015    | .206 $\pm$ .015    | .253 $\pm$ .016    | .227 $\pm$ .009                  | .208 $\pm$ .016    | .237 $\pm$ .015    | .237 $\pm$ .021    | .227 $\pm$ .010                    |
| <b>Execution</b>            |                    |                    |                    |                                  |                    |                    |                    |                                    |
| Total IG *                  | 17.3 $\pm$ 2.7     | 18.1 $\pm$ 2.8     | 13.3 $\pm$ 3.0     | <b>16.4 <math>\pm</math> 1.8</b> | - 15.8 $\pm$ 3.0   | - 16.1 $\pm$ 2.7   | - 10.9 $\pm$ 3.9   | <b>- 14.9 <math>\pm</math> 1.5</b> |
| 'Square letters test'       | 82.4 $\pm$ 2.9     | 60.1 $\pm$ 3.0     | 73.6 $\pm$ 3.3     | 72.1 $\pm$ 2.2                   | 85.9 $\pm$ 3.3     | 69.4 $\pm$ 2.9     | 67.6 $\pm$ 4.2     | 74.8 $\pm$ 2.1                     |
| <b>Task perception</b>      |                    |                    |                    |                                  |                    |                    |                    |                                    |
| Perceived Effort *          | 73.6 $\pm$ 3.5     | 70.5 $\pm$ 3.5     | 64.6 $\pm$ 4.5     | <b>70.4 <math>\pm</math> 2.1</b> | 62.2 $\pm$ 3.8     | 60.0 $\pm$ 3.5     | 60.0 $\pm$ 6.1     | <b>60.9 <math>\pm</math> 2.5</b>   |
| Perceived Frustration       | 36.9 $\pm$ 5.4     | 56.2 $\pm$ 5.5     | 37.7 $\pm$ 6.9     | 44.3 $\pm$ 3.5                   | 38.5 $\pm$ 5.9     | 49.6 $\pm$ 5.4     | 35.7 $\pm$ 9.5     | 43.3 $\pm$ 3.8                     |
| Perceived Performance       | 77.7 $\pm$ 3.4     | 51.4 $\pm$ 3.5     | 69.2 $\pm$ 4.5     | 65.9 $\pm$ 2.6                   | 82.2 $\pm$ 3.8     | 55.5 $\pm$ 3.4     | 64.3 $\pm$ 6.1     | 67.2 $\pm$ 2.9                     |
| Perceived Stress            | 62.7 $\pm$ 4.9     | 55.2 $\pm$ 5.0     | 42.3 $\pm$ 6.4     | 55.2 $\pm$ 3.2                   | 58.4 $\pm$ 5.4     | 56.9 $\pm$ 4.9     | 60.0 $\pm$ 8.7     | 57.9 $\pm$ 3.3                     |
| Perceived Difficulty        | 52.7 $\pm$ 4.2     | 51.0 $\pm$ 4.3     | 52.3 $\pm$ 5.5     | 51.9 $\pm$ 2.8                   | 53.9 $\pm$ 4.7     | 52.7 $\pm$ 4.2     | 54.3 $\pm$ 7.5     | 53.4 $\pm$ 2.6                     |

4 Note: \*  $p < 0.05$  for Decision factor (Between Good and Poor Deciders, regardless of outcome)

## 2A) R-R interval



## 2B) HRV total



## 2C) HFhz

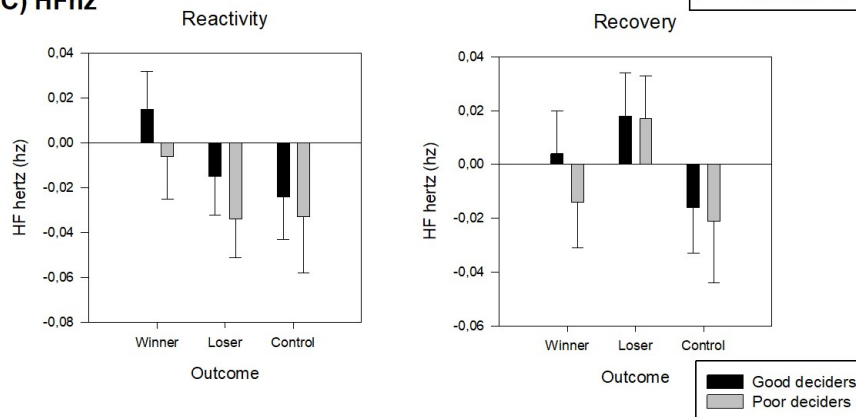


Figure 2: 2A) Means  $\pm$  SEM of R-R interval reactivity (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40). 2B) Means  $\pm$  SEM of the total power of heart rate variability reactivity (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40). 2C) Means  $\pm$  SEM of high frequency band hertz reactivity (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40).

Note: \* ( $p < 0.05$ ) showed *Post-hoc* significant effects of the Decision  $\times$  Outcome interaction, between good or poor-deciders in the indicated Outcome group. # ( $p < 0.05$ ) showed *Post-hoc* significant effects of the Decision  $\times$  Outcome interaction, between the indicated Outcome group (W = Winners, L = Losers) and Controls for the indicated Decision group.

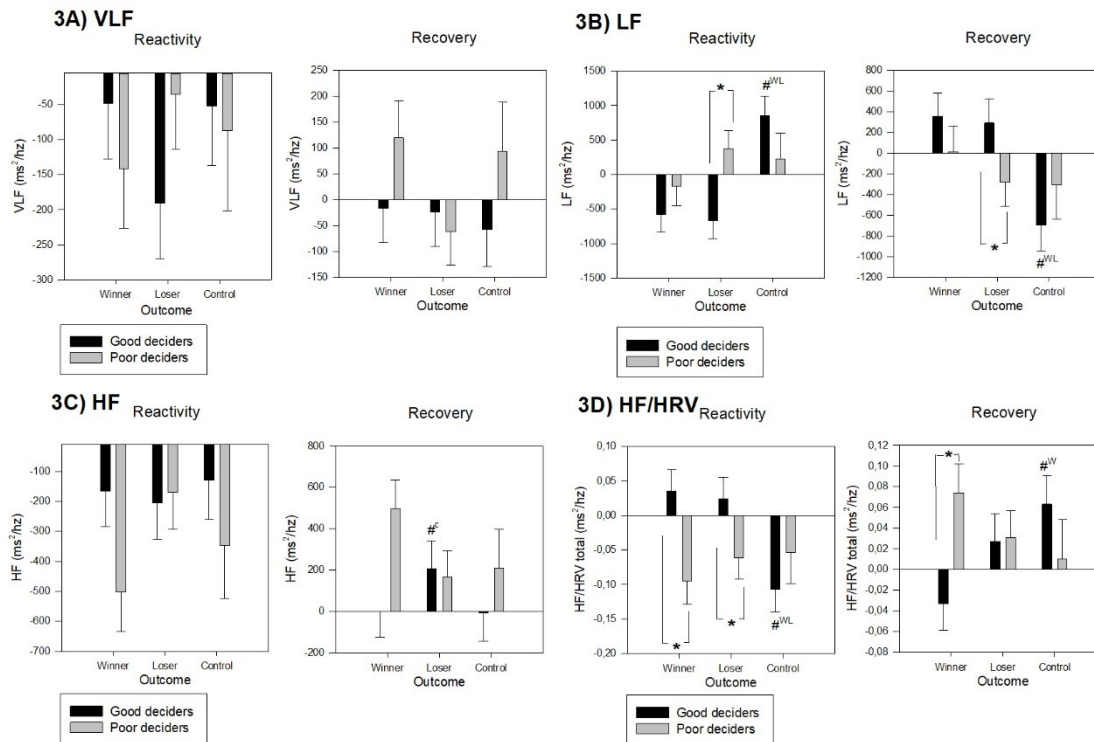


Figure 3: 3A) Means  $\pm$  SEM of very low frequency total power (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40). 3B) Means  $\pm$  SEM of low frequency total power reactivity (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40). 3C) Means  $\pm$  SEM of high frequency total power reactivity (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40). 3D) Means  $\pm$  SEM of high frequency divided by total power of heart rate variability (Task - Baseline) and recovery (Recovery - Task) indexes of Good decision-makers and Poor decision-makers separated by Outcome (Winners/Losers/Control), covariate of BMI (23.40).

Note: \* ( $p < 0.05$ ) showed *Post-hoc* significant effects of the Decision  $\times$  Outcome interaction, between good or poor-deciders in the indicated Outcome group. # ( $p < 0.05$ ) showed *Post-hoc* significant effects of the Decision  $\times$  Outcome interaction, between the indicated Outcome group (W = Winners, L = Losers) and Controls for the indicated Decision group.