Positive emotion induction improves cardiovascular coping with a cognitive task

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Abstract

Feeling positive emotions seems to favour an adaptive cardiovascular response (greater heart rate variability, HRV), associated with improved cognitive performance. This study aims to test whether the induction of a positive emotional state produce such cardiovascular response and therefore, enhance coping and performance in Tower of Hanoi (ToH). 42 Participants were randomly distributed into 2 groups (Experimental and Control). Experimental group was subjected to the evocation of a memory of success, while control group was subjected to an attentional task before performing ToH. Heart Rate Variability (HRV), activity of the zygomatic major muscle (ZEMG) and emotions were measured. Emotional induction increased ZEMG activity, feelings of emotional valence and HRV, but the performance in ToH was not different from control. Experiencing positive emotions seems to favour an adaptive psychophysiological response when faced with a complex cognitive task. These results are discussed in relation to clinical practice and health.

Introduction

Although there is a certain stable predisposition in our perceptions, cognitive capacities, and behavior, all of them can be influenced by the punctual state of the organism. This is the premise of the embodied brain approach (Barrett, 2011; Kiverstein & Miller, 2015), which highlights the need to study the brain in interaction with the body to really understand cognition and behavior. Classic hierarchical models (e.g. the mammalian brain; MacLean, 1990) maintain a "corticocentric" point of view (Kiverstein & Miller, 2015) where the development of the brain cortex would be the one that confers superior cognitive abilities. However, from the embodied brain, it is discussed a reciprocal relationship between the cortex and subcortical regions (including the brainstem and cerebellum), the latter being necessary for the rise of cognitive abilities and, at the same time, modulating their functioning (Parvizi, 2009). Therefore, this approach understands that cognition and emotions are inextricably linked (Mueller, 2011;

41 Pessoa, 2013; Pessoa, 2008). Emotions, seen as "states of action readiness manifest in the body
42 as forms of arousal" (Kiverstein & Miller, 2015, p. 9), are related to the homeostatic equilibrium
43 of the organism in interaction with the environment (Colombetti, 2014), and modulate cognition
44 due to the feedback they provide on the neocortex (Colombetti, 2014; Mueller, 2011; Pessoa,
45 2013).
46 Maybe due to traditional "corticocentric myopia" (Kiverstein & Miller, 2015), it is common to
47 find in cognitive sciences a negative connotation when talking about emotions, considering that
48 these can bias cognition and that repressing them is beneficial (Kahneman, 2011; Li et al., 2017;
49 Sunstein, 2014). It is true that negative emotions such as anger or fear favor defensive or
50 orientation responses (Bradley, 2009), guiding attention towards the most relevant stimuli in the
51 environment (Barros, Parisi, Weber, & Wermter, 2017) and, consequently, limiting some
52 cognitive capacities such as executive functions, working memory or the ability to regulate
53 emotions (Shook, Fazio, & Vasey, 2007; Shook, Pena, Fazio, Sollers III, & Thayer, 2007;
54 Thayer & Friedman, 2004). However, it would be wrong to interpret this as negative per se. In
55 fact, from an evolutionary perspective it would have an adaptive sense, maximizing survival by
56 ignoring less relevant information and providing fast responses to threatening stimuli (Barros et
57 al., 2017; Thayer & Lane, 2009; Vuilleumier, 2005). On the other hand, regarding the impact of
58 positive emotions on cognition, it has been observed that experiencing emotions such as joy,
59 surprise or happiness promotes mental states that help to solve problems and achieve goals
60 (Fredrickson, 2001; Stuss & Levine, 2002). Concretely, positive emotions would favor the
61 working memory (Gray, 2001), verbal fluency (Carvalho & Ready, 2010), taking perspective on
62 a problem (Herrington et al., 2005), information processing and the ability to connect thoughts
63 and ideas in an integrated and flexible way (Fredrickson, 1998; Fredrickson & Losada, 2005;
64 Herrington et al., 2005), among other cognitive skills (Mueller, 2011).
65 As decades of research highlighted, prefrontal cortex (PFC) plays a central role in the
66 functioning of the cognitive skills mentioned above (Carvalho & Ready, 2010; Herrington et al.,
67 2005; Mueller, 2011). For example, imaging data indicated greater PFC activation during a
68 phonemic fluency task (Billingsley et al., 2004), or during the relevant-information selection in
69 an attentional task (Milham, Banich, Claus, & Cohen, 2003), among others. And substantial
70 clinical data evidenced that individuals with deficits in the PFC, especially in the dorsolateral
71 region (DLPFC), experiment difficulties when anticipating future events or choosing among
72 multiple problem-solving strategies (for a review, see Banich, 2004). The specific mechanisms
73 by which positive emotions could improve cognitive skills are still unknown, but it seems that
74 "they are processes that share neuroanatomical underpinnings" (Carvalho & Ready, 2010,
75 p.228). So, neuroscience has indicated that positive emotions also activate PFC, specifically
76 DLPFC (Gray, Braver, & Raichle, 2002; Herrington et al., 2005), with a predominant
77 lateralization of the left hemisphere, widely described by electroencephalogram (EEG) (Carvalho
78 & Ready, 2010; Davidson, 2004; Heller & Nitschke, 1998) and functional magnetic resonance
79 (fMRI) (Gray et al., 2002; Herrington et al., 2005). Thus, as Carvalho & Ready (2010)
80 suggested, although more research is needed to clarify the specific mechanisms, the relationship

81 between positive emotions and the higher cognitive performance could be due to the activation
82 of overlapping cortical areas. In this line, Andreau & Torres Batán (2019) found that selective
83 pre-activation of brain circuits participating in the verbal stimuli recognition could favor the
84 memory of words. And in fact, the own Transcranial direct current stimulation (TDCS) method
85 tries to pre-activate brain regions to enhance certain cognitive functions, such as language
86 (Meinzer, Lindenberg, Sieg, Nachtigall, Ulm, & Flöel, 2014).
87
88 As Brugnera et al., (2018) have recently begun to point out, another way of studying the
89 relationship between positive emotions and cognition, in addition to neuroimaging, would be
90 attending to heart rate variability (HRV). Firstly, experiencing positive emotions, unlike negative
91 ones, does not seem to produce a great withdrawal of the parasympathetic nervous system (PNS)
92 or an increase of the sympathetic nervous system (SNS); in fact, it would contribute to improve
93 the sympathetic-parasympathetic balance (Brugnera et al., 2018). Therefore, through the
94 influence that both autonomous branches exert on the heart, there would be an increase in the
95 HRV or, at least, it would not decrease so much (Brugnera et al., 2018; Shaffer & Ginsberg,
96 2017) as usually happens when facing a challenge or stressor in a neutral emotional state
97 (Castaldo et al., 2015). On the other hand, in line with the Neurovisceral Integration Model
98 (NIM; Park & Thayer, 2014; Thayer & Friedman, 2004; Thayer & Lane, 2009), the increased
99 activity of PFC (induced in this case by positive emotions) would restrain impulses from
100 subcortical structures and would produce a reflex through the vagus nerve which would also be
101 reflected in the increase of HRV (Park & Thayer, 2014). Therefore, in both ways, inducing a
102 positive emotion could increase HRV, or avoid a large reduction in HRV in the face of a
103 challenge. A high HRV, at rest and phasic (i.e., in response to a stressor), is considered an
104 adaptive cardiovascular activity, as it is related to greater cognitive flexibility, better emotional
105 regulation and greater performance in complex tasks that depend on executive functions
106 (Grossmann, Sahdra, & Ciarrochi, 2016; McCraty & Shaffer, 2015; Park & Thayer, 2014;
107 Shook, Pena, et al., 2007; Thayer & Lane, 2009). Thus, although the specificity of HRV would
108 not be comparable and could not replace neuroimaging techniques, this could also be a useful,
109 economic, and non-invasive method for study how positive emotions affect cognition.
110 Therefore, the objective of this study is to test whether the induction of a positive emotional state
111 could produce such adaptive cardiovascular response, associated with higher cognitive
112 performance and therefore, in line with Isen (2000), whether this benefits coping and
113 performance in a task that depends on complex cognitive skills, such as the Tower of Hanoi
114 (ToH; Barroso y Martín & León-Carrión, 2001). The execution of ToH has been linked to the
115 capacity of inhibition, planning, logical reasoning, cognitive flexibility, working memory and
116 problem solving (Barroso y Martín & León-Carrión, 2001; Goldstein, Naglieri, Princiotta, &
117 Otero, 2014), so the strengthening of these skills could improve performance in this task. This
118 performance is usually measured based on the time and number of movements dedicated to
119 solving ToH, as well as, within a fixed time, the number of towers that a person can solve
120 (Barroso y Martín & León-Carrión, 2001). Thus, the higher the number of towers solved, as well

121 as the lower the number of movements and time to solve each tower, the greater the
122 performance.
123 Regarding the induction of the positive emotional state, classical methods such as reading and
124 internalizing positive self-affirmations, seeing happy facial expressions, or listening to music,
125 have proven effective (Gerrards-Hesse, Spies, & Hesse, 1994). However, one of the most recent
126 methods used is the evocation of autobiographical memories about successful life experiences
127 (Brugnera et al., 2018; Yousefi, Sharifi, Tagharrobi, & Akbari, 2015). This method is based on
128 the reminiscence therapy and has proven to be useful in increasing self-esteem, satisfaction with
129 life and happiness (Yousefi et al., 2015). In this study we decided to use this method to carry out
130 positive emotional induction (see Material & Methods for more details). In order to ensure that
131 an emotional change really occurs after induction, it can be evaluated subjectively using
132 questionnaires such as Self-Assessment Manikin (SAM; Bradley & Lang, 1994), but also, since
133 the activity of the zygomatic major muscle has been related to the experience of positive
134 emotions (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Cacioppo & Fridlund, 1986;
135 Ravaja, Saari, Salminen, Laarni, & Kallinen, 2006; Schmidt, Ambadar, Cohn, & Reed, 2006), its
136 measurement would constitute a good objective indicator of the success of emotional induction.
137 Thus, our hypotheses posit that (hypothesis 1) inducing a positive emotional state in some
138 participants will increase the activity of their zygomatic major muscle and their positive
139 emotional valence measured with SAM; (hypothesis 2) this will cause them a higher HRV during
140 the performance of ToH; (hypothesis 3) and this performance will be higher: they will solve
141 more towers in less time and number of movements; all this with respect to a control group not
142 exposed to induction.
143
Materials & Methods
145 Participants
146 Based on the effect sizes found in previous works on emotions induction and HRV (η^2_p = .30;
147 Brugnera et al., 2018), as well as on emotions induction and cognitive performance (η^2_p = .16;
148 Gray, Braver, & Raichle, 2002), a priori power analyses using G*Power indicated a requisite of
149 30-48 participants (power = 80%, α = .05) to perform ANOVAS comparing between groups
150 (intervention vs control) their performance in ToH and their HRV. We recruited 50 participants,
151 however, 8 were eliminated due to drug consumption and technical issues. A total of 42 healthy
152 volunteers (age: M = 23, SD = 2.06; women: N = 28;) were finally included. All of them,
153 students from the University of Valencia, recruited in the classes by asking them if they wanted
154 to participate in exchange for academic credits. Those interested filled out a self-administered
155 questionnaire to ensure that they met the following inclusion criteria: having between 18 and 30
156 years old; not having cardiovascular, endocrine, neurological or psychiatric diseases; not
157 consuming more than 10 cigarettes per day; not consuming drugs and alcohol habitually; not
158 doing more than 10h of physical exercise per week and not having experienced a highly stressful
159 event in the last month. In addition, variables, such as not having carried out strenuous exercise,
160 consumed drugs or alcohol in the last 24 hours, nor smoked or drank stimulant drinks in the 2

161 hours prior to the experiment were controlled upon arrival at the laboratory. The participants
162 were randomly distributed in two groups, experimental (N = 21) and control (N = 21) and both
163 groups were checked for homogeneity in age, gender proportion, body mass index, emotional
164 state through the Self-assessment manikin (SAM), and emotional traits through the Beck-II
165 Depression Inventory (BDI-II) and the Anxiety Trait Questionnaire (STAI-R).
166
167 Questionnaires
168 Self-Assessment Manikin (SAM; Lang, 1980). Evaluates by means of pictograms the three main
169 emotional dimensions: valence, activation, and dominance. Each dimension goes from 1, the
170 extreme of maximum pleasure (valence), greater activation (activation) and feeling of
171 submission (dominance); up to 5, the extreme of maximum displeasure, relaxation and feeling of
172 dominance, respectively.
173 Sociodemographic. Collects information on age, gender and other variables not included in this
174 study.
175 Beck-II Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996). 21 items on Likert scale of
176 4 points (from 0 to 3), which must be added to evaluate depression. The higher the score, the
177 greater the depression (α = .87).
178 Anxiety Trait Questionnaire (STAI-R; Spielberger, Gorsuch, & Lushene, 1970). 20 items in
179 Likert scale of 4 points (where 0 is "never" and 3 is "almost always"), which must be added to
180 evaluate trait anxiety. The higher the score, the greater the anxiety (α = .85).
181
182 Tower of Hanoi (ToH)
183 The ToH consists of a platform with three parallel posts and a certain number of initial pieces,
184 stacked downwards on the left post (the largest at the base, to the smallest at the cusp).The
185 participants have to move all the pieces to the right post, maintaining the same descending order,
186 but complying with the following rules: no more than one piece can be moved at a time, no one
187 piece can be stored outside the posts, and no piece can be stacked on top of a smaller one. When
188 all the pieces are correctly in the right post, the tower is completed; after this, and if there is still
189 time, the task is restarted increasing the difficulty by adding one more piece to the left post.
190 Participants have to solve as many towers as possible within a 6-minutes time limit. Before
191 starting the task, a practice was carried out with 2 pieces. The actual execution started with 3
192 pieces and could increase up to a maximum of 7, depending on whether the previous towers were
193 resolved. Three indicators were obtained to evaluate performance. The first one was the number
194 of towers completed in 6 minutes (the more towers the better the performance). On the other
195 hand, following Barroso y Martín & León-Carrión (2001), we focused on those towers that the
196 whole sample managed to complete within the time limit (in this case, only the towers with 3 and
197 4 pieces were completed by all participants). For each participant, the number of movements and
198 the time needed to complete each tower individually were counted. Thus, the fewer the
199 movements and time in each tower, the better the performance in that tower.
200

Intervention

In the experimental group, a positive emotional induction was carried out through the guided evocation of a successful autobiographical memory, based on reminiscence therapy, since this method has proven effective in increasing happiness (Yousefi et al., 2015). The induction was carried out by the same investigator for all participants. The guide (see annex 1) is composed of direct indications (e.g., "concentrate on the specific place where it occurred") and questions (e.g., " how was that place?"), techniques drawn from the imagined method of practice (Palmi & Mariné, 1996) and reminiscence therapy (Yousefi et al., 2015), respectively. For its part, the control group listened to a neutral text (inspired by a construction documentary; see annex 2). They were instructed to pay attention since at the end they would be asked about the text. The duration was also 10 minutes. In both cases, to ensure that both groups received the same number of sentences and the cadence of the text/stimulation, we controlled the number of sentences and the time of the pauses. The investigator knew to which group the participants had been assigned, but they did not know to which condition (intervention vs. control) they belonged. In addition, another researcher was responsible for analyzing the data without knowing the identity of the groups.

Physiological variables

The PowerLab/16SP (ADInstruments) equipment linked to the LabChart 5.2 software was used. The signals were transmitted at 1000Hz. The details of each signal are specified below.

Facial electromyography of the zygomatic muscle (ZEMG)

The average zygomatic muscle activity was obtained during the last 5 minutes of habituation (baseline, BL), after the ToH-1 and during the intervention time. The recording was made by placing three low voltage Ag/AgCl cup electrodes, one on the nose and the other two on the zygomatic major muscle, following Van Boxtel (2010) indications. A band-pass filter was established between 20 and 250 Hz and a 50 Hz high-pass filter.

Heart rate variability (HRV)

Three single-use Ag/AgCl cup electrodes with Einthoven's third derivation were used to record the electrocardiogram and, in particular, the time interval between beats (R-R) allowing analysis of HRV. Following the recommendations of the Task Force (1996), we standardized 5-minute records so that they could be compared among them. Thus, the 5 minutes of BL and the 5 central of each ToH, were exported and analyzed with the free software Kubios HRV (Tarvainen, Niskanen, Lipponen, Ranta-aho, & Karjalainen, 2014). The signal was filtered using the smooth priors' method and applying the level of artifact correction that was necessary for each case. Of all the indicators that can be analyzed within the HRV, the standard deviation of the interval between normal beats (SDNN) was used, i.e., those that remain after removing ectopic beats. The reasons for selecting this indicator are as follows: on the one hand, SDNN is among the main ones highlighted by the Task Force (1996) to study global HRV; this is because SDNN is

241   mathematically identical to the total power of the spectral analysis or the sum of the Very-Low,
242   Low and High frequency bands that can be extracted from the time domain, for example, by
243   means of Fast Fourier Transformation (Task Force, 1996); Thus, it is an indicator of HRV that
244   includes information of all the contributing cyclic components in their variation (Shaffer &
245   Ginsberg, 2017; Task Force, 1996), which allows to speak about the increase or decrease of
246   HRV in general, as is pretended in this study. Thus, a higher SDNN would imply a higher HRV.
247   On the other hand, this minimizes the chance of α-inflation due to the multiple statistical
248   contrasts avoided by not using the rest of the indicators (Grossmann et al., 2016), many of which
249   also have mathematical redundancy and would only complicate the explanation (Brugnera et al.,
250   2018). Finally, it appears that for short measurements (e.g., 5 minutes), the main contribution to
251   SDNN variations comes from the respiratory sinus arrhythmia (RSA), controlled by the PNS
252   (Shaffer & Ginsberg, 2017), thus, with a single indicator we could speak of global HRV, but also
253   partially infer the behavior of the autonomic nervous system. As Shaffer & Ginsberg (2017)
254   point out, this inference should only be made under normal breathing conditions (between 9 and
255   26 cycles per minute), however, since the participants were controlled for no physical activity
256   and were at rest, following the recommendations of Denver, Reed, & Porges (2007), the
257   respiratory rate was not controlled.
258
259   Protocol
260   The study consists of a single session, the duration of which is approximately one hour and a
261   half. All the participants took part in the session between 15:30 pm and 19:00 pm. Participants
262   were asked to wait in the University hall and accompanied in an elevator to the laboratory,
263   avoiding the use of stairs. The general procedure was reported, and written informed consent was
264   obtained from the participants. Afterwards, they were connected to the polygraph and had 10
265   minutes of rest as habituation. They filled out the SAM questionnaire to assess their subjective
266   emotional state and performed the first ToH (ToH-1) for 6 minutes. After this, the experimental
267   group completed a second SAM and underwent positive emotional induction; the control group
268   performed a distracting task (listening to a text with neutral content). After the intervention, they
269   refilled the SAM and performed the second ToH (ToH-2). When they finished, they were
270   disconnected from the electrodes, completed a battery of questionnaires (sociodemographic
271   variables and emotional traits, to study the homogeneity of the groups) and were measured
272   height and weight. The protocol was approved by the Research Ethics Committee of the
273   University of Valencia (H1393232860606) in accordance with the ethical standards of the
274   Declaration of Helsinki of 1969.
275
276   Statistical analyses
277   In order to detect and eliminate outliers in all the variables of interest the method of the 2.5
278   standard deviations and, for variables measured more than once, the Mahalanobis distance with
279   the criterion of $p < .001$ were employed. Kolmogorov-Smirnoff with Lilliefors correction was
280   used to check normality. The variables of SAM, ZEMG, HRV and time spent to complete the

281 tower of 4 pieces in ToH-2, did not follow the normal distribution. This last variable, as well as
282 those of HRV, were normalized using the log10 method (Field, 2009). For the remaining ones,
283 non-parametric tests were used. Using One-way ANOVAs, the means of the experimental and
284 control group were contrasted in trait questionnaires, performance in ToH (1 and 2) and HRV (in
285 BL, ToH-1 and ToH-2). The Man-Whitney test is used for non-parametric contrasts with SAM
286 and ZEMG in BL, after ToH-1 and after the intervention (or during, for ZEMG). The alpha
287 significance level was set at .05. In addition, the ANOVAs have indicated the partial square eta
288 ($\eta2p$) symbolizing the size of the effect and β-1 (power) symbolizing the power. In the Mann-
289 Whitney test the effect size (r) was calculated with the formula: $r = Z/\sqrt{N}$. All analyses were
290 performed with IBM SPSS Statistics 23.
291
Results
292
293
294   Preliminary analyses
295 As can be seen in Table 1, the distribution of the sample in experimental and control groups is
296 homogeneous, with no statistically significant differences in age, BMI, BDI-II or STAI-R. In
297 addition, although there are more women than men, the distribution of both genders in the two
298 groups maintains a similar proportion.
299
300 <Insert Table 1 here>
301
302 ToH 1 and 2 Results
303 Below are the results of the ANOVAs for each of the measures taken to evaluate the
304 performance in ToH 1 and 2: the number of towers reached in 6 minutes and the number of
305 movements and time used to overcome the towers of 3 and 4 pieces (see table 2).
306
307 <Insert Table 2 here>
308
309 As we can see, during ToH-1, there are no statistically significant differences between groups
310 for any of the analyzed measures. On the other hand, after the intervention, in ToH-2, there are
311 no differences between groups, with the exception of the time spent solving the tower with 4
312 pieces (T4), the time spent by the experimental group being greater than that of the control.
313
314 SAM Results
315 In table 3 we can see the results of the Mann-Whitney test for the contrast between control and
316 experimental group in each SAM dimensions (valence, activation and dominance), for BL, after
317 the first ToH and after the intervention.
318
319 <Insert Table 3 here>
320
321 We can see that none of the emotional dimensions differ in a statistically significant way
322 between experimental group and control in BL, neither after performing the first ToH. However,

323 after the intervention, we can observe how the experimental group shows, with respect to the
324 control group, a lower score in emotional valence, i.e., a more positive emotional valence.
325
326 ZEMG Results
327 As can be seen in table 4, in relation to the facial electromyography of the zygomatic major
328 muscle, the Mann-Whitney test was performed to contrast the level of activity of the
329 experimental group with respect to the control in BL, after ToH-1 and during the intervention.
330 Analyses show that during BL and after ToH-1 there were no statistically significant differences
331 between groups. However, during the intervention there were significant differences in favor of
332 the experimental group, which showed a higher level of activity in comparison with the control
333 group.
334
335 <Insert Table 4 here>
336
337 HRV Results
338 ANOVAs were performed to study the differences in SDNN between experimental group and
339 control during BL, ToH-1 and ToH-2. The analyses show (see figure 1) the absence of
340 differences between groups in both BL (p = .95) and ToH-1 (p = .33); however, during ToH-2
341 (after intervention), the experimental group has a significantly higher level of SDNN (M = 40.85,
342 SD = 15.81) than the control group (M = 30.42, SD = 11.55), $F(1, 37) = 6.05$, $p = .019$, $\eta2p =$
343 .14, power = .66.
344
345 <Insert Figure 1 here>
346
347 ## Discussion
348 This study aimed to investigate effects produced by the induction of a positive emotion, through
349 the evocation of an autobiographical memory of success, on the subsequent performance in the
350 Tower of Hanoi (ToH), on the basis that positive emotions could enhance the cognitive skills
351 needed to perform this task (Fredrickson & Losada, 2005; Herrington et al., 2005; Mueller,
352 2011). The results are controversial because, although the performance obtained by the
353 experimental group (with emotional induction) did not appear to be different from that of the
354 control group (without emotional induction), the first group showed a more adaptive
355 cardiovascular response during the task, with higher HRV, which is usually associated with a
356 better coping of the task (Grossmann et al., 2016; Park & Thayer, 2014; Thayer & Lane, 2009).
357 This leads us to think that positive emotions may not necessarily produce great changes in the
358 result, but they could facilitate better coping with difficulties. These issues will be discussed in
359 more detail below.
360 First, it is important to point out that the distribution of the participants in both groups was
361 homogeneous, presenting an emotional state (in SAM) and trait (in BDI-II and STAI-R), a
362 zygomatic activity (ZEMG) and HRV (SDNN) similar at the beginning of the experiment. As
363 can be seen in figure 1, during the first ToH, both groups showed a similar decrease of HRV with
364 respect to BL. This seems logical if we consider that the participants were facing a complex task

365   that could act as an acute cognitive stressor (Ciabattoni et al., 2017), which would promote an
366   immediate parasympathetic withdrawal and increased sympathetic activity (Castaldo et al., 2015;
367   Hidalgo, Pulopulos, & Salvador, 2019). This would explain the decrease in SDNN, a global
368   HRV indicator that is affected by the autonomous changes described above (McCraty & Shaffer,
369   2015; Shaffer & Ginsberg, 2017; Task Force, 1996). On the other hand, after the first ToH, both
370   the subjective emotional state and the ZEMG remained undifferentiated between groups. In this
371   way, it could be interpreted that both were exposed to intervention with a similar emotional state.
372   However, during the intervention, the group exposed to the guided evocation of the
373   autobiographical memory of success (experimental group) showed significantly higher ZEMG
374   activity than the control group, which merely listened to a narration about constructions. If we
375   consider that ZEMG was indicated as an objective indicator of the experience of positive
376   emotions (Cacioppo et al., 2000; Cacioppo & Fridlund, 1986; Ravaja et al., 2006; Schmidt et al.,
377   2006), we could affirm that, as intended, emotional induction was effective in provoking positive
378   emotions. This interpretation would also be reinforced by the subjective perception of the
379   participants themselves, who expressed in the SAM questionnaire that they felt happier after the
380   intervention. All this would confirm our first hypothesis.
381   Under this differential mood, both groups performed the second ToH. However, their
382   performance scarcely differed between them. They did not complete more towers than in the first
383   attempt, although both finished the towers of 3 and 4 pieces with less movements and time,
384   probably a phenomenon attributable to a learning effect on the task (Ahonniska, Ahonen, Aro,
385   Tolvanen, & Lyytinen, 2000; Welsh & Huizinga, 2005). The only difference between groups
386   was observed in the time taken to complete the tower of 4 pieces, the experimental group being
387   slower than the control. According to the usual ToH evaluation criteria, this would be a worse
388   performance indicator (Barroso y Martín & León-Carrión, 2001), against the expected
389   improvement after the intervention proposed in our third hypothesis. However, focusing on
390   cardiovascular activity during the task, we saw that, although both groups continued showing
391   lower levels of HRV than in BL, the experimental group faced the second ToH with a
392   significantly higher level of HRV than the control group. Looking at figure 1 we can add that
393   these differences were not due to an increase in HRV, but rather to the fact that their level was
394   not as much reduced during the second ToH, as seems to happen in the control group. Given that
395   for short measurements, the fluctuations in the indicator used, SDNN, would be explained more
396   by the RSA controlled by the PNS (McCraty & Shaffer, 2015; Shaffer & Ginsberg, 2017), it
397   could be inferred that the experimental group was perhaps manifesting a lower parasympathetic
398   withdrawal during the second ToH thanks to its positive emotional state. This would be in line
399   with the results described by Brugnera et al. (2018), who found a similar effect but with
400   frequency indicators. On the other hand, returning to the NIM approaches (Park & Thayer, 2014;
401   Thayer & Friedman, 2004), this response may also be evidencing the increased activity of
402   neocortical regions that were expected to induce positive emotions (Brugnera et al., 2018;
403   Herrington et al., 2005) which would favor a less impulsive coping by improving self-control
404   capacity (Segerstrom, Hardy, Evans, & Winters, 2011) and emotional regulation (Grossmann et

405   al., 2016). In fact, this could be an explanation of the longest time spent by the experimental
406   group to overcome the tower of 4 pieces. The group did not perform worse in general terms,
407   completing the same towers in 6 minutes than the control group and executing the same number
408   of movements. Thus, perhaps taking longer in that phase does not imply a worse performance
409   per se, but simply that they were thinking more about the movements before executing them.
410   This would highlight the need to rethink whether the criteria for assessing cognitive task
411   performance are adequate and/or sufficient, as is already being discussed in other cognitive
412   domains such as decision-making (Chater et al., 2018). This debate emphasizes that many
413   normative criteria used to judge whether a person "performs well" are not necessarily suited to
414   the demands of the real world (Haksöz, Katsikopoulos, & Gigerenzer, 2018; Volz & Gigerenzer,
415   2012) or are not the only aspects to consider. For example, importance is given to the outcome,
416   but rarely attention is focused on how the situation is dealt with (Brugnach, Dewulf, Henriksen,
417   & van der Keur, 2011; Keys & Schwartz, 2007), that is, the strategy used or the physiological or
418   psychological state in which it is carried out. This could have implications in clinical practice,
419   where it might be useful to provide strategies to deal with problems in a healthy way and not
420   only focus on achieving a certain result, which may depend on multiple contextual factors that
421   are beyond the control of the patient and therapist. Thus, in line with our second hypothesis, and
422   independently of the result obtained in ToH, it seems that experiencing a positive emotion
423   promoted a better response to difficulties, presenting an adaptive cardiovascular activity that is
424   not only related to better cognitive performance (Grossmann et al., 2016), but also to better
425   coping with stress and threatening situations (Alacreu-Crespo, Costa, Abad-Tortosa, Salvador, &
426   Serrano, 2018; Thayer & Lane, 2009) and better overall health (McCraty & Shaffer, 2015;
427   Thayer & Lane, 2009). In fact, the opposite, i.e. a low level of HRV, is associated with
428   inadequate response to stress or even chronic stress (McCraty & Shaffer, 2015; Park & Thayer,
429   2014); with psychopathological disorders such as major depression, generalized anxiety, panic or
430   schizophrenia (Park & Thayer, 2014); with health problems such as hypertension, diabetes,
431   obesity, arthritis and some types of cancer (Park & Thayer, 2014; Thayer & Friedman, 2004;
432   Thayer & Lane, 2009); and increased risk of heart attack and death (Grossmann et al., 2016).
433   Our study is not exempt from limitations and results must be considered addressing them. So, the
434   sample used is composed by healthy young people with a university level education, however,
435   emotional induction could produce other effects in a sample that, for example, has a different
436   sociocultural level or that presents a cognitive impairment associated with an advanced age or
437   various pathologies, so it would be good to study different samples to provide greater ecological
438   validity to the results. Similarly, no direct effects of induction on cognitive performance have
439   been found. This could be due to a lack of power produced by the reduced sample size; but it
440   should also be noted that only ToH was used to evaluate cognitive performance. ToH is linked to
441   inhibition capacity, planning, logical reasoning, cognitive flexibility, working memory and
442   problem solving (Barroso y Martín & León-Carrión, 2001; Goldstein et al., 2014), but perhaps
443   using tasks that focus on other cognitive domains, the effects were different. It should also be
444   noted that the researcher applying the intervention knew which group the participants belonged

445   to (intervention vs. control). Although participants did not know this information, and another
446   external researcher was responsible for carrying out the analyses without knowing the identity of
447   the groups, the fact that the researcher who applied the intervention knew this information could
448   affect results. Triple-blinded research should be carried out to replicate findings in the future.
449   Moreover, although the distribution is homogeneous in both groups, the number of males is
450   small, which makes it impossible to study differences by gender, something that would be
451   interesting given that, as mentioned, ToH could constitute an acute cognitive stressor (Ciabattoni
452   et al., 2017) and in previous literature it has been pointed out that the physiological response to
453   stress is differential according to gender (Hidalgo et al., 2019). Finally, the results on HRV have
454   been discussed in line with the NIM approach and based on the hypotheses raised in this study
455   This could constitute a bias based on previous knowledge and expectations. Since no other
456   variables have been included to investigate whether the HRV response really constitutes, as we
457   suggested, a better coping with the cognitive task, we recommend caution on these conclusions.
458   Thus, further research is needed to address these issues and make our results robust.
459

Conclusions

461   In view of the results, we must return to the initial premise of the embodiment: the brain should
462   not be studied in isolation. Our data show once again that emotions and cognition are related, and
463   that experiencing positive emotions favors a physiological response that enhances cognition and
464   promotes better coping with difficulties, although this does not always translate into a better
465   result. Moreover, training in the induction of positive emotions could be a useful tool in clinical
466   practice, preparing patients to better cope with stress and the difficulties of life in a healthy way.

467

468

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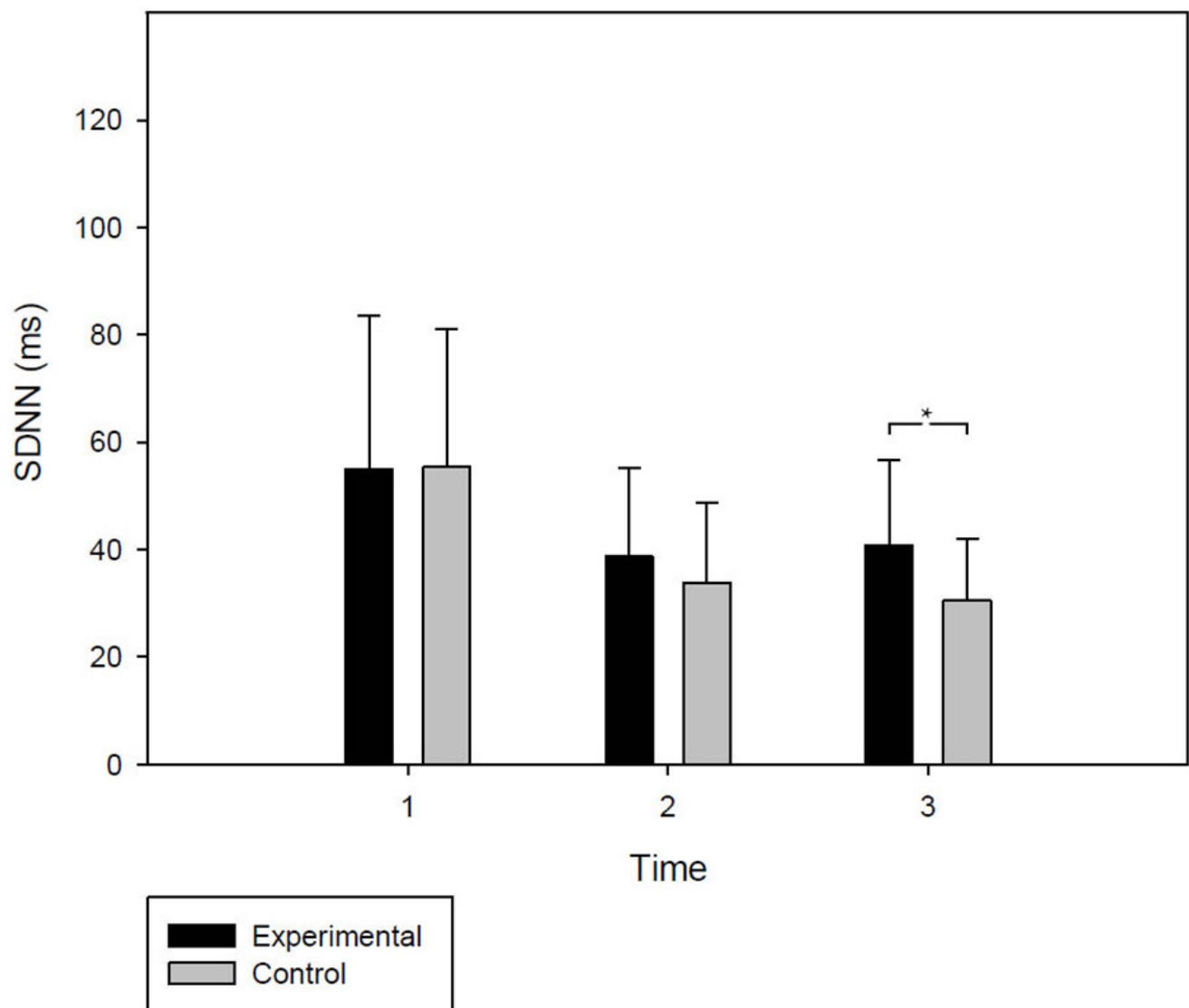
648

Figure 1

Experimental and control group HRV levels during the protocol

HRV levels. SDNN levels are shown (in ms; M + SD), for the two groups (experimental and control), at moments 1: Baseline; 2: Tower of Hanoi 1; and 3: Tower of Hanoi 2. At this last moment, after having experienced emotional induction, the experimental group shows a significantly higher SDNN level than the control group

Data comparison between groups

Homogeneity between groups

1   *Table 1 -* Homogeneity between groups

	Experimental (N = 21)	Control (N = 21)	F	gl between	gl intra	p-value
Age	$M = 22.9 \pm 1.81$	$M = 23.1 \pm 2.3$	0.08	1	40	.76
Sex						
Men	28.6%	38.1%	0.28[†]	1	14[†]	.59
Women	71.4%	61.9%	0.14[†]	1	28[†]	.7
BMI	$M = 23.73 \pm 5.39$	$M = 23.87 \pm 3.91$	0.01	1	40	.92
BDI-II	$M = 7.38 \pm 6.34$	$M = 8.62 \pm 6.32$	0.4	1	40	.53
STAI-R	$M = 21.19 \pm 9.93$	$M = 17.14 \pm 7.35$	2.25	1	40	.14

M, mean; ±, SD; BMI, weight(kg) / size(m)^2; BDI-II, sum of 21 items measuring depression; STAI-R, sum of 20 items measuring anxiety trait. *p*-values were calculated using ANOVA (continuous variables) or chi-square (categorical variables); [†] these values correspond to χ^2 and not to *F,* as well as N and not a gl intra.

Comparison between groups in Tower of Hanoi

ANOVAs of performance indicators in ToH-1 and ToH-2

1   **Table 1** - ANOVAs of performance indicators in ToH-1 and ToH-2

		Experimental	Control	F	gl between	gl intra	p-value	η^2_p	β-1
ToH-1	Completed towers	$M = 2.3 \pm 0.57$	$M = 2.35 \pm 0.74$	0.57	1	38	.81	.001	.05
	Movements T3	$M = 7.22 \pm 0.94$	$M = 7.24 \pm 0.76$	0.03	1	37	.95	0	.05
	Time T3	$M = 16.42 \pm 7.57$	$M = 13.9 \pm 7.58$	1.07	1	37	.3	.02	.17
	Movements T4	$M = 33.95 \pm 14.19$	$M = 27.58 \pm 12.23$	2.19	1	36	.14	.05	.3
	Time T4	$M = 128.2 \pm 83.96$	$M = 83.65 \pm 76.02$	3.09	1	38	.08	.07	.4
ToH-2	Completed towers	$M = 2.8 \pm 0.41$	$M = 2.67 \pm 0.48$	0.9	1	39	.34	.9	.15
	Movements T3	$M = 7.2 \pm 0.89$	$M = 7.45 \pm 1.14$	0.59	1	38	.44	.01	.11
	Time T3	$M = 11.26 \pm 2.4$	$M = 11.55 \pm 3.5$	0.88	1	37	.76	.002	.06
	Movements T4	$M = 29.5 \pm 7.81$	$M = 24.57 \pm 11.1$	2.67	1	39	.11	.06	.35
	Time T4	$M = 62.32 \pm 24.57$	$M = 45.24 \pm 24.32$	7.44	1	38	.01**	.16	.75

ToH, Tower of Hanoi; T3, tower with 3 pieces; T4, tower with 4 pieces; M, mean; ±, SD; Although some contrasts were made with variables transformed with log10, the original means are shown to facilitate interpretation; p-values were calculated using ANOVA; η2p, effect size; β-1, power; **significant contrast to .01 level.

Evolution of emotions during protocol in both groups (control and experimental)

Mann-Whitney Test for SAM emotional dimensions in BL, after ToH-1 and after intervention

1   **Table 1** - Mann-Whitney Test for SAM emotional dimensions in BL, after ToH-1 and after intervention

		Experimental (N = 21)	Control (N = 21)	U	p-value	r
BL	Valence	$Mdn = 3$	$Mdn = 2$	165.5	.21	.18
	Activation	$Mdn = 4$	$Mdn = 4$	207.5	.71	.05
	Dominance	$Mdn = 3$	$Mdn = 3$	196.6	.7	.05
Post ToH-1	Valence	$Mdn = 3$	$Mdn = 3$	208	.95	.008
	Activation	$Mdn = 4$	$Mdn = 4$	183.5	.27	.16
	Dominance	$Mdn = 4$	$Mdn = 3$	188.5	.4	.12
Post Inter	Valence	$Mdn = 2$	$Mdn = 3$	80.5	$< .001$**	.56
	Activation	$Mdn = 4$	$Mdn = 3$	196.5	.51	.09
	Dominance	$Mdn = 3$	$Mdn = 3$	178.5	.25	.17

SAM, Self-Assessment Manikin; BL, Baseline; Post ToH-1, after the first Tower of Hanoi; Post Inter, after the intervention; *Mdn*, median; *p*-values were calculated using Mann-Whitney Test; *r*, effect size ($r = Z/\sqrt{N}$); **significant contrast to .01 level.

Table 4 **(on next page)**

Mann-Whitney Test for ZEMG in BL, after ToH-1 and after intervention

Table 4 - Mann-Whitney Test for ZEMG in BL, after ToH-1 and after intervention

1   **Table 4** - Mann-Whitney Test for ZEMG in BL, after ToH-1 and after intervention

		Experimental (N = 21)	Control (N = 21)	U	p-value	r
BL	ZEMG	*Mdn* = .11	*Mdn* = .12	183.5	.43	.17
Post ToH-1	ZEMG	*Mdn* = .17	*Mdn* = .16	203	.63	.10
Inter	ZEMG	*Mdn* = .32	*Mdn* = .29	132	.017*	.36

ZEMG, electromyography of the zygomatic major muscle; BL, Baseline; Post ToH-1, after the first Tower of Hanoi; Inter, intervention; *Mdn*, median; *p*-values were calculated using Mann-Whitney Test; *r*, effect size ($r = Z/\sqrt{N}$); *significant contrast to .05 level.