

Anxiety and Ironic Errors of Performance: Task Instruction Matters

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1 **Anxiety and Ironic Errors of Performance: Task instruction matters.**

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Abstract

We present five experiments that **examined** Wegner's (1994) theory of ironic processes of mental control in reactive motor performance under pressure for the first time. In Experiments 1, 2 and 4, we **conducted** specific examinations of the incidence of ironic error using a reactive motor task. In Experiments 3 and 5 we **provided** the first tests of whether task instruction moderates the incidence of ironic errors. The task required participants to react to a series of three primary color balls as they rolled down a chute under low- and high-anxiety conditions. **Measures of anxiety, heart rate, heart rate variability and muscle activity confirmed** the effectiveness of the anxiety manipulation. Experiments 1, 2 and 4 revealed that anxiety increased the number of ironic errors. In Experiments 3 and 5, we **provided** the first evidence that instructional interventions can reduce the incidence of anxiety-induced ironic performance errors in reactive motor tasks.

Keywords: Anxiety, ironic error, reactive task, instruction.

40 **Anxiety and Ironic Errors of Performance: Task instruction matters.**

41 The influence of anxiety on motor performance is central to performance psychology
42 (e.g., Woodman & Hardy, 2003). An extensive body of research devoted to determining the
43 nature of the anxiety-performance relationship has investigated theories such as the conscious
44 processing hypothesis (Masters, 1992), attentional control theory (Eysenck, Derakshan,
45 Santos, & Calvo, 2007), and catastrophe models (Hardy, Woodman, & Carrington, 2004).
46 However, these theories do not offer a mechanism via which anxiety can elicit precisely
47 *counter-intentional* errors. These errors are more severe than general errors, and represent the
48 worse possible scenario; that is, making the mistake one least wants to make (Janelle, 1999).
49 For example, a professional soccer player might instruct herself to avoid striking her penalty
50 wide of the post, before proceeding to do exactly that. One can explain such counter-
51 intentional errors through Wegner's (1994) theory of ironic processes of mental control. To
52 date this theory has received comparatively scant attention in the anxiety and motor
53 performance literature. This is surprising when one considers that the consequences of
54 counter-intentional errors in the motor performance domain, especially during tasks that
55 require rapid decisions and responses to ever-changing environmental stimuli (e.g.,
56 competitive sport, emergency services, and armed forces) can be severe. Indeed, we are
57 aware of no study applying ironic processes theory to the anxiety and performance
58 relationship, where the performance task is reactive in nature. We designed the experiments
59 in this manuscript to be the first to examine Wegner's theory of ironic processes of mental
60 control as an explanation for anxiety-induced counter-intentional errors during reactive motor
61 performance.

62 **Ironic Processes of Mental Control**

63 The foundation to Wegner's (1994,) theory is that so-called *operating* and *monitoring*
64 cognitive processes work together to produce our thoughts and actions. Specifically, an

65 intentional *operating process* carries out effortful regulation by consciously searching for,
66 and directing the person toward, mental contents that will yield an intended emotional state or
67 preferred outcome. Meanwhile an ironic *monitoring process* subconsciously searches for
68 signals of failure to achieve the desired state; the monitoring process is unconscious,
69 autonomous, and less demanding of mental effort. If this subconscious *monitor* identifies any
70 such failures then it reactivates the intentional *operating process*, which aims to bring about
71 the regulation by filling the mind with mental contents that are consistent with the desired
72 state.

73 Under normal circumstances, both processes work within one control system and
74 operate together as part of a feedback loop that provides effective mental control for the
75 individual (Wegner, 1994). However, under conditions where there is competition for
76 resources within our limited attentional capacity, such as when anxiety increases and burdens
77 our conscious attention with worrisome thoughts, there is limited cognitive space for the
78 effortful operating process to work effectively. Conversely, the functionality of the
79 monitoring process remains mainly unaffected due to its unconscious and uninterruptable
80 feature (i.e., once they materialize, they cannot be stopped), which yields a search for
81 components related to the failure of the intended state of mind or behavior. Due to this
82 diminishing effectiveness of the operating process, the monitoring process becomes relatively
83 more prevalent with increasing anxiety. More specifically, when the monitoring process
84 carries out a sweep for information on the to-be-avoided outcome (e.g., missing a kick to the
85 left of the post), it brings that very scenario into consciousness. If there is insufficient
86 capacity to re-engage the effortful operating process (e.g., when cognitive load, such as
87 anxiety, increases), this precisely counter-intentional error ensues (Wegner, 1994).
88 Consequently, the ironic monitoring process becomes more salient, and mental control

89 paradoxically starts working against itself by attending to those unwanted thoughts (Janelle,
90 1999).

91 **Irony Effects and Motor Performance: Existing Research**

92 Wegner, Ansfield and Pilloff (1998) provided some seminal evidence to support
93 Wegner's (1994) theory as an explanation for counter-intentional errors in the motor
94 performance domain. In one study, participants were asked to avoid moving a hand-held
95 pendulum along a particular axis (or simply to hold it steady without mention of a direction),
96 and in a second study they were asked not to hit golf ball past the glow spot. Consistent with
97 ironic processes of mental control theory, participants under mental (working memory) load
98 made more counter intentional-errors than those who were under no such load.

99 *Others have reported similar effects . For example, Dugdale and Eklund (2003)*
100 *investigated the incidence of ironic effects in a well-learned wobble board task. Skilled dancers*
101 *were required to balance on a wobble board for twenty seconds. Results revealed that*
102 *participants were less stable on the wobble board during trials where they were instructed*
103 *“don't wobble” compared to trials where they were instructed to “hold steady”. Further, in a*
104 *dart throwing task, Oudejans, Binsch, and Bakker (2013) demonstrated that the combination*
105 *of negatively worded instructions (“Be careful not to hit...”) and induced anxiety*
106 *significantly increased the number of darts landing in the specifically to-be-avoided zone*
107 *when compared to negatively worded instructions under low –anxiety conditions.*

108 Woodman, Barlow and Gorgulu (2015) also conducted experiments using a dart
109 board, which they divided into a central target (i.e., bull's-eye) and four equally sized
110 quadrants that extended out from the bulls-eye to the edge of the board. Participants were
111 instructed to aim for the bulls-eye while being particularly careful not to hit one of the the
112 four quadrants (e.g., top-right zone). Results revealed that performance deteriorated from
113 low- to high-anxiety conditions, and was characterized by an anxiety-induced increase in the

114 number of darts landing in the specifically to-be-avoided zone. Extending this work, Barlow,
115 Woodman, Gorgulu and Voyzey (2016) revealed that trait neuroticism moderates the
116 incidence of ironic errors during high-anxiety conditions. Individuals scoring relatively high
117 in neuroticism made more ironic errors than those who were relatively low in neuroticism
118 during football penalty shooting and dart throwing tasks. Finally, Gray, Orn and Woodman
119 (2017) revealed that experienced baseball pitchers displayed an anxiety-induced increase in
120 the number of balls pitched to an ironic (avoid) zone, while the kinematics of their technique
121 remained stable. This finding supports an ironic processes account of performance
122 breakdown over the explanations offered by self-focus theories (e.g., conscious processing
123 hypothesis; Masters, 1992), since self-focus theories predict that experienced performers
124 break down under anxiety by regressing to a more novice-like technique. Taken together
125 these findings provide encouraging support for Wegner's (1994) ironic processes theory as an
126 explanation for counter-intentional errors, including those that occur under anxiety, in motor
127 performance.

128 Two main shortcomings remain in the limited research to date. First, previous anxiety
129 and ironic effects research has considered only self-paced aiming movements, which
130 arguably comprise a limited portion of daily activities for the majority of people. Making
131 decisions and responses based on ever-changing stimuli in our environment occupies an
132 arguably larger portion of day-to-day life (Gorgulu, 2017). Moreover, time pressures inherent
133 in reactive tasks likely present an additional load (e.g., Wegner & Erber, 1992) that is absent
134 from self-paced tasks, and which could increase the likelihood of ironic errors in reactive
135 situations. Accordingly, research designed to scrutinize the predictions of ironic processes
136 theory in anxiety-laden reactive tasks is clearly warranted. Such research could encourage
137 coaches and psychologists to carefully consider ironic effects in addition to other more well-
138 known theories (e.g., attentional control theory; conscious processing hypothesis) when

139 designing interventions to prevent any adverse effects of anxiety on the performance of their
140 athletes. Currently, there is no test of ironic processes theory in reactive, externally paced
141 contexts.

142 Second, while recent research has identified conditions that might promote ironic
143 effects (e.g., Barlow, Woodman, Gorgulu, & Voyzey, 2016; Gray, Orn, & Woodman, 2017),
144 there has been no research dedicated to interventions aimed at reducing the incidence of
145 ironic errors. From a theoretical perspective, one method of reducing the likelihood of ironic
146 effects could be manipulating task instructions to ensure that the monitoring process is
147 searching for features that are more difficult to find than those sought by the operator
148 (Wegner, 1994). This could be especially effective in time-limited reactive motor tasks,
149 where one often faces the choice of either making a reactive movement or doing nothing. For
150 example, a cricket batsman has to decide whether to play a shot (i.e., an action) or to leave
151 the ball (i.e., an inaction), and against pace bowlers who deliver balls at speeds in excess of
152 80 mph, if this decision is not made in less than 500 ms then inaction is the default outcome
153 (Land & McLeod, 2000). Both action and inaction options in this example could require
154 varying levels of stimulus detection and stimulus identification stages of information
155 processing, but playing a shot would require an additional stage of response programming in
156 order to bring that behavior to fruition (Schmidt, 1980). Accordingly, one could argue that
157 playing a shot (i.e., action) represents a more cognitively demanding and time-consuming
158 process than leaving the ball (i.e., inaction). Thus, instructions tailored to burden the
159 monitoring process with a search for features consistent with actions rather than inactions
160 might help to reduce the likelihood of the monitor coming to the fore. Our experiments will
161 test this theoretically-driven prediction. **Importantly, if the predictions are supported, this**
162 **body of research will provide the first framework for athletes, coaches and psychologists for**
163 **using instructional interventions to mitigate ironic errors during reactive sports.**

188 the course of the Experiment 1 to Experiment 5. **All the experiments (Experiments 1-5) were**
189 **approved by the University research ethics committee.**

190 The GPower 3.1 (Faul, Erdfelder, Buchner, & Lang, 2013) calculation software
191 indicated that by adopting an alpha of .05 and a sample size of 53 the experiment was
192 powered at .80 to detect significant differences between conditions for effect sizes exceeding
193 $f = .20$ (i.e., small-to-medium size effects), by repeated measures analysis of variance (Cohen,
194 1992). While there are limited previous data upon which to base these calculations,
195 Woodman et al.'s (2015) test of ironic effects, adopting a similar design, revealed large
196 within-subject effects (η_p^2 's = .25). Accordingly, if similar effects were to emerge, the
197 samples we recruited in each of Experiment 1 through to Experiment 5 were more than
198 adequately powered to detect them.

199 **Design and Task.** We adopted a within-subject design; all participants completed a
200 reactive motor task under both low- and high-anxiety conditions. Participants sat adjacent to
201 the bottom end of a 174cm length black chute, raised 58cm above the ground at the lower
202 end, and set at a gradient of 27 degrees (Figure 1). Their task was to react to a series of red
203 and blue balls as each ball rolled down the chute. Specifically, using a table tennis bat held in
204 their dominant hand, participants either stopped the ball (i.e., they held the bat firm against
205 the end of the chute) or they allowed the ball to continue its trajectory off the end of the chute
206 to the ground (i.e., they moved the bat away from the chute end). **Before commencing each**
207 **condition** we told participants, "every ball you stop will go into a prize bucket, the red ball
208 will score you plus five points and the blue ball will score you minus five points. Obviously,
209 you should be very careful *not to stop* the blue balls! Please try to score as many points as
210 possible."

211 We secured a wooden board partition to the rear end of the chute in order to prevent
212 participants from seeing the color of the ball before it entered the chute. We concealed the top

213 92cm of the chute to allow for an appropriate choice response time (450ms) on seeing the ball
214 and its color. We determined this response time via pilot testing, which indicated that this
215 time ensured that participants had enough time to respond to ball color, but not so much as to
216 make the task easy. This response time is consistent with response times observed in previous
217 studies using similar choice-based tasks (Miller & Low, 2001).

218 Our task and instructions established a target ball and a non-target ball. In the above
219 example, the target ball is red, and the non-target ball is blue. **The instructions were modified**
220 **between participants to ensure that each ball color had an equal turn at being the target and**
221 **the non-target ball over the course of the experiment (i.e., fully counterbalanced).** Participants
222 responded to 30 balls (15 blue and 15 red) in both low-anxiety and high-anxiety conditions.
223 Details of the anxiety manipulation are in the Procedure section below.

224 ** INSERT FIGURE 1 ABOUT HERE **

225 **Measures**

226 **Anxiety.** Anxiety was measured using the Mental Readiness Form-3 (MRF-3; Krane,
227 1994). Participants were asked to express how they felt *right now* by responding to three 11-
228 point Likert-type scales. From left to right the scales are anchored at extremes with *not*
229 *worried* and *worried* for cognitive anxiety; and *not tense* and *tense* for somatic anxiety. Thus,
230 high scores represent high cognitive anxiety, and high somatic anxiety, respectively. The
231 MRF-3 is commonly used in anxiety and motor performance research (e.g., Barlow et al.,
232 2016; Robazza, Bortoli, & Nougier, 2000; Woodman & Davis, 2008; Woodman et al., 2015).

233 **Cardiac Activity.** To increase experimental rigor we also obtained some objective
234 psychophysiological indices of anxiety. We measured heart rate and heart rate variability via
235 electrocardiogram (ECG). We placed disposable silver/silver chloride electrodes (Blue
236 sensor, Ambu, St Ives, UK) on the right and left clavicals and on the lowest left rib. An
237 amplifier (Dual BioAmp, ADInstruments, Oxford, UK) connected to a 16-bit digital-to-

238 analog convertor (Powerlab, ADInstruments) and a computer running Chart 7 software (Chart
239 v7.3.7, ADInstruments), were used to acquire the ECG signals. Recordings were
240 subsequently imported into Kubios HRV version 2.2 software (Tarvainen, Niskanen,
241 Lipponen, Ranta-aho & Karjalainen, 2014) for offline analyses. Specifically, we computed
242 heart rate (beats per minute) as well as the root mean square of successive R-R intervals (r-
243 MSSD), as a time-domain measure of heart rate variability. We chose these measures because
244 increased heart rate and decreased r-MSSD have previously been associated with elevated
245 pre-competitive anxiety (e.g., Barlow et al., 2016; Mateo et al., 2011; Murray & Raedeke,
246 2008).

247 ***Muscle activity.*** As an additional objective measure of arousal and tension associated
248 with anxiety, we recorded muscle activity in the dominant forearm. We placed two
249 silver/silver chloride electrodes (Neuroline 720, Ambu, St Ives, UK) 2 mm apart, over the
250 belly of the extensor carpi radialis muscle, and a reference electrode (Blue sensor, Ambu, St
251 Ives, UK) on the left clavicle. The signal was amplified (Dual BioAmp, ADInstruments,
252 Oxford, UK), filtered (50-500 Hz) and then processed at a sample rate of 1000 Hz by a 16-bit
253 PowerLab data acquisition system (ADInstruments, Oxford, UK) connected to a computer
254 running Chart 7 software (ADInstruments, Oxford, UK). We chose the extensor carpi radialis
255 based on pilot testing and previous research implicating this muscle in anxiety-induced
256 increases in grip force during motor tasks (e.g., Cooke et al., 2010; Smith et al., 2000).

257 ***Performance.*** To measure performance we counted the number of target and non-
258 target balls that were stopped in each condition. An electronic buzzer system was connected
259 to the lower end of the apparatus to allow us to determine clearly whether a ball was
260 successfully stopped. The start position for each trial required participants to hold the bat
261 flushes to the end of the chute. This depressed the buzzer switch and ensured that the buzzer
262 was silenced. Any subsequent movement of the bat away from the end of the chute activated

263 the switch and caused the buzzer to sound. Participants were told that the buzzer had to
264 remain silent for a stop to be deemed successful. This criterion prevented participants from
265 making multiple bat movements, such as initially moving the bat away from the end of the
266 chute, and then returning it in time to stop the ball. The range of scores was 0-15 for each
267 ball, where the best score would be 15 for the target balls, and 0 for the non-target balls.

268 **Procedure.** Each participant individually attended a single laboratory session lasting
269 approximately 60 minutes. Upon entry to the laboratory, we first briefed participants about
270 the experiment, and then we used exfoliant gel (NuPrep, Weaver, Aurora, USA) and alcohol
271 wipes (Uni-Wipe, Universal, Middlesex, UK) to prepare the electrode sites for
272 psychophysiological recordings. Next, we affixed the electrodes and checked the signals, and
273 then we described the task and instructions as detailed in the Design and Task section above.
274 Participants then completed a familiarization block, comprising 10 balls (5 red, 5 blue)
275 delivered in a random order. This allowed participants to become accustomed to the nature of
276 the task and allowed the experimenter to verify that participants understood the instructions
277 before the main experimental conditions.

278 After the familiarization block, participants were told that they would now complete
279 the same task for two more blocks of trials, containing 30 balls each. They were then asked to
280 complete the MRF-3, were reminded of the instructions, and then the 30-ball low-anxiety
281 condition commenced. The balls (15 red and 15 blue) were delivered in an order that was
282 randomized prior to the start of the experiment, and then fixed as the same random order for
283 all participants. The instructions were repeated half way through this condition. After the
284 final ball, participants were then given a 5-minute break.

285 After the break, the experimenter provided participants with additional instructions
286 designed to increase their anxiety, ahead of the final high-anxiety block. Specifically, we told
287 participants that their performance in this final block would be recorded as part of a

288 competition and that we would display all scores on a television screen located in a busy
289 indoor thoroughfare of the university. We told them that the winner of the competition (i.e.,
290 the highest number of points scored) would receive a £100 (approx. US\$125) prize, and that
291 the second and third placed participants would receive prizes of £30 and £20, respectively.
292 Participants were then asked to complete the MRF-3, they were reminded of their
293 instructions, and then the 30-ball high-anxiety condition commenced. Once again, the balls
294 (15 red and 15 blue) were delivered in an order that was randomized prior to the start of the
295 experiment, and then fixed as the same random order for all participants. Also consistent with
296 the low-anxiety condition, we reminded participants of their instructions half way through the
297 block. We decided that the low-anxiety condition should always precede the high-anxiety
298 condition to minimize any anxiety carryover effect (cf. Hardy & Hutchinson, 2007;
299 Woodman et al., 2015). On completion of the high-anxiety block, the participants were
300 thanked for their participation and fully debriefed. They were also informed that the
301 researcher would be in touch on completion of data collection if they had won a cash prize.

302 **Data Reduction.** The psychophysiological measures were obtained continuously
303 throughout the experiment. For our analyses, we calculated heart rate and heart rate
304 variability from 30 seconds before the delivery of the first ball until 30 seconds after the
305 delivery of the final ball in each condition. Ball delivery was identified by a switch affixed to
306 the top of the chute, which triggered each time a ball was released, and was interfaced with
307 the data-acquisition system to place an event marker in the Chart 7 software that was
308 acquiring the psychophysiological recordings. To analyze muscle activity, we rectified the
309 electromyographic signal and then averaged activity across the trials for each condition
310 during the final second prior to ball release. We focused our analyses here because this was
311 the time when participants were in the ready position gripping the bat at the end of the chute
312 and preparing for the ball to be released. It was expected that any anxiety-induced increases

313 in tension would manifest as an increase in grip force (and the associated forearm muscle
314 activity) during these final seconds of motor preparation (e.g., Smith et al., 2000). Due to
315 excessive artifacts, the electrocardiogram and the electromyogram recordings were
316 unscorable for twelve and six participants, respectively. Occasional missing data are reflected
317 in the degrees of freedom reported in the results section.

318 **Statistical Analyses.** Data were screened for outliers (none were identified in
319 Experiments 1-5) and a normal distribution was confirmed prior to analyses taking place. We
320 conducted paired-samples *t*-tests to examine the effectiveness of our anxiety manipulation,
321 and repeated measures ANOVA to examine the effects of anxiety on performance. The
322 results of univariate tests are reported with the Greenhouse-Geisser correction procedure
323 applied for analyses that violated the sphericity of variance assumption.

324 Results

325 **Anxiety manipulation.** Paired samples *t*-tests were conducted to analyse our self-
326 report and psychophysiological data. The results are summarized in Table 1. They confirm
327 the effectiveness of the anxiety manipulation. Specifically, we observed the expected
328 increases in cognitive anxiety, somatic anxiety, muscle activity and heart rate, along with the
329 expected decrease in r-MSSD, from the low- to the high-anxiety condition.

330 ** INSERT TABLE 1 ABOUT HERE **

331 **Performance.** A 2 (condition: low anxiety, high anxiety) \times 2 (ball: target, non-target)
332 fully repeated measures ANOVA was employed to analyze performance. This yielded a
333 significant Condition \times Ball interaction, $F(1, 52) = 27.02, p < .001, \eta_p^2 = .34$. Subsequent
334 paired sample *t* tests revealed that participant scores comprised fewer target balls, $t(52) =$
335 $2.45, p = .018$, and more non-target balls, $t(52) = 5.19, p < .001$, in the high-anxiety
336 compared to the low-anxiety condition (see Figure 2).

337
338

** INSERT FIGURE 2 ABOUT HERE **

339 Discussion

340 The primary purpose of Experiment 1 was to examine Wegner's (1994) theory of
341 ironic processes of mental control in an externally paced motor task. As hypothesized,
342 participants caught significantly more of the forbidden non-target balls in the high-anxiety
343 condition compared to the low-anxiety condition. This finding can be interpreted in support
344 of Wegner's (1994) theory. The increased feelings of worry in the high-anxiety condition
345 could have consumed some of the conscious attentional resources required by the operating
346 process, thereby compromising its effectiveness, and allowing the normally unconscious
347 monitoring process to come to the fore.

348 In addition to making more errors on the non-target balls, participants also made more
349 errors on the target balls (i.e., caught fewer of them) when anxiety was increased. This
350 pattern of worse performance on both target and non-target balls under anxiety represents a
351 worst-case scenario in terms of limiting the number of points that each participant accrued.
352 Moreover, it is compatible with previous ironic effects research. For example, Woodman and
353 colleagues (2015) reported fewer darts hitting the target, and more darts hitting the to-be-
354 avoided zone, under the high-anxiety condition in their dart throwing study. However, due to
355 the increased errors on the target balls, one could argue that our findings reflect general
356 performance deterioration rather than a uniquely ironic breakdown during the high-anxiety
357 condition. Specifically, it is possible that attentional resources were overloaded (e.g., Eysenck
358 et al., 2007) causing an increase in all types of errors (e.g., target and non-target), rather than
359 specifically priming ironic errors, as would be predicted by Wegner (1994). In Experiment 2
360 we introduced the third ball in an attempt to examine this possibility.

361 Experiment 2

362 The aim of Experiment 2 was twofold: (a) to replicate the findings of Experiment 1
363 with a new sample to increase reliability and methodological rigor, and (b) to examine the

364 relative merits of ironic processes versus an attentional overload account of performance
365 breakdown under anxiety. In brief, attention-based models of performance (e.g., Eysenck et
366 al., 2007) contend that we possess a limited attentional capacity, and that anxiety serves to
367 consume attentional resources. Consequently, increasing anxiety reduces goal-driven
368 attention, and can impair both processing efficiency and performance effectiveness (Eysenck
369 & Calvo, 1992; Eysenck et al., 2007). While these theories have some overlap with ironic
370 processes theory, a key distinction is that anxiety-induced performance impairments
371 according to the former would be characterized by inefficient processing (e.g., slowed
372 responses) and a range of general errors, while the latter would predict that impairment would
373 be characterized by errors that are specifically ironic in nature (Wegner, 1994). Our
374 comparison of these competing theoretical accounts of performance was permitted by the
375 addition of a third ball, which had no instruction attached. Accordingly, we had a target ball,
376 a to-be-avoided non-target (ironic error) ball, and a non-target (non-error) ball. Based on the
377 view that stopping balls (i.e., inaction in the current task) represents an easier outcome than
378 programming an action in time-limited reactive tasks (cf. Land & McLeod, 2000; Schmidt,
379 1980), we formulated alternate predictions about the non-target (non-error) ball. In support of
380 an attentional overload account of our findings (e.g., Eysenck et al., 2007), one would expect
381 that the number of non-target (non-error) balls stopped would increase from low- to high-
382 anxiety conditions. This would reflect the high-anxiety condition combining with any
383 confusion that may be caused by the third ball, to prompt attentional overload, slowing
384 processing down, and making the default inaction (i.e., stopping the ball) more likely.
385 Alternatively, in support of Wegner's (1994) ironic processes of mental control theory, we
386 hypothesized that there would be an anxiety-induced increase in the number of non-target
387 (ironic error) balls stopped, while the number of non-target (non-error) balls stopped would
388 remain unchanged. Such a finding would suggest that any anxiety-induced performance

389 impairment can be specifically attributed to an increase in ironic errors, rather than a more
390 general slowing down and increased likelihood of inaction under pressure.

391 **Method**

392 **Participants.** The sample comprised 40 participants (21 men, 19 women; $M_{\text{age}} =$
393 22.65, $SD = 6.3$; 34 right handed, 6 left handed). We recruited participants according to the
394 same criteria as in Experiment 1. We excluded participants who had already taken part in
395 Experiment 1 to ensure that all participants had no previous experience with the task.
396 Informed consent obtained from all participants.

397 **Design and Task.** We adopted the same two-condition (low-anxiety; high-anxiety)
398 within-subject design, and the same reactive motor task as detailed in Experiment 1, but with
399 a modification. Specifically, we introduced a third ball color (yellow) and told participants
400 “every ball you stop will go into a prize bucket, the red ball will score you plus five points
401 and the blue ball will score you minus five points, obviously you should be very careful not
402 the stop blue balls! Please try to score as many points as possible.” No instruction or point
403 value was attached to the third ball color. These instructions were designed to create a target
404 ball, a non-target (ironic error) ball, and a non-target (non-error) ball. In the above example,
405 the target ball is red, the non-target (ironic error) ball is blue and the non-target (non-error)
406 ball is yellow. The instructions were modified between participants to ensure that each ball
407 color had an equal turn at being the target, the non-target (ironic error), and the non-target
408 (non-error) over the course of the experiment (i.e., fully counterbalanced). Participants
409 reacted to 45 balls (15 blue, 15 red and 15 yellow) in both low-anxiety and high-anxiety
410 conditions.

411 **Measures**

412 **Manipulation Check.** We measured anxiety, cardiac activity and muscle activity
413 using the same methods as described in Experiment 1.

414 **Performance.** To measure performance we counted the number of the target, non-
415 target (ironic error) and non-target (non-error) balls that were stopped, in each condition. The
416 same electronic buzzer system as described in Experiment 1 was used to determine whether a
417 ball was successfully stopped. The range of scores was 0-15 for each ball, where the best
418 score would be 15 for the target balls, and 0 for the non-target (ironic error) balls. The
419 number of non-target (non-error) balls stopped had no bearing on the number of points
420 accrued so was of little performance-related consequence to the participants.

421 **Procedure.** The procedure and anxiety manipulation were largely the same as
422 described in Experiment 1. The only difference is that the familiarization block contained 15
423 balls (5 blue, 5 red, 5 yellow) instead of 10, and the anxiety conditions each contained 45
424 balls (15 blue, 15 red, 15 yellow) instead of 30. This increase in a number of balls reflects the
425 addition of the third ball color in this experiment. The laboratory session lasted
426 approximately 75 minutes.

427 **Data Reduction and Statistical Analyses.** Measures of heart rate, r-MSSD and
428 muscle activity were computed from the continuous recordings using identical methods to
429 those described in Experiment 1. Due to excessive artefacts, the electrocardiogram recordings
430 were unscorable for six participants. Occasional missing data are reflected in the degrees of
431 freedom reported in the results section. Statistical analyses were performed using the same
432 strategy as described in Experiment 1.

433 **Results**

434 **Anxiety manipulation.** Paired samples *t*-tests were conducted to analyze the self-
435 report and psychophysiological data. The results confirm the effectiveness of the anxiety
436 manipulation. Specifically, we observed the expected **significant** increases in cognitive
437 anxiety and somatic anxiety, **and a non-significant trend for increases** in muscle activity and

438 heart rate, along with the expected **significant** decrease in, r-MSSD, from the low- to the
439 **high-anxiety condition** (see Table 2).

440 ** INSERT TABLE 2 ABOUT HERE **

441 **Performance.** We performed a 2 (condition: low anxiety, high anxiety) \times 3 (ball:
442 target, non-target ironic error, non-target non-error) fully repeated measures ANOVA to
443 analyze performance. Results revealed no significant main effect for anxiety, $F(1, 39) = 1.80$,
444 $p = .19$, $\eta_p^2 = .04$, a significant main effect for ball $F(2,78) = 34.54$, $p < .001$, $\eta_p^2 = .47$, and a
445 significant condition \times ball interaction, $F(2, 78) = 10.03$, $p < .001$, $\eta_p^2 = .20$. Follow-up
446 paired sample t tests indicated that participant scores comprised fewer target balls, $t(39) =$
447 2.44 , $p = .019$ and more non-target (ironic error) balls, $t(39) = 3.18$, $p < .001$, in the high-
448 anxiety compared to low-anxiety condition. The number of non-target (non-error) balls
449 stopped did not change $t(39) = 1.39$, $p = .17$ (see Figure 3).

450 ** INSERT FIGURE 3 ABOUT HERE **

451 Discussion

452 The primary aim of Experiment 2 was to examine the relative merits of an ironic
453 process versus an attentional overload account of performance breakdown under anxiety. In
454 accord with Wegner's (1994) theory of ironic processes of mental control, we found that
455 participants significantly stopped more non-target (ironic error) balls in the high-anxiety
456 condition than in the low-anxiety condition, while the number of non-target (non-error) balls
457 stopped was unchanged. These data favour an ironic processes explanation rather than an
458 attentional overload explanation for the impaired performance under anxiety observed in
459 Experiments 1 and 2. Specifically, participants were more likely to do the thing they were
460 specifically instructed not to do (i.e., to stop the non-target ironic error balls). The number of
461 non-target (non-error) balls stopped remained stable, which is important because such a
462 pattern precludes a uniform attentional overload account of the results. That is, participants

463 were not simply uniformly slowed under anxiety. Having established support for Wegner's
464 theory as an explanation for anxiety-induced performance impairments in reactive tasks, a
465 logical next applied step is to focus on methods of reducing the likelihood of such errors.
466 Those methods are the focus of Experiment 3.

467 **Experiment 3**

468 Presently, there are no studies that focus on instructional interventions designed to
469 reduce the likelihood of ironic errors during motor tasks. Instructions that burden the
470 monitoring process with a relatively more difficult search than the operator could achieve this
471 goal. Importantly, in Experiments 1 and 2, we instructed participants to “be particularly
472 careful not to stop” the non-target (ironic error) ball. In this case, the operating process would
473 have been searching for features associated with *not stopping* (i.e., an action; to move the bat
474 out of the way before the ball reached the end of the chute), while the monitor would have
475 been searching for features associated with stopping (i.e., an inaction; holding the bat firm).
476 Given that action requires more programming than inaction in time-limited reactive tasks
477 (e.g., Land & McLeod, 2000; Schmidt, 1980), we seemingly gave the monitoring process an
478 easier search than we gave the operator in Experiments 1 and 2, maximizing the likelihood of
479 ironic errors under anxiety. To reverse this in Experiment 3, we instructed participants to “be
480 particularly careful not to let [the non-target (ironic error) balls] go.” With this revised
481 instruction, the operator should have a comparatively easy search for inaction (i.e., stopping)
482 while the monitoring process has the more difficult search for features associated with an
483 action (i.e., letting go). Accordingly, for our theoretically-driven argument to be supported,
484 we hypothesized that the anxiety-induced increase in ironic errors observed in Experiment 1
485 and 2 would be absent in Experiment 3.

486 **Method**

487 **Participants.** The sample comprised 41 individuals (24 men, 17 women; $M_{\text{age}}= 22.63$,
488 $SD= 3.92$; 39 right handed, 2 left handed). We recruited participants according to the same
489 criteria as in Experiment 1. We excluded participants who had already taken part in
490 Experiments 1 or 2 to ensure that all participants had no previous experience with the task.

491 **Design and Task.** We adopted the same two-condition (low-anxiety; high-anxiety)
492 within-subject design, and the same reactive motor task as detailed in Experiment 2, but we
493 changed the instruction. Specifically, we told participants “every ball you let go will go into a
494 prize bucket, the red ball will score you plus five points and the blue ball will score you
495 minus five points, obviously you should be very careful not to let the blue balls go! Please try
496 to score as many points as possible.” As per Experiment 2, no instruction or point value was
497 attached to the third ball color. Participants reacted to 45 balls (15 blue, 15 red and 15
498 yellow) in both low-anxiety and high-anxiety conditions.

499 **Measures**

500 **Manipulation Check.** We measured anxiety, cardiac activity and muscle activity
501 using the same methods as described in Experiments 1 and 2.

502 **Performance.** To measure performance we counted the number of target, non-target
503 (ironic-error), and non-target (non-error) balls that were let go, in each condition. The same
504 electronic buzzer system as described in Experiments 1 and 2 was used. However, this time
505 participants were informed that the buzzer must sound continuously from the point at which
506 the bat is removed, and must sound before the ball strikes the bat, for a let go to be deemed
507 successful. Once again, the range of scores was 0-15 for each ball, where the best score
508 would be 15 for the target balls, and 0 for the non-target (ironic error) balls.

509 **Procedure.** The procedure was identical to that reported in Experiment 2.

510 **Data Reduction and Statistical Analyses.** Heart rate, r-MSSD and muscle activity
511 were determined in the same way as reported in Experiments 1 and 2. All files were useable

512 in this experiment; hence, there were no missing data. Statistical analyses were performed
513 using the same strategy as described in Experiments 1 and 2.

514 **Results**

515 **Anxiety Manipulation.** Paired samples *t*-tests were conducted to analyse our self-
516 report and psychophysiological data. The results are summarised in Table 3. Once again, they
517 confirm the effectiveness of our anxiety manipulation.

518 ** INSERT TABLE 3 ABOUT HERE **

519 **Performance.** We conducted a 2 (condition: low anxiety, high anxiety) \times 3 (ball:
520 target, non-target ironic error, non-target non-error) fully repeated-measures ANOVA to
521 analyze performance. Results revealed no significant main effect for anxiety, $F(1, 40) = 1.33$,
522 $p = .25$, $\eta_p^2 = .03$, a significant main effect for balls, $F(2, 80) = 50.08$, $p < .001$, $\eta_p^2 = .55$, and
523 no significant anxiety \times ball interaction $F(2, 80) = 0.29$, $p = .75$, $\eta_p^2 = .01$. Participants let
524 more target balls go than non-target (non-error) and non-target (ironic error) balls; the
525 number of times these latter two balls were let go did not differ (see Figure 4). This reflects
526 consistent and relatively good performance across both anxiety conditions.

527 ** INSERT FIGURE 4 ABOUT HERE **

528 **Discussion**

529 Experiment 3 tested our theoretically-driven prediction that instructions which give
530 the monitoring process a more difficult search than the operator may reduce the likelihood of
531 ironic errors occurring. The results of Experiment 3 represent the first support for this
532 hypothesis. Specifically, by instructing participants “not to let [the non-target (ironic error)
533 balls] go”, we provided the operating process with a comparatively easy search for inaction
534 (i.e., stopping) while the monitoring process had the more difficult search for features
535 associated with an action (i.e., letting go). Results confirmed that there was no deterioration
536 in performance and no increase in ironic errors during the high-anxiety condition. This is

537 despite the anxiety manipulation being equal in strength to those that did impair performance
538 in Experiments 1 and 2. Accordingly, Experiment 3 provides the first evidence that
539 instructional interventions can reduce the incidence of anxiety-induced ironic performance
540 errors in reactive motor tasks. Although these results are encouraging, one could argue that
541 the data in support of our hypotheses that ironic errors occur during reactive motor tasks
542 (Experiment 2) and can be alleviated by instructional interventions (Experiment 3) would be
543 more compelling had the non-target (non-error) ball used in these experiments been a non-
544 target (error) ball. Specifically, we could have attached a negative consequence to the third
545 ball, but of less severity than the negative consequence already attached to the ironic error
546 ball. Doing so would have given participants a clear target ball and two forms of error balls,
547 the severe “ironic error” ball, and a less severe “other error” ball. Compelling support for
548 Wegner’s theory would be revealed if anxiety increases errors on the “ironic error” ball only
549 in this dual error configuration. This more stringent design was adopted in Experiment 4.

550 **Experiment 4**

551 The aim of Experiment 4 was to replicate the findings of Experiment 2 with a new
552 sample to increase reliability and methodological rigor. The latter aim was permitted by the
553 addition of a point value for the third ball. The purpose in Experiment 4 was to differentiate
554 ironic from non-ironic error by clearly establishing two error balls. To do so, we introduced a
555 new scoring system, awarding plus and minus five points for the target ball, and the non-
556 target (ironic error) ball, respectively, and minus two points for the non-target (other error)
557 ball. With this revised scoring system, in support of Wegner’s (1994) ironic processes of
558 mental control theory and in accord with Experiment 2, we hypothesized that there would be
559 an anxiety-induced increase in the number of non-target (ironic error) balls stopped, while the
560 number of non-target (other error) balls stopped should remain unchanged.

561 **Method**

562 **Participants.** The sample comprised 24 individuals (17 men, 7 women; $M_{age}= 25.58$,
563 $SD= 4.52$; 20 right handed, 4 left handed). We excluded participants who had already taken
564 part in previous experiments of this study to ensure that all participants had no previous
565 experience with the task.

566 **Design and Task.** We adopted the same two-condition (low-anxiety; high-anxiety)
567 within-subject design, and the same reactive motor task as detailed in Experiments 1, 2 and 3
568 but with a modification. Specifically, we told participants “every ball you stop will go into a
569 prize bucket, the red ball will score you plus five points, the yellow ball will score you minus
570 two points, and the blue ball will score you minus five points. Obviously you should be very
571 careful not to stop the blue balls! Please try to score as many points as possible.” These
572 instructions were designed to create a target ball, a non-target (ironic error) ball, and a non-
573 target (other-error) ball. In the above example, the target ball is red, the non-target (ironic
574 error) ball is blue and the non-target (other-error) ball is yellow. The instructions were
575 modified between participants to ensure that each ball color had an equal turn at being the
576 target, the non-target (ironic error), and the non-target (non-error) over the course of the
577 experiment (i.e., fully counterbalanced). Participants reacted to 45 balls (15 blue, 15 red and
578 15 yellow) in both low-anxiety and high-anxiety conditions.

579 **Measures**

580 **Manipulation Check.** We measured anxiety, cardiac activity and muscle activity
581 using the same methods as described in Experiments 1, 2 and 3.

582 **Performance.** To measure performance we counted the number of target, non-target
583 (ironic-error), and non-target (other-error) balls that were stopped, in each condition. The
584 same electronic buzzer system as described in Experiments 1, 2 and 3 was used to determine
585 whether a ball was successfully stopped. The range of scores was 0-15 for each ball, where

586 the best score would be 15 for the target balls, and 0 for the non-target (ironic error) and the
587 non-target (other error) balls.

588 **Procedure.** The procedure was identical to that reported in Experiments 1, 2 and 3.

589 **Data Reduction and Statistical Analyses.** Heart rate, r-MSSD and muscle activity
590 were determined in the same way as reported in Experiments 1, 2 and 3. Due to excessive
591 artifacts, the electrocardiogram and the electromyogram recordings were unscorable for four
592 and two participants, respectively. Occasional missing data are reflected in the degrees of
593 freedom reported in the results section. Statistical analyses were performed using the same
594 strategy as described in Experiments 1, 2 and 3.

595 **Results**

596 **Anxiety Manipulation.** Paired samples *t*-tests were conducted to analyse our self-
597 report and psychophysiological data. The results are summarised in Table 4. They again
598 endorse the effectiveness of our anxiety manipulation with all variables changing in the
599 expected direction. **All the changes were statistically significant with the exception of muscle**
600 **activity.**

601 ** INSERT TABLE 4 ABOUT HERE **

602 **Performance.** We conducted a 2 (condition: low anxiety, high anxiety) \times 3 (ball:
603 target, non-target ironic error, non-target other-error) fully repeated-measures ANOVA.
604 Results revealed no significant main effect for anxiety $F(1, 23) = .44, p = .51, \eta_p^2 = .01$, a
605 significant effect for balls, $F(2, 46) = 41.26, p < .001, \eta_p^2 = .64$, and a significant anxiety \times
606 ball interaction $F(2, 46) = 10.32, p = .001, \eta_p^2 = .31, \epsilon = .68$. Follow-up paired sample *t* tests
607 indicated that participant scores comprised fewer target balls, $t(23) = 2.65, p = .01$, and more
608 non-target (ironic error) balls, $t(23) = 3.55, p < .001$, in the high-anxiety compared to low-
609 anxiety condition. The number of non-target (other-error) balls stopped did not change $t(23)$
610 $= 1.30, p = .20$ (see Figure 5).

611 ** INSERT FIGURE 5 ABOUT HERE **

612 **Discussion**

613 The primary aim of Experiment 4 was to replicate the findings of Experiment 2 to
614 increase the reliability of our conclusions, as the replication would give a greater confidence
615 in the results and thus better support for Wegner's (1994) theory of ironic processes. We also
616 sought to increase methodological rigor from Experiment 2 by revising the task instructions
617 in order to clearly establish two error balls, and test whether anxiety elicited an increase in
618 errors on the severe "ironic error" balls only.

619 Results from Experiment 4 provide support for the results of Experiment 2 and
620 therefore Wegner's (1994) theory of ironic processes of mental control. In Experiment 4,
621 participants significantly stopped more non-target (ironic error) balls in the high-anxiety
622 condition compared to the low-anxiety condition. Importantly, the number of non-target
623 (other-error) balls stopped was unchanged across anxiety conditions. Thus, Experiment 4 was
624 able to differentiate ironic from non-ironic error and thereby add more compelling support for
625 the conclusion that anxiety can elicit a specific increase in ironic errors during reactive motor
626 tasks. We have already articulated that instructional interventions could reduce susceptibility
627 to these errors in Experiment 3, but to add further confidence to this conclusion, a next
628 logical step would be to test the effectiveness of the instructions used in Experiment 3, with
629 the dual-error scoring system used in Experiment 4. This was our aim in Experiment 5.

630 **Experiment 5**

631 The purpose of our final experiment was to replicate the findings from Experiment 3
632 in order to support our theoretically driven argument for instructional interventions to reduce
633 the likelihood of ironic performance errors during reactive tasks. In that experiment we
634 argued that instructions that load the monitoring process with a relatively more difficult
635 search than the operator should help reduce the likelihood of specifically ironic errors.

636 However, we concede that in Experiment 3 we only had one obvious error ball (i.e., ironic
637 error ball, minus five points). In Experiment 4 we modified our scoring system to establish
638 two types of error (*ironic error*, minus five points; and *other error*, minus two points). We
639 adopted this dual-error scoring system in Experiment 5. If our instructional intervention (i.e.,
640 giving the monitor a more difficult task) really does help alleviate specifically ironic errors,
641 we hypothesized that the anxiety-induced increase in ironic errors that we observed in
642 Experiment 4 should be absent in Experiment 5.

643 **Method**

644 **Participants.** The sample comprised 23 individuals (16 men, 7 women; $M_{\text{age}}= 23.43$,
645 $SD= 3.62$; 23 right handed). We recruited participants according to the same criteria as in
646 Experiment 1. We excluded participants who had already taken part in Experiments 1, 2, 3
647 and 4 to ensure that all participants had no previous experience with the task.

648 **Design and Task.** We adopted the same two-condition (low-anxiety; high-anxiety)
649 within-subject design, and the same reactive motor task as detailed in Experiments 1, 2, 3 and
650 4 but we modified the instruction. Specifically, we told participants “every ball you let go
651 will go into a prize bucket, the red ball will score you plus five points, the yellow ball will
652 score you minus two points, and the blue ball will score you minus five points. Obviously,
653 you should be very careful not to let the blue balls go! Please try to score as many points as
654 possible.” Participants reacted to 45 balls (15 blue, 15 red and 15 yellow) in both low-anxiety
655 and high-anxiety conditions.

656 **Measures**

657 **Manipulation Check.** We measured anxiety, cardiac activity and muscle activity
658 using the same methods as described in Experiments 1, 2, 3 and 4.

659 **Performance.** To measure performance we counted the number of target, non-target
660 (ironic-error), and non-target (non-error) balls that were let go, in each condition. The same

661 electronic buzzer system as described in Experiments 1, 2, 3 and 4 was used. However, this
662 time participants were informed that the buzzer must sound continuously from the point at
663 which the bat is removed, and must sound before the ball strikes the bat, for a let go to be
664 deemed successful. Once again, the range of scores was 0-15 for each ball, where the best
665 score would be 15 for the target balls, and 0 for the non-target (ironic error) and non-target
666 (other error) balls.

667 **Procedure.** The procedure was identical to that reported in Experiment 4.

668 **Data Reduction and Statistical Analyses.** Heart rate, r-MSSD and muscle activity
669 were determined in the same way as reported in Experiments 1, 2, 3 and 4. Due to excessive
670 artifacts, the electrocardiogram and the electromyogram recordings were unscorable for three
671 and two participants, respectively. Occasional missing data are reflected in the degrees of
672 freedom reported in the results section. Statistical analyses were performed using the same
673 strategy as described in Experiments 1, 2, 3 and 4.

674 **Results**

675 **Anxiety Manipulation.** Paired samples *t*-tests were conducted to analyse our self-
676 report and psychophysiological data. The results are summarised in Table 5. They again
677 endorse the effectiveness of our anxiety manipulation with **all variables changing in the**
678 **expected direction. All changes were significant with the exception of muscle activity.**

679 ** INSERT TABLE 5 ABOUT HERE **

680 **Performance.** We conducted a 2 (condition: low anxiety, high anxiety) \times 3 (ball:
681 target, non-target ironic error, non-target non-error) fully repeated-measures ANOVA to
682 analyze performance. Results revealed no significant main effect for anxiety, $F(1, 22) = .12$,
683 $p = .72$, $\eta_p^2 = .006$, a significant main effect for ball, $F(2, 44) = 38.87$, $p < .001$, $\eta_p^2 = .63$, $\epsilon =$
684 $.69$, and no significant anxiety \times ball interaction $F(2, 44) = 1.71$, $p = .19$, $\eta_p^2 = .07$.

685 Participants let more target balls go than non-target (other-error) and non-target (ironic error)

686 balls; the number of times these latter two balls were let go did not differ (see Figure 6). This
687 reflects consistent and relatively good performance across both anxiety conditions since the
688 instructions were changed from Experiment 4 to Experiment 5.

689 ** INSERT FIGURE 6 ABOUT HERE **

690 **Discussion**

691 The primary purpose of Experiment 5 was to replicate the Experiment 3 and thereby
692 provide more compelling evidence that instructional interventions can mitigate against
693 anxiety-induced increases in specifically ironic performance errors. Results confirmed no
694 deterioration in performance and no increase in ironic errors during the high-anxiety
695 condition. The findings of Experiments 3 and 5 thus supported our theoretically driven
696 argument that burdening the monitor with a relatively more difficult search than the operator
697 can prevent ironic errors. This represents the first support for instructional interventions to
698 reduce ironic errors during reactive motor performance.

699 **General Discussion**

700 We conducted five experiments to address two limitations from the meagre extant
701 literature examining Wegner's (1994) ironic processes of mental control in a performance
702 setting. Specifically, we provide the first examination of ironic effects theory in an externally
703 paced task under low- and high-anxiety conditions. Moreover, we report the first
704 manipulation of task instruction designed to reduce the incidence of ironic performance
705 errors.

706 In support of Wegner's (1994) theory, in Experiment 1, results demonstrate that
707 participants made significantly more ironic errors when anxious. To our knowledge, this is
708 the first evidence to support ironic processes theory as an explanation for performance
709 breakdown under anxiety during reactive motor tasks. The results of Experiments 2 and 4
710 confirmed these findings and – by the addition of a third ball color (Experiment 2) and an

711 additional type of error (Experiment 4) – revealed that any ironic performance errors were
712 unlikely to be accounted for simply by an indiscriminate anxiety-induced performance
713 decline (Woodman et al., 2015). Taken together, the results of these three experiments
714 suggest that instructions that prime the monitoring process with an easier search than the
715 operating process increase the prevalence of ironic errors. This is due to anxiety increasing
716 strain on our limited attentional capacity, preventing actions being programmed fast enough
717 to stop the forbidden error from occurring. Time-pressure concerns are particularly relevant
718 to reactive motor tasks. For instance, in the present experiments, participants had just 450 ms
719 for their action to be programmed in order for them to successfully get out of the non-target
720 ironic error ball's path. With anxiety increasing the burden on the limited attentional system
721 during the high-anxiety condition, successful operating process performance was more
722 difficult to accomplish in the available time, and hence the monitor was more likely to come
723 to the fore.

724 Crucially, the results of Experiments 3 and 5 offer a solution to the ironic performance
725 problem. Specifically, by reframing task instruction in order to burden the monitoring process
726 with the more time-intensive action-based search, the anxiety-induced increase in ironic
727 errors observed in Experiments 1, 2 and 4 was eradicated in Experiments 3 and 5.
728 Collectively, these results represent the first evidence to support Wegner's (1994) ironic
729 processes theory in reactive motor tasks, and the first to offer a practical and theoretically-
730 driven solution to limit the troublesome ironic error. The key applied implication of our
731 finding is that the instructions we issue to ourselves and to others should be framed to ensure
732 that the operating process always has an easier search than the monitor. **For example,**
733 **Gorgulu and Woodman (2016) argued that coaches should tell their athletes what to do (e.g.,**
734 **strike the soccer ball into the net) rather than what to avoid (e.g., don't hit the post). The**
735 **current data support this recommendation and indicate that this is equally important for**

736 reactive tasks where movement decisions have to be made under time pressure. The current
737 data can also be interpreted to endorse holistic process goals as a way for performers to
738 support their operating process and promote successful motor performance. Holistic process
739 goals encompass the key elements of a movement in a single phrase (e.g., “smooth”, when
740 applied to a golf putt; Mullen, Jones, Oliver & Hardy, 2016) and thereby satisfy the need for
741 an instruction of what do rather than what to avoid. Further, holistic process goals have been
742 found to reduce anxiety (Kingston & Hardy, 1997), which should reduce the likelihood of the
743 monitoring process coming to the fore (Woodman et al., 2015). Moreover, when used by a
744 sample of experienced athletes, holistic process goals such as “reach” and “drive” were
745 associated with superior performance (e.g., less errors) during high-anxiety conditions
746 (Mullen & Hardy, 2010). Thus, we recommend that performers are issued with a clear and
747 simple positive instruction (e.g., holistic process goals), to limit their susceptibility to ironic
748 errors in sport. It would be interesting for future research to empirically examine this
749 recommendation by testing the effects of holistic process goals on the incidence of
750 specifically counter-intentional errors in the field (e.g., real-life sport).

751 **Limitations and Future Directions**

752 Although our results are highly consistent across studies, they should be interpreted in
753 light of some limitations. First, we adopted a fixed condition order (i.e., low-anxiety
754 condition; high-anxiety condition). This reduced the likelihood of anxiety carryover effects
755 (Woodman et al., 2015), but provided an opportunity for learning effects. Specifically,
756 participants may have been advantaged in the high-anxiety condition compared to the low-
757 anxiety condition due to greater task familiarity / practice. Our data argue against the
758 presence of learning effects, since performance was consistently worse in the high-anxiety
759 condition. Nonetheless, it would be interesting for future research to re-examine our findings
760 using well-learned tasks / expert populations to mitigate the risk of learning effects. For

761 instance, testing the theory with expert sport performers and ecologically valid reactive sport
762 tasks would help increase the generalizability and utility of our conclusions (Henrich, Heine,
763 & Norenzayan, 2010).

764 Second, future studies examining the merits of attentional models of performance
765 such as ironic processes theory would do well to employ techniques to measure attention. For
766 example, probe reaction time could be assessed during performance to provide an insight into
767 the attentional load that participants are experiencing (Lam, Masters & Maxwell, 2010). Such
768 research has the potential to provide even more compelling evidence that anxiety-induced
769 performance breakdown is attributable to worry consuming our limited attentional resources
770 and leaving insufficient space for effective goal-driven (e.g., operating process) control, as
771 predicted by Wegner's (1994) theory.

772 **Conclusion**

773 In conclusion, our findings provide the first support for Wegner's ironic effects theory
774 in an externally-paced task. Moreover, we offer a practical instruction-based solution that can
775 reduce susceptibility to ironic errors and instead help individuals to thrive under pressure.
776 Specifically, performers and practitioners should be educated about ironic effects theory, and
777 encouraged to frame instructions in a way that burdens the monitoring process with the more
778 difficult task.

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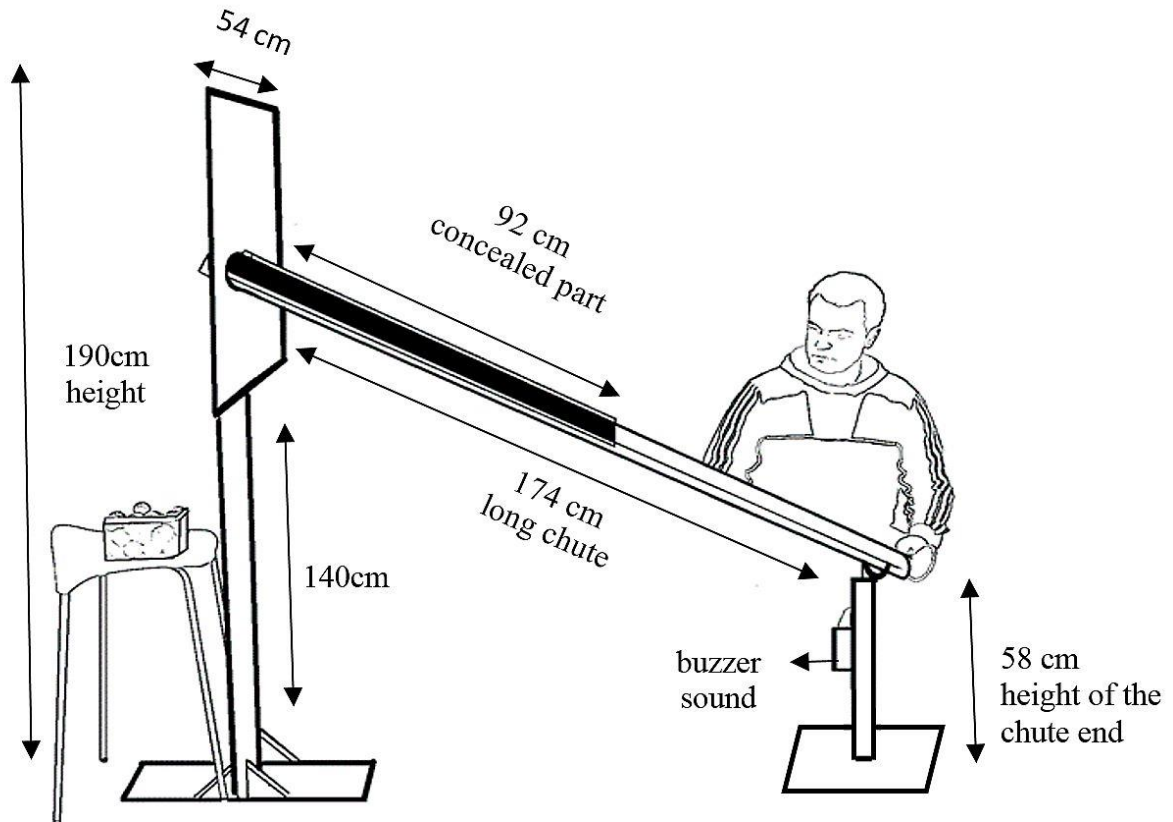
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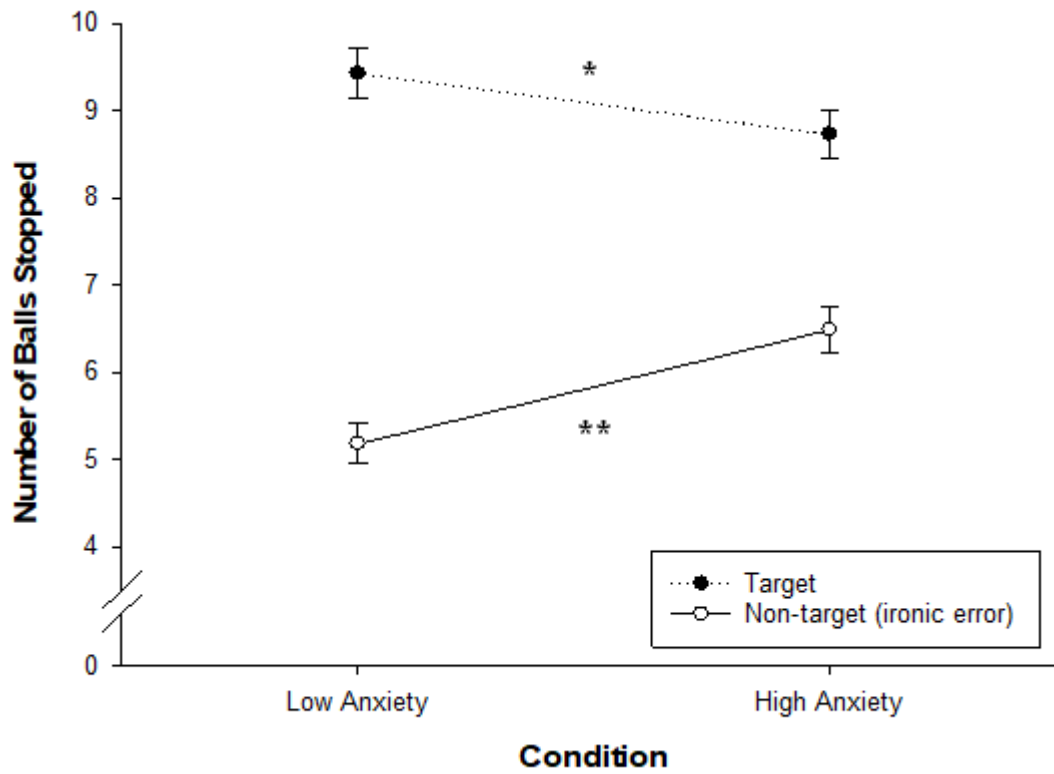
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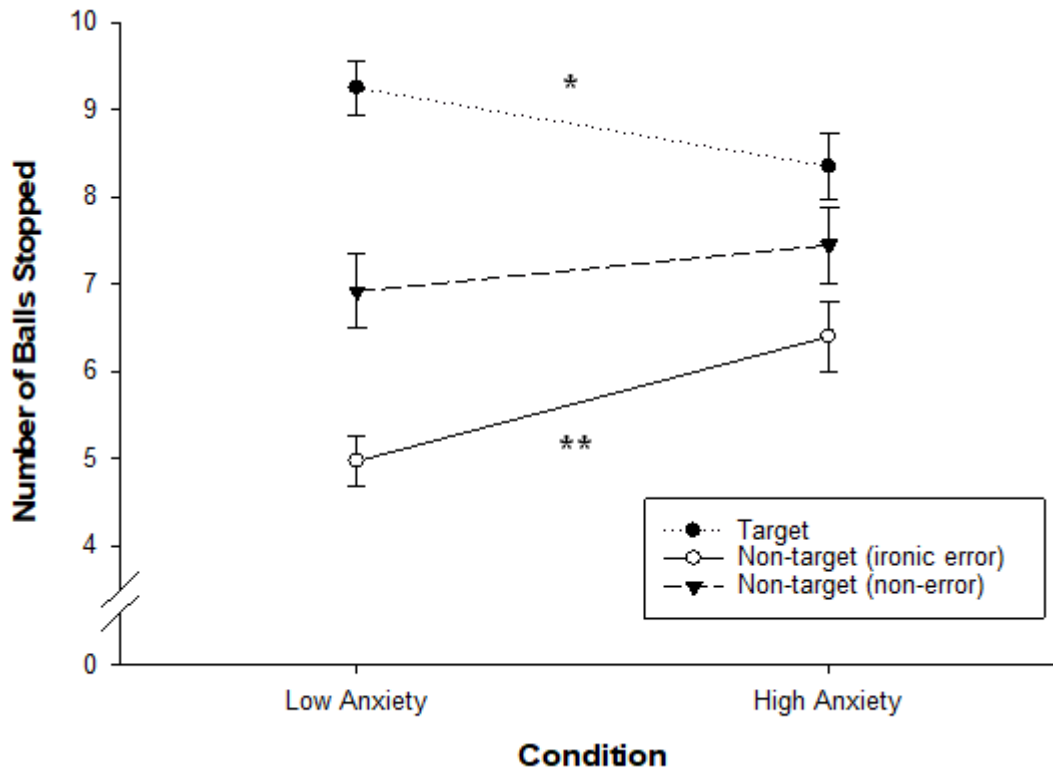
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Figure 1. Illustration of the apparatus used. The buzzer system is described in the performance measures section.



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Figure 2. Mean number of target balls and non-target ironic error balls under low-anxiety and high-anxiety conditions in Experiment 1. Error bars indicate standard error of the means. * $p < .05$, ** $p < .01$.



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 908 **Figure 3.** Mean number of target balls, non-target-non- error balls and non-target ironic error
 909 balls under low-anxiety and high-anxiety conditions for Experiment 2. Error bars indicate
 910 standard error of the means. * = $p < .05$, ** = $< .01$.
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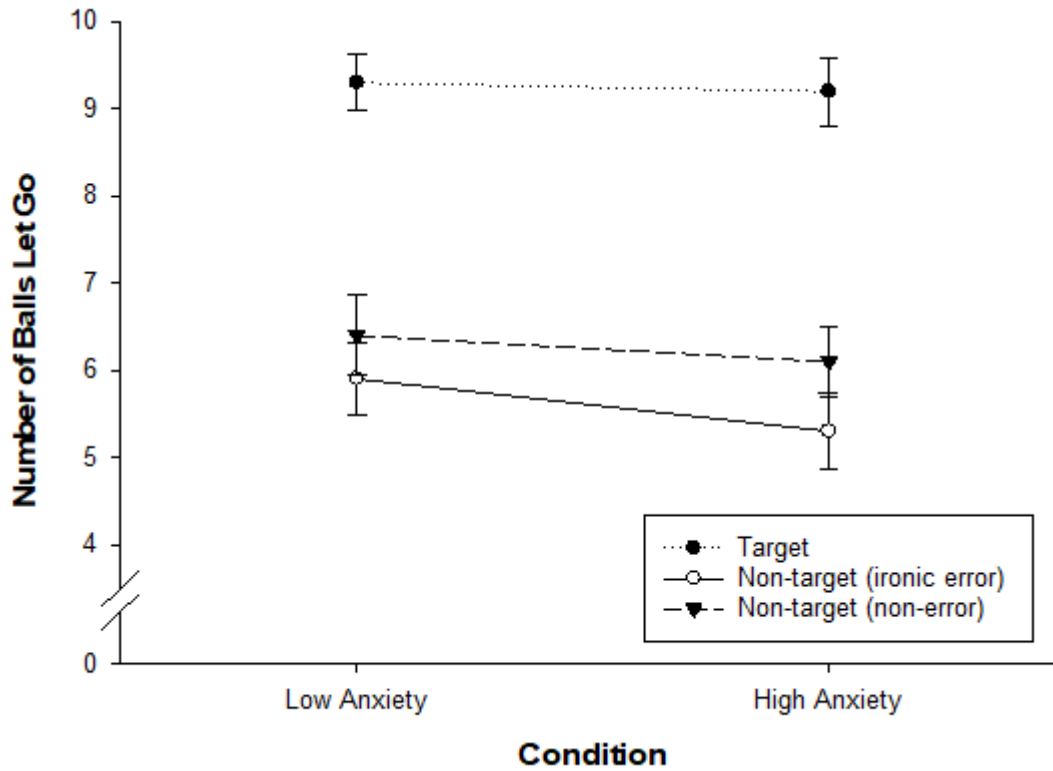
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924 **Figure 4.** Mean number of target balls, non-target-non-error balls and non-target ironic error
 925 balls under low-anxiety and high-anxiety conditions for Experiment 3. Error bars indicate
 926 standard error of the means.
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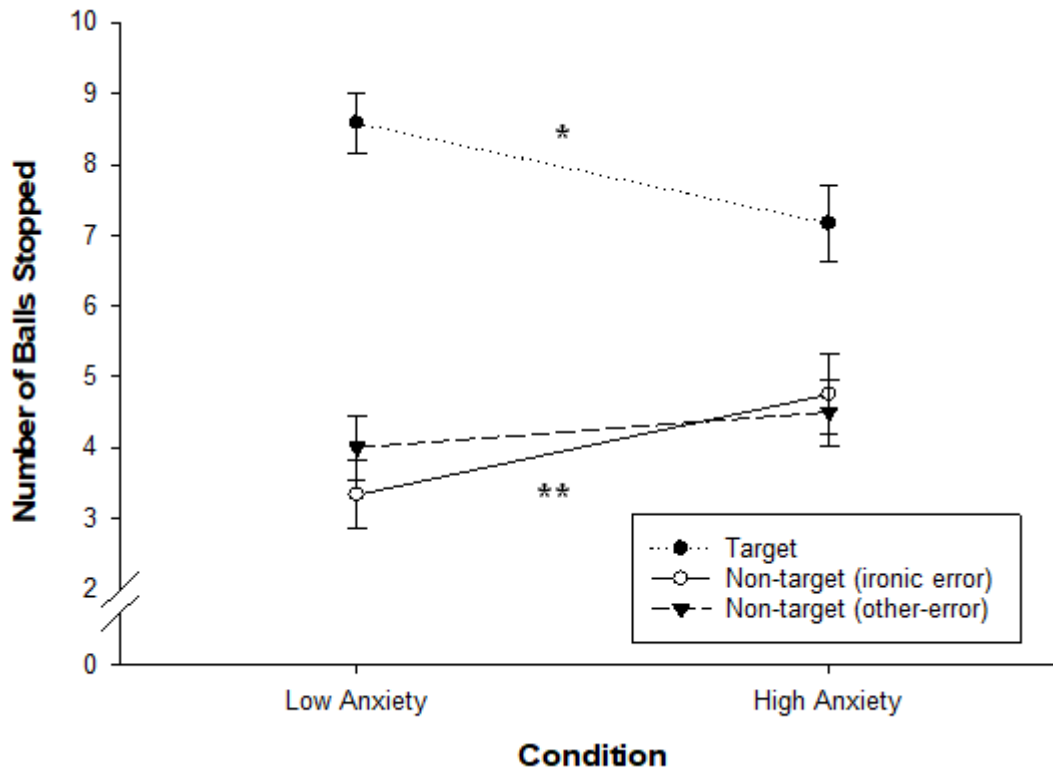
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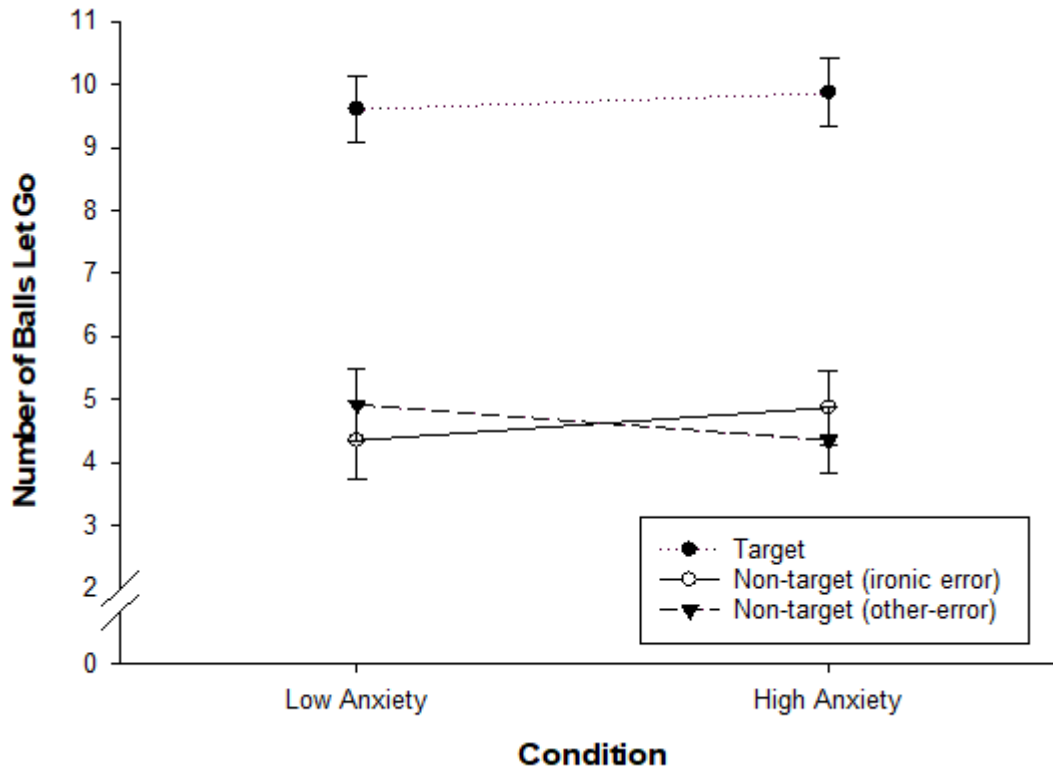
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Figure 5. Mean number of target balls, non-target-other-error balls and non-target ironic error balls under low-anxiety and high-anxiety conditions for Experiment 4. Error bars indicate standard error of the means. * = $p < .05$, ** = $p < .01$.

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959 **Figure 6.** Mean number of target balls, non-target-other error balls and non-target ironic error
 960 balls under low-anxiety and high-anxiety conditions for Experiment 5. Error bars indicate
 961 standard error of the means.
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977 **Table 1**

978 *Descriptive statistics confirming the effectiveness of the anxiety manipulation in Experiment*
 979 *1.*

Measure	Condition		
	Low-Anxiety	High-Anxiety	
	Mean (SD)	Mean (SD)	<i>t</i> (52)
Cognitive anxiety	4.96 (2.69)	7.35 (2.58)	5.66***
Somatic anxiety	5.47 (2.58)	7.45 (2.18)	5.70**
			<i>t</i> (41)
Heart rate (bpm)	92.85 (15.28)	95.44 (14.39)	2.38*
r-MSSD (ms)	44.19 (27.51)	33.53 (17.33)	3.09**
			<i>t</i> (47)
Muscle activity (μV)	27.01 (11.89)	29.59 (13.81)	2.14*

980 *Notes: *p < .05, ** p < .01, *** p < .001.*

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998 **Table 2**999 *Descriptive statistics confirming the effectiveness of the anxiety manipulation in Experiment*

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Measure	Condition		<i>t</i> (39)
	Low-Anxiety	High-Anxiety	
Cognitive anxiety	Mean (SD) 4.77 (1.95)	Mean (SD) 7.40 (2.3)	6.78***
Somatic anxiety	5.25 (2.03)	7.55 (1.72)	5.90***
Heart rate (bpm)	90.59 (16.36)	92.81 (15.61)	1.73 [†]
r-MSSD (ms)	59.29 (33.54)	47.84 (26.02)	3.04**
Muscle activity (μV)	23.31 (10.55)	25.22 (12.42)	1.73 [†]

1001 *Notes: ** $p < .01$, *** $p < .001$, [†] = .09.*

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1019 **Table 3**1020 *Descriptive statistics confirming the effectiveness of the anxiety manipulation in Experiment*

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Measure	Condition		<i>t</i> (40)
	Low-Anxiety	High-Anxiety	
	Mean (SD)	Mean (SD)	
Cognitive anxiety	4.85 (2.46)	7.29 (2.00)	6.27***
Somatic anxiety	5.14 (2.44)	7.46 (2.00)	6.49***
Heart rate (bpm)	87.36 (12.30)	91.23 (14.03)	4.02***
r-MSSD (ms)	50.35 (23.82)	41.43 (18.92)	3.63***
Muscle activity (μ V)	23.45 (12.67)	25.29 (15.17)	2.68*

1022 *Notes: * $p < .05$, *** $p < .001$.*

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1041 **Table 4**1042 *Descriptive statistics confirming the effectiveness of the anxiety manipulation in Experiment*1043 *4.*

Measure	Condition		<i>t</i> (<i>df</i>)
	Low-Anxiety	High-Anxiety	
	Mean (SD)	Mean (SD)	
Cognitive anxiety	3.70 (2.21)	6.66 (2.61)	4.67***
Somatic anxiety	4.29 (2.25)	6.33 (2.40)	3.58***
			<i>t</i> (19)
Heart rate (bpm)	85.69 (17.37)	90.46 (20.03)	3.51***
r-MSSD (ms)	56.30 (32.96)	47.33 (33.10)	2.84*
			<i>t</i> (21)
Muscle activity (μ V)	21.28 (9.06)	22.09 (9.62)	-.48

1044 *Notes: * $p < .05$, *** $p < .001$.*

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1060 **Table 5**1061 *Descriptive statistics confirming the effectiveness of the anxiety manipulation in Experiment*

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Measure	Condition		
	Low-Anxiety	High-Anxiety	
	Mean (SD)	Mean (SD)	<i>t</i> (22)
Cognitive anxiety	5.69 (1.91)	6.82 (2.20)	2.39*
Somatic anxiety	5.21 (1.85)	6.56 (2.27)	2.44*
			<i>t</i> (19)
Heart rate (bpm)	80.91 (11.26)	86.11 (14.88)	2.71*
r-MSSD (ms)	49.92 (24.94)	39.48 (21.75)	2.52*
			<i>t</i> (20)
Muscle activity (μ V)	20.25 (7.67)	20.40 (7.47)	-.15

1063 *Notes: *p < .05.*