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Ironic and Reinvestment Effects in Baseball Pitching: How Information about an Opponent Can Influence Performance under Pressure

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Abstract

Are pressure-induced performance errors in experts associated with novice-like skill execution (as predicted by reinvestment/conscious processing theories) or expert execution towards a result that the performer typically intends to avoid (as predicted by ironic processes theory)? The present study directly compared these predictions using a baseball pitching task with two groups of experienced pitchers. One group was shown only their target while the other was shown the target and an ironic (avoid) zone. Both groups demonstrated significantly fewer target hits under pressure. For the target-only group, this was accompanied by significant changes in expertise-related kinematics variables. In the ironic group, the number of pitches thrown in the ironic zone was significantly higher under pressure and there were no significant changes in kinematics. These results suggest that information about an opponent can influence the mechanisms underlying pressure-induced performance errors.

Ironic and Reinvestment Effects in Baseball Pitching: How Information about an Opponent Can Influence Performance under Pressure

There have been several different theories proposed to explain pressure induced failures/errors in performance (reviewed in Beilock & Gray, 2007). While numerous researchers have attempted to test the proposed causal links between pressure, anxiety and performance in these theories (e.g., whether attention turns outward or inwards under pressure), few have attempted to compare these theories in terms of the specific motor control mechanisms through which performance breaks down under anxiety. For example, conscious processing (Baumeister, 1984) and reinvestment theories (Masters, 1992) propose that an experienced performer influenced by pressure will fail because her/his skill execution will have the characteristics of a novice. Conversely, the theory of ironic processes (Wegner, Erber & Zanakos, 1993) proposes that pressure will cause a skilled performer to maintain a movement profile typical of an expert but act as though he/she has a different goal: achieving a result that was intentionally avoided (e.g., hitting a tee shot straight into a hazard a golfer was trying to avoid). We focus on these two theories because they make specific predictions about motor control mechanisms. We did not include a discussion of the distraction theory of pressure-induced failures (Wine, 1971) and associated theories such as attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) because, to our knowledge, these theories do not make specific predictions about the motor control processes (excluding eye movements) involved in choking under pressure. While previous studies have tested their movement predictions individually, we have no knowledge of a direct comparison between ironic processes and reinvestment theories.

Consistent with conscious processing and reinvestment theories of choking under pressure (Baumeister, 1984; Masters, 1992), several studies have provided evidence that pressure can cause expert performers to exhibit movement patterns typical of a novice. For example, Gray (2004) reported that pressure can cause an increase in the variability of the timing in different phases of a baseball swing, a characteristic of novice batting performance. This has also been shown in golf, as pressure can cause golfers to revert to a novice control strategy for adjusting the stroke for different putts of varying distances (Gray, Allsop & Williams, 2011). Specifically, while under pressure, some expert golfers show a decrease in the variation of downswing amplitude with changes in distance (as compared to low pressure conditions) and instead seem to control putt length by varying downswing velocity. In a final example, eye movement research has also provided evidence consistent with reinvestment theory predictions. The duration of the final fixation before the initiation of an action, termed the quiet eye period, typically increases as a function of skill level (Vickers, 1996). Pressure is associated with a reduction in this duration in experts (Wilson, Vine & Wood, 2009). However, it is important to note that none of these studies included clearly defined ironic errors.

Turning to ironic processes theory, Woodman, Barlow & Gorgulu (2015) recently provided evidence of performance breakdowns under pressure consistent with the predictions of this theory. In field hockey, shooting, and dart throwing tasks, performers were more likely to hit an ironic zone (i.e., a zone associated with point penalties) under pressure as compared to performance in a low pressure condition. Analysis of the dart throwing data showed that the precision of throws into the ironic zone was significantly higher in the pressure condition. This suggests that the greater number of ironic errors was not due to more erratic movement control (as might be expected of a lesser-skilled performer) but rather due to an expert "ability" to make specific errors. However, while this study provides valuable insight on the effect of pressure on sports performance, it did not include analysis of body or eye movements and results were not directly compared to data collected in conditions for which there was no ironic error defined.

The differences between these two sets of studies brings up an important issue that, to our knowledge, has not been previously studied: how does information about an opponent's tendencies affect potential pressure-induced performance errors? With the recent proliferation of the use of sports analytics in most sports, teams have begun providing athletes with complex statistics related to the strengths and weakness of their opponents. For example, pre-game preparations for a basketball defender may include graphical displays of the opposing player's shooting percentages around the basketball court. Likewise, a baseball pitcher might be shown a "heat map" representing a particular hitter's batting average for pitch locations throughout the strike zone. While it has been shown that athletes can use this type of information to improve performance (e.g., Alain & Proteau, 1980; Gray, 2015), it has the potential to change how athletes respond to pressure. Specifically, ironic processes theory predicts that explicitly highlighting the location of an ironic zone (i.e. an opponent's strength) either graphically of verbally would increase the likelihood of an ironic error occurring under pressure. For example, leaving a basketball shooter open in the exact location where they shoot the best on the final play of a game or throwing a pitch into a batter's "wheelhouse" (i.e. the location where they have the highest batting average) in the ninth inning.

The aims of the present study were twofold. First, we sought to directly compare the movement predictions of reinvestment/conscious processing theories and the theory of ironic processes. Namely, in experienced athletes are pressure-induced performance failures associated with novice-like skill execution or expert execution with an ironic goal? Another way to conceptualize this distinction is in terms of the different types of errors proposed in the schema theory of motor control (e.g., Schmidt & Lee, 1982). In these terms, the theory of ironic processes predicts that performers will make "program selection" errors (i.e., skilled execution of an inappropriate action) under pressure while reinvestment/conscious processing theories predict that performers will make "program execution" errors (i.e., noisy/unskilled execution of the appropriate action). The second goal was to determine whether and how the addition of information about an opponent's strengths and weaknesses influences performance under pressure. To achieve these ends, two groups of experienced baseball pitchers were asked to perform a pitching task that involved throwing a ball at a projection of a strike zone, plate and baseball batter. One group was shown only their target while the other was shown their target with an overlaid ironic zone (i.e., an area for which the participant was told the batter had a high batting average). An A-B-A design was used with pitching performance (location and velocity) and pitching kinematics measured in a low-pressure pre-test, a high pressure phase and a low-pressure post-test. The experiment was designed to test the following hypotheses:

(i) For both groups, the number of pitches thrown in the target zone would be significantly lower in the high pressure phase than in the other two phases.

(ii) For the ironic display group, the number of pitches thrown in the ironic zone would be significantly higher in the high pressure phase than in the other two phases due to errors in action selection.

(iii) Consistent with the theory of ironic processes (Wegner et al., 1993), it was predicted that, for the ironic display group, pressure would produce only action selection errors. Therefore, there would be no significant changes in the kinematic variables across the different phases of the experiment.

(iv)

(v) For the target only group, it was predicted that pressure would produce action execution errors. Therefore, in the pressure phase there would be a significant difference (relative to the low-pressure phases) in the experience-related kinematic variables (described in detail below) in a direction consistent with a regression towards novice skill execution.

Methods

Participants

Twenty-four experienced male baseball pitchers completed the study. All participants played for a college baseball teams affiliated with the National Junior College Athletic Association (NJCAA USA) at the time of participation and none had any professional baseball experience. They were recruited through contacts with coaches and were randomly allocated into two groups of twelve (the target-only group and the ironic group) as described below. For the target only group, there were 10 right-handed pitchers, the mean age was 22.6 (SD = 1.3, Range = 19-24), the mean number of years of competitive playing experience was 11.8 (SD = 1.9, Range = 9-13), and the mean earned run average (ERA) in the last complete season was 3.41 (SD = 1.6, Range = 2.7-4.4). For the ironic group, there were 11 right-handed pitchers, the mean age was 23.9 (SD = 1.7, Range = 19-25), the mean number of years of competitive playing experience was 12.2 (SD = 1.7, Range = 10-14), and the mean ERA in the last complete season was 3.37 (SD = 1.6, Range = 2.6-4.1). Note, for context, the mean ERA for the 50 NJCAA pitchers with the most innings pitched in 2015-2016 was 3.21. Independent samples t-tests revealed that there were no significant group differences for age, years of playing experience or ERA (*p*'s all >.5). The number of participants was derived from a power analysis based on the average differences in pitching performance between expert and novice pitchers found in previous research using a comparable pitching task (Gray, 2015). The following % of targets hit values were used for the power analysis: Group 'A' mean = 83, Group 'B' mean = 69, *SD* = 10.2, Power = 0.8. All participants gave informed consent and the experiment was given ethics approval by the [redacted] Institutional Review Board (IRB).

Apparatus

The pitching task involved throwing a regulation (74.68 mm) baseball towards a wall projection (see Figure 1) of a batter standing at home plate. The mark left by the ball was recorded by the experimenter after each trial. All left handed pitchers threw towards left handed batters (i.e., positioned on the left side of the plate in Figure 1) and vice versa. We made this design choice because typically pitchers are more effective when pitching to a batter standing on the same side of the plate. Furthermore, when asked to pitch for a short duration (i.e., "in relief") like in the present study they would typically face this type of batter (Kahn, 2000). We did not ask pitchers to alternate between throwing to batters on either side of the plate (as they would typically do as a starting pitcher) because we wanted to keep the number of pitches thrown low enough to reduce the effects of fatigue. The strike zone (large square) was divided into four quadrants with one of the quadrants covered in black.

For the pitchers in the target only group, all other quadrants were white. The black target quadrant was chosen randomly in each trial. We decided to change the location of the target on every trail to better represent what occurs in actual baseball (i.e., a catcher will typically call for pitches in different location from pitch to pitch). Participants in this group were instructed:

"Imagine you are pitching to a batter who has a poor batting average for pitches thrown in the location indicated by black. On each pitch, you should try hit the black target zone with a fastball and if you do this you will receive 1 point. If you throw the pitch in any other location you will receive 0 points".

The ironic group participants, however, threw to a projection with a single red quadrant in addition to the black target quadrant. The black target quadrant as well as red ironic zones were chosen randomly in each trial. Participants in this group were instructed:

"Imagine you are pitching to a batter who has a poor batting average for pitches thrown in the location indicated by black and a high batting average for pitches thrown in the location indicated by red. On each pitch, you should try hit the black target zone with a fastball and if you do this you will receive 1 point. If you hit the red zone you will lose 1 point so you should avoid trying to throw the ball in that location. Finally, if you throw the pitch in any other location you will receive 0 points".

In order to measure pitching kinematics, motion trackers (ProMove-mini, Inertia Technology™) were placed on the pitcher's lead foot, lead calf, bicep of throwing arm, forearm of throwing arm and the center of their back. These locations were chosen specifically so that we could measure kinematic variables that have been shown to differ as a function of pitching experience, described below. The recording rate was 1 KHz. Pitch speed was measured using a radar gun (Pocket Radar Ball Coach™) mounted on a tripod.

As a manipulation check, anxiety was measured in two different ways. Note, that it was assumed that a change in anxiety is indicative of an increase in perceived pressure as proposed by Gucciardi, Longbottom, Jackson and Dimmock (2010). First, heart rate was measured using a heart rate monitor (Polar H7 Bluetooth) that comprised a strap worn around the chest. Second, cognitive anxiety was measured using the cognitive anxiety subscale of the Immediate Anxiety Measures Scale (IAMS; Thomas, Hanton & Jones, 2002). The questionnaire is composed of three items. An example item is "I'm concerned about performing poorly". Participants are then asked to rate, on a scale of 1 (not at all) to 4 (very much so), whether each item is indicative of their thoughts and feelings. Thomas et al. (2002) demonstrated the IAMS to be a valid and reliable measure of anxiety with the items significantly correlating with the corresponding subscales of the Competitive State Anxiety Inventory 2-revised (CSAI-2R; Cox, Martens & Russell, 2003). In the present study, the IAMS was administered immediately after the instructions were given and before the participant began pitching for all phases of the experiment.

Procedure

After being equipped with the tracking devices, pitchers were given five practice pitches in which they were asked to throw the ball in the center of the strike zone followed by five practice pitches in which they were asked to hit a target quadrant marked in black. They next completed three phases of 30 pitches each: a low pressure pre-test phase, a high pressure phase and a low-pressure post-test phase. During both low-pressure phases the conditions were as described. The anxiety manipulation in the high pressure phase involved a combination of evaluative and ego-threatening instructions and monetary incentives. Specifically, participants were read the following script before the beginning of this phase (note, the text in the parentheses was only read to the ironic group):

"You are now entering the competition phase. During this phase your goal is still to hit the black target with a fastball and you will again be given 1 point for each target hit. (If you hit the red zone you will lose 1 point so you should avoid trying to throw the ball in that location). There are 11 other pitchers in this study. The pitcher that accumulates the most points in this competition will win $50 and the final standings will be emailed to all participants. Your performance in this phase will also be videotaped and evaluated by a coach."

As described in the script, a video camera was setup up during the pressure phase. During the low-pressure post-test phase the video camera was removed and participants were told that the end of the competition had been reached. Similar manipulations have been shown to successfully increase anxiety in a variety of contexts, including, aviation (e.g., Allsop & Gray, 2014), surgery (e.g., Malhorta, Poolton, Wilson, Ngo, & Masters, 2012) and sport (e.g., Gray & Allsop, 2013). Participants were given 15 minute breaks between each phase.

On each pitch, participants were given feedback verbally from the experimenter about the points earned for each pitch. They could also, of course, see the final ball contact location for themselves. No feedback was given about pitch speed.

Data Analysis

Two primary performance variables were used: number of targets hit and mean pitch velocity. Both of these variables were analysed using 2x3 mixed ANOVAs with group (Target-only, Ironic) as the between subject factor and phase (Pre-test, Pressure, Post-test) as the within-subjects factor. The manipulation check variables (mean heart rate and cognitive anxiety score) were also analysed with 2x3 mixed ANOVAs. For the ironic group, the mean number of pitches thrown in the ironic zone was analysed using a one-way repeated measures ANOVA with phase as the factor.

Four kinematic variables were analysed. These particular variables were chosen because previous research has shown them to be significantly related to skill level in pitching (Fleisig, Chu, Weber & Andrews, 2009).   As we have demonstrated in previous studies of baseball pitching (Gray, 2004) and golf putting (Gray et al., 2013), if pressure does lead to conscious processing/reinvestment, it should result in change in these skill-related variables. The specific variables measured were: the standard deviation of the lead foot landing position, the standard deviation of the maximum upper torso rotational velocity, the standard deviation of the throwing elbow flexion angle, and the mean angular separation of the body's main axis and the final location of the pitch. The three standard deviation variables reflect how consistently the pitcher is executing their delivery. Another way to think of the body-angle separation variable is that it is a reflection of the extent to which the ball goes where the pitcher intends as indicated by where there body is pointing (i.e., low deviation) as opposed to a different location (i.e., high deviation). For all of these variables, values are typically higher for lesser skilled pitchers (Fleisig et al., 2015). These variables were analysed using a 2x3 mixed MANOVA.

Results

Pre-Experiment Pitching Performance

The mean number of targets hit for the 5 practice pitches were 4.1 (*SD* = 2.4) and 4.3 (*SD* = 3.1) for the target-only and ironic display groups respectively. Comparable values for pitch velocity were 35.7 (*SD* = 6.2) and 36.0 (*SD* = 7.9) m/s. There were no significant group differences for either variable, *p*'s >0.5.

Manipulation Checks

The mean heart rates increased significantly in the pressure phase of the study: pre-test, *M* = 83.6 (*SD* = 5.2); pressure, *M* = 88.7 (*SD* = 5.9); post-test, *M* = 84.4 (*SD* = 5.5), $F(2, 44) = 9.2$, $p < 0.001$, $\eta_p^2 = .29$. Similar results were also obtained for the cognitive anxiety scores: pre-test, *M* = 1.9 (*SD* = .7); pressure, *M* = 3.0 (*SD* = .7); post-test, *M* = 2.1 (*SD* = .3), $F(2, 44) = 46.8$, $p < 0.001$, $\eta_p^2 = .48$. There was no evidence of group related influences on these variables, *p*'s >0.05.

Pitching Performance

Figure 2 shows the mean number of pitches that were thrown in the target zone. The ANOVA performed on these data revealed a significant main effect of phase as for both groups the number of targets hit was lower in the pressure phase, $F(2, 44) = 42.7$, $p < 0.001$, $\eta_p^2 = .66$. The main effect of group and group x phase interaction were not significant (*p*'s both >0.2).

For the ironic group, the mean number of pitches thrown in the ironic zone increased significantly in the pressure phase: pre-test, M = 2.1 (SD = 1.2); pressure, M = 5.8 (SD = 1.4); post-test, M = 2.8 (SD = 1.5), $F(2, 44) = 22.0$, $p < 0.001$, $\eta_p^2 = .67$. The distribution of pitches that missed the target zone in the pressure phase was compared for the two groups using chi-square goodness of fit tests of proportions. For the target only group, this test revealed no significant difference between the distribution of misses and a random distribution (i.e., 1/3 probability for each non-target quadrant), $\chi^2(2) = 0.75$, $p > 0.7$. For the ironic group, there was a significant difference between the observed distribution of misses and a random distribution, $\chi^2(2) = 15.75$, $p < .001$.

Table 1 shows the mean pitch velocity. The ANVOA performed on these data revealed no significant main effects or interactions, p's all > 0.05. To evaluate potential speed-accuracy trade-off effects, bivariate correlations between the mean number of targets hit and mean pitch velocity were calculated separately for the two groups in the three phases of the experiment. Correlations were as follows. Target-only: pre, $r(10) = -.36$; pressure, $r(10) = -.38$; post, $r(10) = -0.24$. Ironic-display: pre, $r(10) = -0.31$; pressure, $r(10) = -.25$; post, $r(10) = -.29$. Although all of these correlations were in the expected direction (i.e., fewer targets hit for higher pitch velocity), none of the values were statistically significant, *p's* all >0.1.

Pitching Kinematics

The MANOVA performed on the four kinematic variables revealed significant main effects of group, $F(4, 19) = 7.9$, Wilks $\lambda = 0.37$, $p = .001$, $\eta_p^2 = .62$, phase, [$F(8, 15) = 5.9$, Wilks $\lambda = 0.24$, $p = .002$, $\eta_p^2 = .76$, and a significant group x phase interaction, $F(8, 15) = 5.7$, Wilks $\lambda = .002$, $p = .001$, $\eta_p^2 = .75$. Figure 3 shows the mean standard deviation of lead foot landing location. The ANOVA performed on these data revealed a significant main effect of group, $F(1, 22) = 9.79$, $p = .001$, $\eta_p^2 = .31$,and phase, $F(2, 44) = 4.1$, $p =.02$, $\eta_p^2 = .16$. These effects were qualified, however, by a significant group x phase interaction, $F(2, 44) = 7.48$, $p =.002$, $\eta_p^2 = .25$. Pairwise t-tests with Bonferroni correction (critical p=.008) revealed that for the target-only group the standard deviation of lead foot landing position was significantly higher in the pressure phase as compared to both the pre-test, $t(11) = 4.4$, $p = 0.001$, and post-test phases, $t(11) = 3.2$, $p = 0.007$. There was no significant difference between the pre and post phases (p>0.5). For the ironic group, there were no significant differences between any of the phases *(p's* all >0.5).

As shown in Table 2, a similar pattern of results was obtained for two of the other kinematics variables: the mean standard deviation of pitching elbow flexion angle, group x phase interaction; $F(2, 44) = 10.5$, $p <.001$, $\eta_p^2 = .32$, and the mean pitch-body axis angular deviation, group x phase interaction; $F(2, 44) = 21.6$, $p <.001$, $\eta_p^2 = .49$. There were no significant main effects or interactions for the mean standard deviation of maximum upper torso rotational velocity.

Control Experiments

To address the possibility that the results for the ironic group were due to the fact that we used an "attentionally-grabbing" color (red) for the to-be-avoided quadrant we conducted a control experiment using grey ironic quadrants as illustrated in Figure 1. This involved 8 experienced pitchers that did not participate in the main experiment. In this control experiment, there were two phases (low pressure and pressure) which were identical to the main study. The pattern of results was similar to what was found in the main experiment using the red target. Namely, a pairwise t-test revealed that the number of pitches thrown in the ironic zone was significantly higher under pressure (as compared to low pressure) when the grey ironic zone was used, $t(7) = 2.4$, $p = .001$, $d = 0.88$.

In order to evaluate the importance of being able to see the ironic zone we ran a second control experiment using 12 experienced pitchers that did not participate in the main study. In this control experiment, there were two phases (low pressure and pressure) which were identical to the main study. In both phases, participants were told the location of the ironic zone verbally (i.e., “the hitter has the highest average for pitches up and away”) before each pitch rather than being shown the location. The display was identical to the one used for the target-only group in the main study (Figure 1, top panel). Results were similar to that found in the main study. The mean number of pitches in the ironic zone was significantly higher under pressure ($M = 6.0$, $SD = 1.4$) as compared low pressure ($M = 1.9$, $SD = 1.0$), $t(22) = 8.4$, $p<0.001$, $d = 2.8$. Furthermore, the number of pitches thrown in the ironic zone for the pressure and low pressure phases was not significantly different for the participants in this control experiment ($M = 4.0$, $SD = 1.7$) and the ironic-zone group in the main study ($M = 3.7$, $SD = 2.4$), $p>0.5$.

Discussion

The primary goal of the present study was to perform a direct test of the movement predictions for conscious processing/reinvestment and ironic processes theories of pressure-induced performance errors. The results of the present study provide evidence consistent with both theories. For the target-only group, the significant decline of pitching performance in the pressure phase (i.e., fewer targets hit) was accompanied by three significant kinematic changes that were indicative of a regression to an earlier stage of skill acquisition. Specifically, under pressure pitchers had significantly greater variability in their lead foot landing location and pitching elbow flexion angle, and a significantly higher pitch location-body axis deviation. In terms of the first two variables, a higher degree of variability in skill execution can be indicative of a performer consciously controlling an action by attending to body movement as opposed to the low variability which is typically associated when execution is automatic and proceduralized (Gray, 2011). The axis deviation variable is essentially a measure of the degree to which the ball goes to the location the pitcher intended it to as indicated by the alignment of his or her body axis (Fleisig et al., 2015). In other words, these kinematic effects suggest that pitching performance declined in the under pressure due to a regression to a more novice-like form of movement control as is predicted in conscious processing/reinvestment theories.

Turning to the ironic-display group, the significant decrease in targets hit under pressure seemed to occur for different reasons. For this group, there were no significant changes in the kinematic variables suggesting that movement execution was still "expert-like" under pressure. Or in, other words, participants in this group did not seem to make action execution errors under pressure. Particularly telling is the lack of change in the body axis variable which suggests that pitchers in this group were throwing the ball where they aimed it under pressure. Instead of there being a change in the execution of the pitch under pressure, there seemed to be a change only in where they threw it i.e., an action selection error. Consistent with the findings of Woodman, Barlow and Gorgulu (2015), pitchers in the ironic-display group appeared to act as if their goal was to throw a pitch into the ironic zone in the pressure phase. Unlike the target-only group whose misses were equally distributed, the ironic display group had a significant increase in the number of pitches thrown to the ironic zone under pressure. All of these effects are consistent with the predictions of ironic processes theory.

An interesting point to consider is why participants in the ironic display group did not produce both action selection errors (as indicated by more throws into the ironic zone) and action execution errors (as indicated by changes in the kinematic variables). We would argue that this can be explained in terms of the attentional focus of the performer. Specifically, the ironic instruction to avoid a certain location serves to provide an external target for which attention can be focused on. It is just the “wrong” target. This external target would then serve to prevent attention from turning inwards (leading to conscious processing of skill execution) much in the same way as external, secondary tasks have been used as a technique to prevent choking under pressure (e.g., Jackson, Ashford & Norsworthy, 2006). It is important to note that the results of our second control experiment suggest that this pattern of results for the ironic group occurs both when performers are presented with a visible, ironic target zone and when they are just told about its location. For the target-only group, we propose that the lack of this salient, external target increases the likelihood that they will turn their attention inwards in attempt to consciously control skill execution as has been shown in numerous previous studies (e.g., Gray, 2004). It will be important for future research to empirically test this proposed explanation (e.g., by probing a performer’s attentional focus during ironic and non-ironic zone conditions or by assessing gaze behavior).

Measuring attention control and gaze behaviour may also provide a means for connecting the present work with distraction theories of pressure-induced performance failures. For example, attentional control theory proposes that pressure can cause the bottom-up, stimulus-driven attentional system to take over resulting in an increased focus on threating stimuli (Eysenck et al., 2007). Is it this change in attentional control that produces ironic errors or is it occurring at different level of the perceptual-motor system (e.g., goal selection)? The fact that ironic effects can be produced when there is no clear threatening visual target (e.g., our second control experiment in which participants were only told about the location of the ironic zone) suggests that ironic effects are not primarily due to changes in attentional control. The present study also provides evidence that ironic errors do not seem to occur at level of action execution but further work is still needed to identify the underlying processes.

The present findings have some important implications for theories of performance under pressure. In particular, they provide further support for Wegner et al.'s (1993) ironic processes theory of mental control. In this theory, it is proposed that performance involves two processes: an intentional *operating process* which consciously searches for mental contents which will yield the preferred performance outcome and a *monitoring process* which subconsciously searches mental contents that are related to a failure to achieve the performer's goal in an attempt to avoid such processes. It is further proposed that, under conditions of high anxiety or pressure, the monitoring process becomes more salient resulting in an increased likelihood the performer will become consciously aware of perceptual-motor processes that will result in the to-be-avoided outcome. The result is that the performer is more likely to specifically and precisely do what they intend not to do, the ironic error. Previous research evaluating this theory has exclusively focused on performance outcomes e.g., is the frequency of ironic errors higher under pressure. In the present study, we have expanded on these findings by evaluating some of the underlying motor control processes associated with ironic errors. Specifically, in the present study there was no significant change in the pattern of movement kinematics associated with the production of ironic errors. In other words, as predicted by Wegner's theory, performance under pressure broke down precisely (action selection error) rather than due to a loss of control (action execution error).

It will be interesting to see if other behavioural measures which are known to relate to skill-level are affected by pressure (e.g., the "quiet eye" duration; Vickers, 1996) in a similar manner. It is also interesting to note that unlike in previous research on ironic effects, we varied the target and ironic zone locations from trial-to-trial rather than having them remain constant and produced highly similar effects.

The present results add to the evidence from previous research in support of conscious processing and reinvestment theories. Specifically, the pattern of results from the target-only group was consistent with a regression to an earlier stage of skill acquisition under pressure. In comparing the two groups in our study, it is quite striking how the simple addition of a to-be-avoided quadrant seemed to eliminate the large kinematic effects found for the target-only group. It will be interesting for future research to investigate intermediate conditions. For example, a condition in which a multi-level "heat map" is used with gradations in the degree to which specific locations should be targeted or avoided.

On a practical level, the present study raises an important caution about how information about an opponent's tendencies is given to an athlete. Although the performance outcomes (in terms of the number of overall target hits and misses) was identical for the two groups in the present study, their performance success would not likely have been equivalent if they were facing a real batter. Because the ironic group had a higher proportion of misses in the ironic zone, it is more likely the batter would have hit the ball solidly against this group. The clear implication of the present results is that a pitcher should only be shown or told about the locations for which the batter does not hit well (i.e., the pitcher's targets) before stepping on the mound. The present results also raise the interesting possibility that it may be possible to trick a pitcher into throwing an effective pitch by falsely indicating to them that an opponent's area of weakness is actually an area of strength.

There are some limitations of the present study. First, we only analysed group-level effects. Recent research has shown that the effects of pressure in general (e.g., Gray et al., 2013) and ironic effects specifically (Barlow, Woodman, Gorglu & Voyzey, 2016) can have large individual differences. For example, Barlow et al. found that ironic performance errors occur at a higher rate for individuals that score high on measures of neuroticism. Therefore, it will be interesting for future research to include personality measures. A second important limitation is that we removed all game context (e.g., the pitch count and score) from the pitching tasks. Given that this type of context is known to have a large effect on pitching strategy (Kahn, 2000) it will be important to determine whether it also influences how performance breaks down under pressure. Finally, the proportion of left-handed pitchers in our sample (12.5%) was lower than that typically found in college baseball (25-30%) and we did not require pitchers to throw to both left-handed and right-handed batters. Therefore, future research should examine how the observed effects are related to pitcher handedness and batter stance.

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Table 1. Mean pitch velocity (m/s) for the different phases of the experiment

Group	Pre-test	Pressure	Post-test
Target-only	35.2 (0.6)	33.9 (0.7)	34.3 (0.4)
Ironic display	36.0 (0.7)	35.5 (0.6)	35.4 (0.5)

Table 2. Mean values for three of the kinematics variables

Group	Variable	Pre-test	Pressure	Post-test
Target-only	SD(Elbow)	1.5 (.08)	2.1 (.09)	1.4 (.06)
Ironic display	SD(Elbow)	1.5 (.09)	1.4 (.09)	1.3 (.05)
Target-only	Body DEV	.17 (.02)	.4 (.03)	.18 (.01)
Ironic display	Body DEV	.15 (.02)	.18 (.03)	.17 (.01)
Target-only	SD(Torso)	22.0 (1.9)	24.7 (1.7)	21.1 (1.2)
Ironic display	SD(Torso)	23.8 (1.1)	24.2 (1.8)	23.0 (1.3)

SD(Elbow), SD Pitching Elbow Flexion Angle; Body DEV, mean pitch-body axis angular deviation; SD(Torso), mean standard deviation of maximum upper torso rotational velocity.

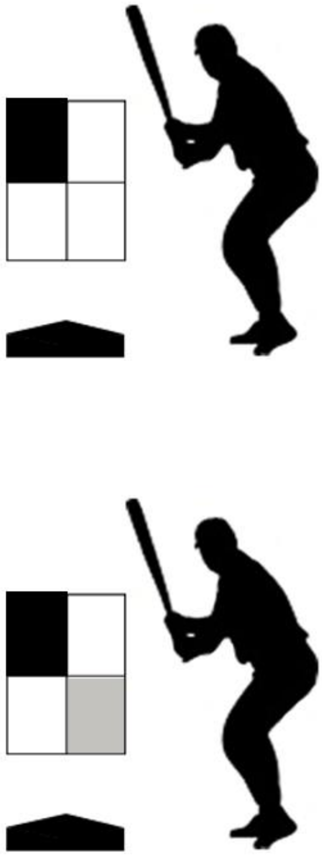

Figure 1 – Illustration of the displays for the target-only (top) and ironic display (bottom) groups. For both groups, the task was to throw a ball to the quadrant marked with black for which 1 point was awarded. For the ironic display group, participants were penalized 1 point for hitting the quadrant marked with grey (note, this quadrant was red in the actual experiment). For any other pitch location, both groups received 0 points. The locations of the target and ironic zones were randomized from trial to trial.

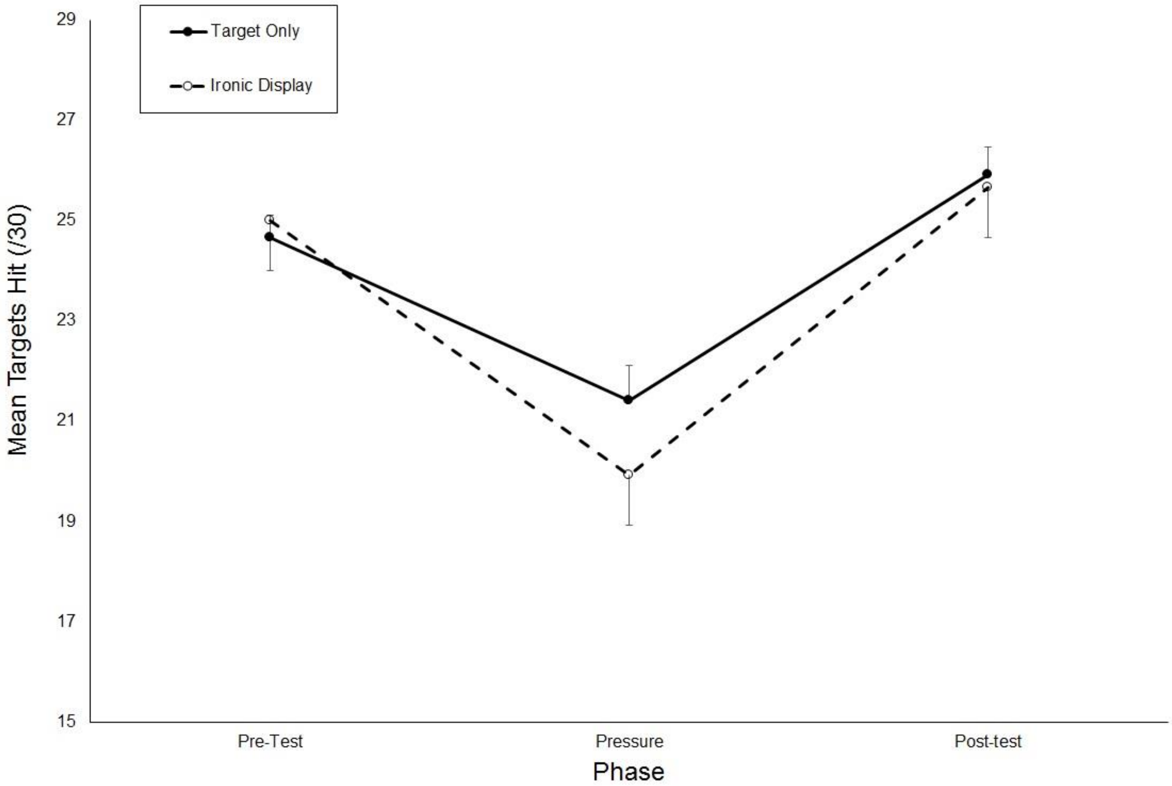

Figure 2 – Mean number of target hits for the two groups in the different phases of the experiment. Error bars are standard errors.

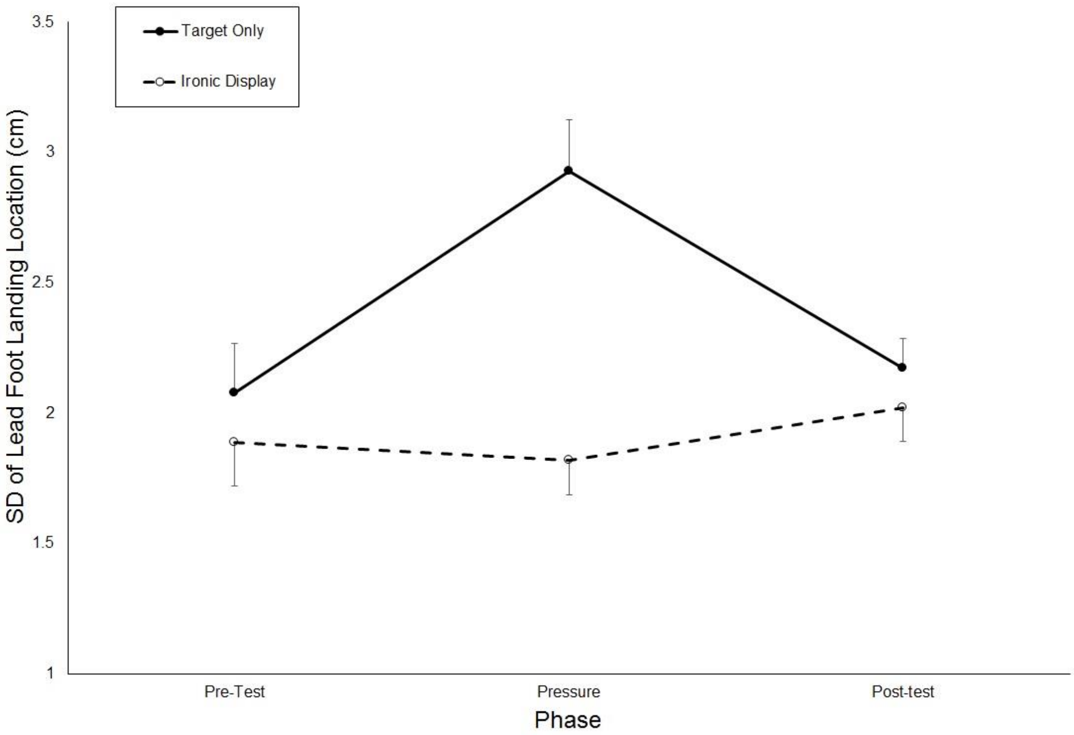

Figure 3 – Mean standard deviation of lead foot landing location for the two groups in the different phases of the experiment. Error bars are standard errors.