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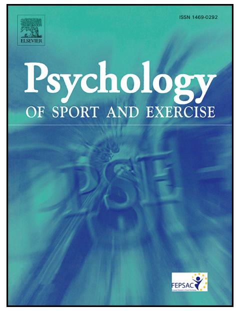

Inhibitory control, conscious processing of movement and anxiety

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Inhibitory control, conscious processing of movement and anxiety

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Abstract

It has been suggested that a high propensity for reinvestment (i.e., conscious processing of movements) can disrupt performance, but the mechanisms responsible are not well understood. The purpose of this study was to examine whether people with superior inhibition function (i.e., ability to suppress unwanted thoughts and behaviours) were better able to suppress conscious processing of their movements (i.e., reinvestment). Inhibition function was assessed using a Go/NoGo button-press task, and individual propensity for reinvestment was assessed using the Movement Specific Reinvestment Scale (MSRS) and the Decision-Specific Reinvestment Scale (DSRS). The results revealed positive associations between inhibition function and reinvestment propensity, with better inhibition function evident in people who displayed a higher propensity to reinvest (MSRS and DSRS). Hierarchical regression analyses revealed that trait anxiety moderated the relationship between inhibition and movement specific reinvestment, with higher MSRS scores associated with better inhibition function in people with low trait anxiety. This association was not significant among people with high trait anxiety. Possible explanations for these results are discussed.

Key words: Inhibition; Reinvestment; Anxiety

Introduction

The Theory of Reinvestment (Masters, 1992; Masters & Maxwell, 2008) proposes that there are individual differences in the inclination to use executive control to regulate their behaviours. Previous research, for example, suggests that a high propensity for movement specific reinvestment may disrupt natural regulation of movements, which can reduce their efficiency (Maxwell, Masters, & Eves, 2000; Poolton, Masters, & Maxwell, 2006; Lam, Maxwell, & Masters, 2009a, 2009b). Theoretically, the ability to inhibit executive control of movements may prevent movement specific reinvestment. Consequently, the current study was designed to examine whether inhibition ability is associated with the propensity for reinvestment. Although the relationship between working memory capacity, reinvestment and attention has been examined (e.g., Buszard, Farrow, Zhu & Masters, 2013; Laborde, Furley, & Schempp, 2015; Wood, Vine, & Wilson, 2016), no previous studies, to our knowledge, have examined directly the relationship between movement specific reinvestment and inhibition.

Inhibition is considered to be one of the fundamental executive functions necessary for complex cognitive tasks, such as learning and performing motor skills and making decisions under time pressure (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Diamond, 2013; Howard, Johnson, & Pascual-Leone, 2014; Engle, 2018). Inhibition is thought to aid executive control by suppressing irrelevant thoughts and inappropriate behaviours, and allowing the most relevant information to be processed during performance of tasks (Miyake et al., 2000; Engle & Kane, 2004; Diamond, 2013; Howard et al., 2014; Engle, 2018).

Despite the lack of research into the relationship between inhibition and reinvestment, it has been suggested that there may be a direct association between rumination tendency and inhibition function (Linville, 1996; Hertel & Gerstle, 2003; Joormann, 2006; Whitmer & Banich, 2007; Joormann & Tran, 2009; De Lissnyder, Koster, Derakshan & De Raedt, 2010; Joormann & Gotlib, 2010; Berman et al., 2011; De Lissnyder, Derakshan, De Raedt & Koster, 2011). Rumination refers to a style of thinking that involves repetitive conscious processing of one's negative emotions and experiences. People who tend to brood over negative emotions and experiences display impaired inhibition function compared to those who do not (Lineville, 1996; Davis & Nolen-Hoeksema, 2000; Watkins & Brow, 2002; De Lissynder et al., 2010, De Lissnyder et al., 2011; Yang, Cao, Shields, Teng, & Liu, 2016). Thus, there is good reason to believe that there may be a link between inhibition and propensity for reinvestment, given that reinvestment involves conscious processing of one's behaviours (i.e., movements/decisions).

One of the factors that influences both inhibition function and reinvestment is anxiety. Anxiety has been shown to impair inhibition function by having an adverse effect on attentional control, a key function of the central executive. It has been suggested that anxiety increases susceptibility to distractions (e.g., task-irrelevant stimuli or worrisome thoughts) which impairs efficiency of inhibition functions (Attentional Control Theory; Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011).

Furthermore, anxiety has been shown to trigger reinvestment (Masters, 1992; Liao & Masters, 2002; Chell, Graydon, Crowley, & Child, 2003; Wilson, Chattington, Marple-

Horvat, & Smith, 2007; Gucciardi & Dimmock, 2008; Masters & Maxwell, 2008; Kinrade, Jackson, & Ashford, 2015). Studies have shown that performance by people with a high propensity for reinvestment tends to be less robust under high anxiety conditions than in people with a low propensity for reinvestment (Masters, Polman, & Hammond, 1993; Mullen & Hardy, 2000; Beilock & Carr, 2001; Mullen, Hardy, & Oldham, 2007; Gucciardi & Dimmock, 2008). Poolton, Maxwell, and Masters (2004) even used structural equation modelling to estimate that golf-putting performance by high reinvesters can decrease by as much as 30% in anxiety inducing situations, suggesting that under pressure high reinvesters tend to consciously process their movements more than low reinvesters.

Consequently, the purpose of this study was to investigate the association between inhibition function (i.e., the ability to suppress irrelevant thoughts or behaviours) and propensity for reinvestment (i.e., inclination to use executive control to consciously regulate behaviours) using the Movement Specific Reinvestment Scale (MSRS; Masters, Eves, & Maxwell, 2005) and the Decision-Specific Reinvestment Scale (DSRS; Kinrade, Jackson, Ashford, & Bishop, 2010). Given that anxiety has been shown to have a causal effect on reinvestment and a disruptive influence on inhibition function, we examined the moderating effect of anxiety on the relationship between inhibition function and propensity for reinvestment. We predicted that people with high inhibition function would have a lower propensity for reinvestment because they are less likely to use executive control to regulate their behaviours. We anticipated that anxiety would have a moderating effect on the association between inhibition function and reinvestment.

Method

Participants

Ninety-one university students (45 male, 46 females; mean age 19.64 years, *SD* = 3.08) were recruited for the study, which was conducted in a computer laboratory. Ethical approval for the study was provided by the University Human Research Ethics Committee and informed consent was obtained from all participants.

Design and Procedure

Participants were first asked to complete the Movement Specific Reinvestment Scale (MSRS, Masters et al., 2005) and the Decision-Specific Reinvestment Scale (DSRS, Kinrade et al., 2010) as measures of individual propensity for movement-specific and decision-specific reinvestment, respectively. Trait anxiety was then assessed with the Trait-Anxiety subscale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). The MSRS comprises 10 items that assess an individual's propensity to consciously monitor and control their movements (e.g., "I am always trying to think about my movements when I carry them out" or "I am concerned about my style of moving"). The items are rated on a 6-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (6). The cumulative scores range from 10 to 60, with higher scores indicating greater conscious processing associated with movement. The DSRS comprises 13 items that assess an individual's propensity to consciously monitor and control processes involved in decision-making (e.g., "I'm always trying to figure out how I make decisions" or "I often find myself thinking over and over about poor decisions that I have made in the past"). The items are rated on a 5-point Likert scale ranging from *extremely uncharacteristic* (0) to *extremely characteristic* (4). The cumulative scores range from 0 to 52, with higher scores indicating greater conscious processing of decisions associated with movement. The Trait-Anxiety subscale of the State-Trait Anxiety Inventory comprises 20 items (e.g., "I worry too much over something that doesn't really matter") that are rated on a 4-point Likert scale ranging from *almost never* (1) to *almost always* (4). The cumulative scores range from 20 to 80, with higher scores indicative of greater general anxiety.

Following administration of the questionnaires, participants completed a Go/NoGo task to assess their inhibition functions (Psychology Experiment Building Language, PEBL, Mueller and Piper, 2014).[1] The Go/NoGo task displayed a square in the middle of the screen, with a blue star visible in the center of each quadrant of the square. Every 1500ms one of the blue stars was replaced by the letter P or R, which appeared for 500ms. Participants were instructed to respond as quickly as possible by left-clicking the mouse when the letter P appeared (Go trials, response activation) but not to respond when the letter R appeared (NoGo trials, response inhibition). The task included ten practice trials with feedback, and one test block with 100 trials without feedback (Go/NoGo ratio 4:1; Bezdjian, Baker, Lozano, & Raine, 2009).

Data Analysis

[1] PEBL is a free software that includes numerous psychology tasks licensed under General Public Licence. The parameters of the ready-made experimental tasks can be modified, which allowed us to adjust the number of trials. The software can be downloaded from http://pebl.sourceforge.net/.

There were four possible outcomes during the Go/NoGo task: respond on Go trials (correct), non-respond on Go trials (omission error), inhibit a response on NoGo trials (correct) and incorrectly respond on NoGo trials (commission error). All outcomes were converted into percentiles but only omission and commission errors were used in the analyses as studies have shown that omission errors reflect inattention while commission errors reflect impaired inhibition (Barkley, 1991; Halperin, Wolf, Greenblatt, & Young, 1991; Bezdjian et al., 2009).

In addition to response accuracy, we also computed average response time (RT) and response time variability (RTV) in trials involving Go responses to further index inhibition (see Barkley, 1991; Halperin et al., 1991; Kindlon, Mezzacappa, & Earls, 1995; Nigg, 1999; Bellgrove, Hester, & Garavan, 2004; Simmonds, Fotedar, Suskauer, Pekar, Denckla, & Mostofsky, 2007; Simmonds, Pekar, & Mostofsky, 2008; Bezdjian et al., 2009; Nakata, Sakamoto, & Kakigi, 2012).[2] The sum of RT for Go trials was divided by the total number of hits (i.e., correct responses to Go trials) to tabulate the average RT for Go trials (Go RT). The RTV for Go trials (Go RTV) was calculated using intra-individual coefficient of variation (ICV = Go RT_{SD} / Go RT_{M}) to control for differences in mean response time (see Bellgrove et al., 2004).

[2] Studies have shown a high correlation between commission error and response time variability (Simmonds et al., 2007; Bezdjian et al., 2009) and a significant correlation between neural activation related to inhibition function and response time variability (Bellgrove et al., 2004; Simmonds et al., 2007; Nakata et al., 2012), indicating that increased response time variability for Go stimuli reflects poor inhibitory control.

We set up four exclusion criteria adopted from Bezdjian et al. (2009). First, we removed trials with RT less than 120ms. The average time needed for visual processing is 150ms during the Go/NoGo task (Thorpe, Fize, & Marlot, 1996), suggesting that RTs close to 120ms were not purposeful responses but an unintentional coincidence. Second, if there was a missing response to a Go trial (*n*th trial) prior to a trial with an RT less than 120ms (RT_{n+1} < 120ms), we corrected the *n*th trial as "Responded." In addition, the RT of the *n*th trial was corrected by combining the allotted response time (1450ms) with the RT of the next trial (RT_n = 1450ms + RT_{n+1}). We considered these to be slow responses to previous trials, which occurred when the next trial had appeared, although this seldom occurred. Lastly, to eliminate participants who responded/non-responded without regard to the stimuli, participants with commission errors higher than 75% and a hit rate (i.e., correct response to Go trials) lower than 75% were removed. As a result, n=5 participants were excluded from the study. Data were then visually screened using box-plots to check for skewness and outliers (i.e., values more than 3 times the interquartile range), and n=3 participants were removed from the analysis.

Pearson's product-moment correlation coefficients were used to examine the association between propensity for reinvestment (MSRS/DSRS scores) and inhibition function. Hierarchical regression analysis was conducted to examine whether anxiety moderated the relationship between inhibition function and propensity for reinvestment (see Figure 1). For the analysis, we followed the steps recommended by Frazier, Tix, and Barron (2004). First, the inhibition function variables (NoGo error, Go RT, and Go RTV) and moderator variable (Anxiety) were standardized to control for problems associated with multicollinearity (M = 0, SD = 1). Next, product terms were calculated by multiplying each standardized predictor variable by the standardized moderator variable – because there were three predictor variables and one moderator variable, three product terms were produced. Variables were entered into a regression equation in a step-wise manner. In the first step, the predictor and moderator variables were entered. In the second step, the product term was entered. For the second step, a significant moderator effect was indicated by significant change in the R^2 for the product term. Regression assumptions were tested and satisfied: the average variance of inflation factor (VIF) values was not considerably greater than 1, tolerance values were greater than 0.7, and the maximum VIF values remained below 1.5. The Durbin-Watson statistics were within an acceptable range (1 to 3). The level of significance was set at $p = 0.05$.

[INSERT FIG. 1 NEAR HERE]

Fig. 1 An illustrative model of the moderation effect of anxiety on the association between inhibition function and reinvestment

Results

Correlational Analysis

Significant correlations were found between Go RTV and MSRS scores ($r = -.249$, $p = .023$), and Go RTV and DSRS scores ($r = -.261$, $p = .017$). Better inhibition function was associated with a high propensity for movement specific reinvestment and for decision-specific reinvestment, as indicated by less variable response times on Go trials (see Table 1).

Table 1 Correlation matrix for inhibition function, propensity for reinvestment and trait anxiety

Variables	Mean	SD	1	2	3	4	5	6	7
Reinvestment									
1. MSRS	39.60	7.48	-						
2. DSRS	30.01	8.05	0.53**	-					
Go/NoGo task									
3. Go error (%)	1.07	2.74	-0.15	-0.10	-				
4. NoGo error (%)	38.03	17.18	-0.17	-0.11	0.05	-			
5. Go RT (ms)	404.74	39.45	0.04	0.05	0.15	-0.51**	-		
6. Go RTV (ms)	0.19	0.03	-0.25*	-0.26*	0.48**	0.30**	0.02	-	
Trait Anxiety									
7. Trait-STAI	41.46	9.04	0.22*	0.45**	0.02	0.21	0.01	0.04	-

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MSRS, Movement Specific Reinvestment Scale; DSRS, Decision-Specific Reinvestment Scale; RT, response time; RTV, response time variability; Trait-STAI, Trait-anxiety subscale of State-Trait Anxiety Inventory

Hierarchical Regression Analysis

The results of the hierarchical regression analyses are presented in Table 2.

Table 2 Hierarchical regression analyses for testing moderator effects

	B	*SE B*	95% CI	β	*R² Change*
MSRS (Predictor NoGo error)					
Step 1					
NoGo error (z-score)	-1.67	0.81	-3.29, -0.05	-0.22*	
Anxiety (z-score)	2.01	0.81	0.40, 3.63	0.27*	0.10*
Step 2					
NoGo error x Anxiety	0.46	0.77	-1.07, 1.99	0.06	0.004
MSRS (Predictor Go RT)					
Step 1					
Go RT (z-score)	0.28	0.81	-1.34, 1.90	0.04	
Anxiety (z-score)	1.66	0.81	0.04, 3.28	0.22*	0.05
Step 2					
Go RT x Anxiety	0.55	1.12	-1.67, 2.77	0.05	0.003
MSRS (Predictor Go RTV)					
Step 1					
Go RTV (z-score)	-1.92	0.79	-3.49, -0.36	-0.26*	
Anxiety (z-score)	1.74	0.79	0.17, 3.30	0.23*	0.12**
Step 2					
Go RTV x Anxiety	2.40	0.90	0.60, 4.19	0.27**	0.07**
DSRS (Predictor NoGo error)					
Step 1					
NoGo error (z-score)	-1.68	0.80	-3.28, -0.08	-0.21*	
Anxiety (z-score)	3.94	0.80	2.35, 5.54	0.49**	0.24**
Step 2					
NoGo error x Anxiety	0.09	0.76	-1.43, 1.60	0.01	0.01
DSRS (Predictor Go RT)					
Step 1					
Go RT (z-score)	0.36	0.81	-1.24, 1.96	0.05	
Anxiety (z-score)	3.59	0.81	1.99, 5.19	0.45**	0.20**
Step 2					
Go RT x Anxiety	-0.21	1.10	-2.41, 1.98	-0.02	0.01
DSRS (Predictor Go RTV)					
Step 1					
Go RTV (z-score)	-2.24	0.77	-3.77, -0.71	-0.28**	
Anxiety (z-score)	3.68	0.77	2.15, 5.20	0.46**	0.28**
Step 2					
Go RTV x Anxiety	1.12	0.91	-0.69, 2.93	0.12	0.01

Note: * $p < 0.05$, ** $p < 0.01$

Abbreviations: MSRS, Movement Specific Reinvestment Scale; DSRS, Decision-Specific Reinvestment Scale; RT, response time; RTV, response time variability

Results from the regression analyses revealed a significant interaction between Go RTV and Anxiety for MSRS (*B* = 2.40, $p = .009$). No significant interactions were found for any other inhibition variables. Post-hoc probing of the significant interaction effect was conducted using *t*-tests to compare each regression line against zero (Holmbeck, 2002). Regression lines were then plotted (Figure 2). For people with high trait anxiety, Go RTV was not significantly related to MSRS, $B = 9.40$, $t(82) = 0.28$, $p = .777$. For people with low trait anxiety, however, Go RTV was significantly and negatively associated with MSRS, with low Go RTV (better inhibition) related to higher scores on MSRS, $B = -130.53$, $t(82) = -3.66$, $p = .001$.

[INSERT FIG. 2 NEAR HERE]

Fig. 2 The interaction between inhibition (Go RTV) and trait anxiety for scores on the Movement Specific Reinvestment Scale (MSRS)

Discussion

This study examined the association between inhibition function and propensity for reinvestment (MSRS and DSRS) and sought to establish whether anxiety has a moderating effect on the relationship between inhibition function and propensity for reinvestment. We postulated that people with good inhibitory control would be better at suppressing executive control of their movements or decisions. Thus, we hypothesized that inhibitory function would be negatively correlated with propensity for reinvestment. Instead, in this study, superior inhibition function (reflected by lower Go RTV) was observed among participants who scored high on the Movement Specific Reinvestment Scale (MSRS) and/or the Decision-Specific Reinvestment Scale (DSRS).

It is possible that a corollary of greater conscious processing by people with a high propensity for reinvestment was superior attention during the Go/NoGo task, and thus better inhibition scores. Superior attention to conscious processing of the movement might have facilitated performance of the Go/NoGo task. There has been much discussion of the role of conscious control in directing attention and suppressing inappropriate behaviours (e.g., Schneider, Dumais, & Shiffrin, 1984; Norman & Shallice, 1986; Baddeley & Logie, 1999). For example, Attentional Control Theory (ACT, Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan and Eysenck, 2009) assumes that the way attention is directed plays a key role in central executive functions, such as inhibition (and can be compromised as a result of anxiety).

On the other hand, it is also possible that those who consciously processed their movements were more likely to strategise about the task. Given the 4:1 Go/NoGo ratio, one of the strategies could have been to respond rapidly regardless of the type of stimulus present. This strategy would have resulted in 80% accuracy. However, by eliminating participants with commission error higher than seventy-five percent, we attempted to reduce the likelihood that this occurred. Nonetheless, we acknowledge that it remains a possibility and further studies are required to investigate the relationship between reinvestment and strategic behaviour.

Our moderation analyses demonstrated that anxiety moderated the relationship between inhibition function and reinvestment propensity, possibly because attention was affected by anxiety. Among low trait anxious individuals, people with high MSRS scores benefited from (goal-directed) attention and therefore exhibited good inhibition ability (reflected by low Go RTV). On the other hand, among high trait anxious individuals, there was no association between MSRS scores and inhibition ability. ACT (Eysenck et al., 2007) suggests that high anxious individuals function less efficiently than low anxious individuals, and thus use compensatory strategies (e.g., increased effort) to maintain similar performance levels despite the reduced processing efficiency. However, ACT suggests that high anxious individuals may not use these compensatory strategies during non-demanding tasks, such as our simple button-pressed Go/NoGo task. As a result, the association between superior inhibition ability and high MSRS score was not found for high anxious individuals. Further research is warranted to address these explanations, as attention was not directly measured in our study.

So far, we have attempted to indirectly explain our results by arguing that people with a high propensity for reinvestment had superior attention on the task. It is possible, however, that they simply had better inhibition function. These individuals might have learned to suppress their tendency to consciously control movements better than people with low propensity for reinvestment. Studies have shown negative effects of conscious control (e.g., increased accumulation of task-relevant knowledge and performance breakdown) but humans are adept at developing cognitive processes that allow them to cope with such disadvantages. Jackson, Ashford, and Norsworthy (2006), for example, suggested that high reinvesters performed motor tasks better than low reinvesters during skill-focused conditions (designed to cause conscious processing of their movements) because high reinvesters were acclimatized to conscious processing, as suggested by Baumeister (1984). In line with this argument, people with a high propensity for reinvestment might have learned to control their catastrophic habit by suppressing such thoughts. However, our moderation analysis suggests that such learned abilities were diminished among high trait anxious individuals. From an applied perspective, it may be the case that athletes or performers with a cocktail of both high trait anxiety and the propensity for movement specific reinvestment, which can often be problematic in high pressure situations, benefit most strongly from inhibition training.

An interesting consideration would be to examine whether a more complex Go/NoGo task, rather than our simple Go/NoGo task, would result in different inhibition scores among people with high and low reinvestment propensities. Studies have shown that performance of tasks can deteriorate when there is an overload of cognitive processes (Baddeley & Logie, 1999; Baddeley, 2010). More complex forms of Go/NoGo tasks include additional rules such as "respond only after two consecutive Go stimuli" or respond "when *both* lights in the middle of the screen are switched on", which require more cognitive processing. Indeed, fMRI studies have shown that more complex Go/NoGo tasks recruit more brain regions than the simple Go/NoGo task (Mostofsky et al., 2003; Simmonds et al., 2008). As a result, it would be worthwhile to investigate the effect of increased cognitive task load on people who tend to consciously process information (i.e., high reinvesters).

Conclusion

Higher propensity for reinvestment was associated with superior inhibition function. Although our study is preliminary, it provides an important departure point for further exploration of how people with different propensities for conscious control of their movements process cognitive information, and how inhibition function and anxiety might change the reinvestment process.

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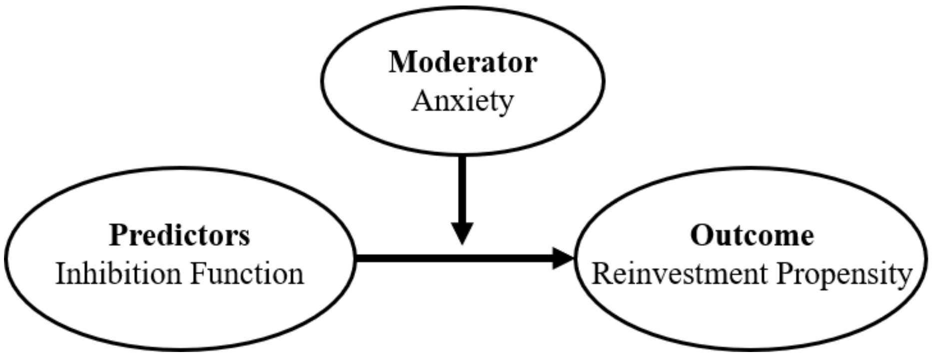
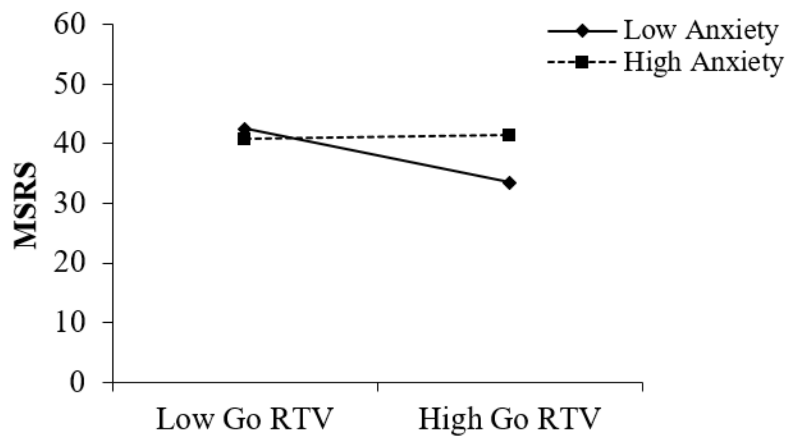

Moderator
Anxiety
Predictors
Inhibition Function
Outcome
Reinvestment Propensity



MSRS
60
50
40
30
20
10
0
Low Go RTV
High Go RTV
Low Anxiety
High Anxiety

Highlights

- The link between propensity for reinvestment and inhibition was investigated
- Higher reinvestment scores were associated with better inhibition ability
- Anxiety moderated the link between movement specific reinvestment and inhibition

Conflict of Interest

The authors declare no conflict of interest.