Title: Subjectively perceived control drives affective, neural, and motivational markers of self-related outcome valuation

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Abstract

Experiencing one's own life as controllable is essential for human well-being. Based on the theory that subjectively perceived control (SPC) hinges on the attribution of events to the self, we test the effects of SPC on the affective evaluation of task outcomes, neural dynamics, and ensuing behavioral preferences. In three independent studies we show that SPC increases dynamics in self-evaluative affect and engages brain networks processing self-referential information in the cortical midline. Specifically, the ventromedial prefrontal cortex tracks both outcome value and SPC and covaries with self-evaluative affect. Furthermore, high SPC and greater affective dynamics relate to greater functional coupling between the ventral striatum and cortical midline structures during outcome consumption. Finally, we show that these affective reactions promote motivation and the subjective value of controllable tasks. Our investigations emphasize the importance of subjective models of how behavior leads to desired outcomes for positive affect and intrinsic motivation.

Introduction

The subjective experience of being in control of one's environment is essential for well-being (Leotti, Iyengar, & Ochsner, 2010; Ryan & Deci, 2000; Ryff, 1989). The importance of control beliefs has been formulated in influential theories (Ajzen, 2002; Bandura, 1977; Rotter, 1966) and demonstrated in decades of empirical studies. Control beliefs can thereby determine whether individuals will show effort (Eccles & Wigfield, 2002), make career choices (Guay, Senecal, Gauthier, & Fernet, 2003), and are more generally considered to be a protective factor for various psychiatric phenomena (Kadden & Litt, 2011; Muris, 2002; Weisz, Weiss, Wasserman, & Rintoul, 1987). In contrast, the conviction of having no control and thus being at the mercy of one's environment has been linked to learned helplessness and major depression (Nolen-Hoeksema, Girgus, & Seligman, 1986), a debilitating psychiatric condition that is characterized by attenuated affect, reduced levels of motivated behavior and diminished self-esteem (World Health Organization, 1993).

Having opportunities to choose is a fundamental prerequisite of exerting control (Leotti et al., 2010). Choice opportunities allow to pick between options with different value (Bartra, McGuire, & Kable, 2013; Kable & Glimcher, 2007), and thus are a means for maximizing the probability of achieving desired outcomes, avoiding potential hazards, and reducing uncertainty (Rushworth & Behrens, 2008). The importance of exerting control over one's environment has stimulated the idea that having choices per se carries intrinsic value (Leotti et al., 2010). Studies have demonstrated that humans favor choice options that are followed by a second choice over those that are not (Bown, Read, & Summers, 2003), or prefer tasks with more over those with fewer choice options (Suzuki, 1997). Relatedly, humans prefer stimuli selected freely during a preceding task over those that a computer had selected for them, despite equal monetary value of the stimuli (Cockburn, Collins, & Frank, 2014). Neuroscience studies also support the notion that choices have intrinsic value. Despite a lack of response-outcome-contingency, it has been shown that choices are preferred over non-choices, and cues signaling an upcoming choice were associated with increased activity in the ventral striatum (VS; Leotti & Delgado, 2011, 2014), a region

implicated in dopaminergic reward processing (O'Doherty, Buchanan, Seymour, & Dolan, 2006; Pagnoni, Zink, Montague, & Berns, 2002).

Although having choices is the condition precedent for exerting control, the lynchpin of theory and empirical evidence relating subjectively perceived control (SPC) to well-being are self-related thoughts and subjective models of whether an outcome can be achieved due to the capabilities of the agent (Ajzen, 2002; Ryan & Deci, 2000; Ryff, 1989). The experience of SPC should increase if internal models of behavior are available that explain how actions – if executed correctly – yield a specific outcome (Ly, Wang, Bhanji, & Delgado, 2019), in contrast to settings in which the available choices are unrelated to the outcomes obtained (Leotti & Delgado, 2011, 2014). For the experience of SPC it is one thing betting on a color in a game of roulette and another shooting a penalty even in the unlikely case of similar outcome probabilities. Since in the latter situation the scoring of a goal can be attributed to the self, own efforts, and abilities, SPC should be more pronounced with broader implications for self-related affect and motivation (Tracy & Robins, 2004; Williams & DeSteno, 2008).

Theories on self-conscious affect predict that differences in SPC shift the valuation of outcomes and result in distinct patterns of affective experience (Ferguson, Stegge, Eyre, Vollmer, & Ashbaker, 2000; Tangney, Stuewig, & Mashek, 2007). Precisely, the attribution of outcomes to controllable and internal causes (Rotter, 1966) is a necessary condition for the experience of the self-conscious affect of pride (Tracy & Robins, 2007b). The concept of pride essentially hinges on a subjective model of control – the belief that an outcome was caused by one's own actions – resulting in self-approval in case the event is relevant for personal goals (Leary, 2007; Tracy & Robins, 2007a). Pride experiences thus underlie self-esteem (Tracy, Cheng, Robins, & Trzesniewski, 2009), foster intrinsic motivation (Williams & DeSteno, 2008), and thus mediate the contribution of SPC to well-being (Ryff, 1989; Tracy et al., 2009). In contrast, positive events caused by uncontrollable factors such as winning a lottery also drive affective dynamics such as momentary happiness (Rutledge, de Berker, Espenhahn, Dayan, & Dolan, 2016; Rutledge, Skandali, Dayan, & Dolan, 2014), but do not have similar consequences in terms of self-relevance and motivation (Williams

& DeSteno, 2008). In this line, earnings that have been obtained through own efforts and labor are valued more than windfall gains (Norton, Mochon, & Ariely, 2012), thereby contributing to the effort paradox that the value of effort sometimes exceeds its costs (Inzlicht, Shenhav, & Olivola, 2018).

In the present study we test how SPC impacts the affective valuation of outcomes, how this relates to shifts in neural processing of objectively similar task outcomes and provide evidence that the subjective value of control is related to affective dynamics. To do so, we introduce a novel paradigm that in addition to mere choice (Leotti & Delgado, 2011) extends the concept of SPC to an experimental condition allowing subjects to attribute task outcomes to their own performance (Ly et al., 2019), while controlling outcome probabilities. This is a key step since with increasing SPC outcomes also get more predictable and less uncertain in everyday life (Ajzen, 2002; Bandura, 1977; A. Clark, 2013; Huys & Dayan, 2009).

As predicted by theory, affective and especially pride dynamics should be most strongly modulated by outcomes if these are perceived to depend on one's own behavior. Aside from the ventral striatum, prior evidence suggests the ventromedial prefrontal cortex (vmPFC) to be a key cortical interface for integrating SPC in outcome valuation. The vmPFC has extensive connections with the ventral tegmental area, the amygdala and the striatum (Kim et al., 2011; Price, 2007), is associated with domain general computations of value (Bartra et al., 2013; Clithero & Rangel, 2014) and has been linked to behavioral control and persistence in the face of failure (Bhanji & Delgado, 2014; Maier & Seligman, 2016; Salomons, 2004). The vmPFC belongs to structures of the cortical midline implicated in self-related processing (CMS; Denny, Kober, Wager, & Ochsner, 2012; Northoff & Bermpohl, 2004; van der Meer, Costafreda, Aleman, & David, 2010). Specifically, the vmPFC has been associated with the generation of affective meaning (Etkin, Egner, & Kalisch, 2011; Roy, Shohamy, & Wager, 2012), the value of revealing information about the self (Tamir & Mitchell, 2012), and updating of self-esteem and self-relevant optimistic beliefs (Kuzmanovic, Jefferson, & Vogeley, 2016; Will, Rutledge, Moutoussis, & Dolan, 2017). These findings suggest the vmPFC to serve a central function for the SPC-dependent valuation of task outcomes and associated self-related affective dynamics.

110 In a series of three consecutive experiments with independent samples (total *N*=129) we
111 systematically manipulate levels of SPC beyond having a choice or not. We use a novel paradigm inducing
112 low, medium, and high SPC (LC, MC, HC) via, respectively, a non-choice task, a choice task, and a
113 performance-based task that allows attributing outcomes to the self. Across all three conditions, rates of
114 successes (WIN) and non-successes (noWIN) are kept at 50% (see figure 1). In study 1 we test whether
115 affective responses to outcomes depend on SPC as predicted by theory. In study 2, we replicate and extend
116 study 1 by characterizing affective and neural dynamics in response to outcomes obtained at different
117 levels of SPC during task execution. We focus our analyses on brain regions processing reward value and
118 self-referential processes, specifically the vmPFC. As a last step, in study 3 we predict the subjective value
119 of SPC based on the dynamics of self-related positive affect by introducing an adaptive preference task.
120 Our results support the broad impact of SPC on affect, motivated behavior and underlying brain function.
121 We find that the value of control is associated with self-related affective responses and may even outweigh
122 a monetary detriment entailed by preferences for control.
123

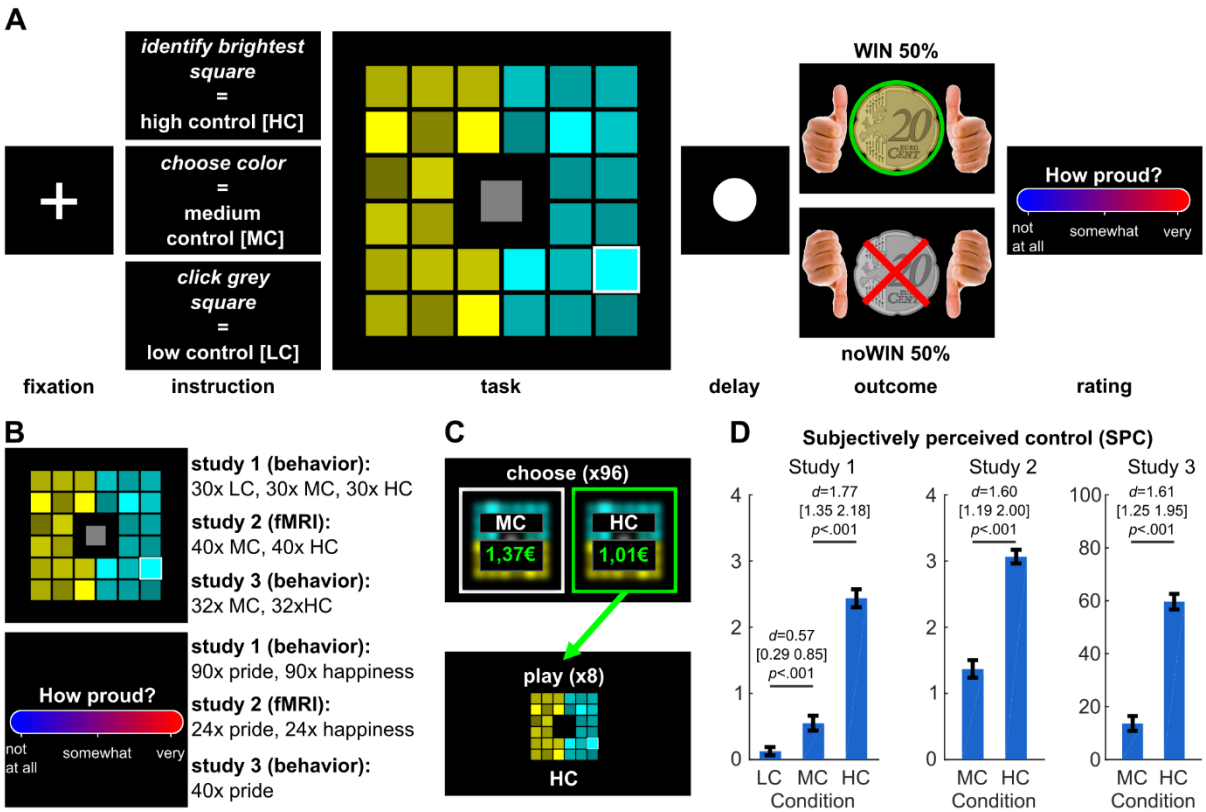

Figure 1. Overview about the experimental paradigm and the three studies. **A** Trial structure of the task. A fixation cross was followed by a cue indicating that the participant has to find the brightest square within either turquoise or yellow (high control, HC), choose between yellow and turquoise (medium control, MC), or play a gamble by clicking on the grey square in the middle (low control, LC; only presented in study 1). After the cue, the task grid occurred and was followed by a delay and task outcomes. Pride and happiness ratings regarding the preceding outcome were presented after the outcome phase. **B** Overview of the three studies. The task was presented in each study with varying numbers of trials and conditions. **C** In study 3, after the main task, 96 trials of a choice task were presented. The choice options offered to play either HC or MC with adaptively changing amounts of money determined using a staircase algorithm. Participants were informed that some of the chosen options would be actually presented and that the associated monetary gain would be awarded at the end of the experiment. **D** Subjectively perceived control (SPC) ratings for each study. *d* = Cohen's *d*. Values in brackets represent lower and upper bounds of 90% confidence intervals. HC=high control. MC=medium control. LC=low control. Errorbars are +/- 1 standard error of the mean.

Results

Study 1: Subjectively Perceived Control Differentiates Affective Dynamics Of Pride And Happiness

Study 1 directly manipulated levels of subjectively perceived control (SPC) above and beyond having a choice or not. In brief, we presented participants (*N*=40) with a grid of one centered grey square and 32 surrounding squares that were separated into two parts of shaded colors (see figure 1). This allowed to implement three different conditions that were pseudorandomly presented and cued before each trial. On the lowest level of SPC, successes (WIN outcomes; 0.20 €) and non-successes (noWIN outcomes; 0.00 €) depended on an automated gamble which was initiated by clicking on the grey square (low control, LC; see figure 1). On the medium level of SPC, WIN and noWIN outcomes allegedly depended on the correct choice between the two colors (medium control, MC). On the highest level of SPC, WIN and noWIN outcomes depended on whether subjects were able to identify the brightest square within the shades of one color (high control, HC). Unknown to the participants, across all three conditions outcome probabilities were held constant at 50% by predefined feedback (see methods for details). Each condition was presented 30 times, i.e. a total of ninety trials was presented, and ratings of both pride and happiness were acquired after each outcome. After completion of the experimental tasks, subjects rated their SPC together with subjective experience of outcome probabilities for the different conditions.

Subjects experienced the HC condition as more controllable than the other conditions (main effect of condition: $F(1.74, 76.72)=133.97$, $p<.001$; planned comparisons: HC>MC: $t(39)=11.21$, $p<.001$, $d=1.77$, 90% CI=[1.35; 2.18]; MC>LC: $t(39)=3.60$, $p<.001$ $d=0.57$, 90% CI=[0.29; 0.85]; Bonferroni-corrected for

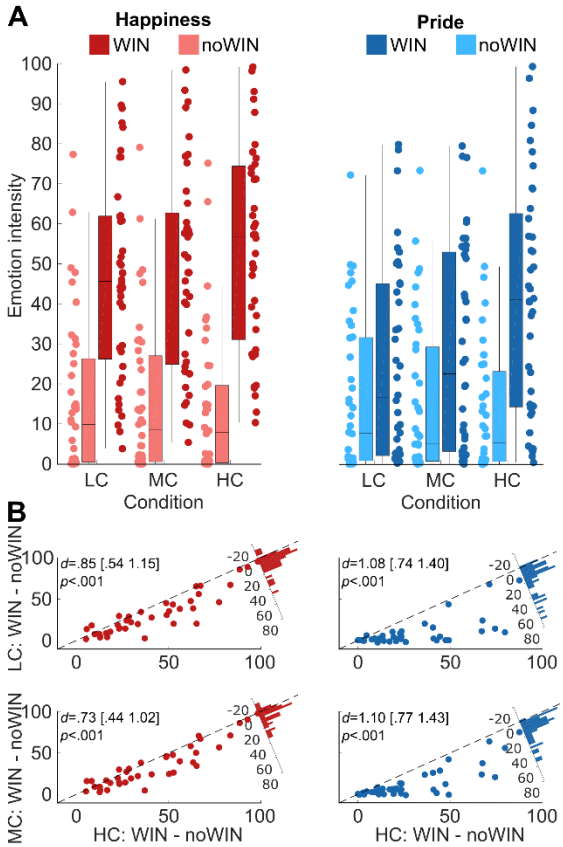

Figure 2. Task effects on emotion ratings in study 1 **A** Emotion ratings from study 1, separate for pride and happiness, high, medium and low control as well as outcome valence. **B** Scatterplots depict reactivity to WIN vs noWIN outcomes for happiness (left) and pride (right) in dependence of SPC condition (x-axis: HC; y-axis (top): LC; y-axis (bottom): MC). Top and bottom rows depict relationships between emotion reactivity in LC and HC, as well as MC and HC, respectively. Histograms in top right corners visualize the differences in emotion reactivity between HC and LC (top row), or HC and MC (bottom row). HC=high control. MC=medium control. LC=low control. *d*=Cohen's *d*. Values in brackets represent 90% confidence intervals for *d*.

multiple comparisons, one-sided). As predicted by theory, the dynamics in the pride experiences induced by succeeding (WIN vs noWIN) depended more strongly on the level of SPC than it was the case for happiness ratings (condition*affect*outcome valence: $F(1.29,50.10)=11.44$, $p<.001$, $\eta_p^2=.23$; figure 2, for full rmANOVA effects, see Supplement 1 – table S1). Paired comparisons showed that affect ratings were higher for WIN than for noWIN outcomes for both happiness (LC: $t(39)=7.85$, $p<.001$; MC: $t(39)=8.16$, $p<.001$; HC: $t(39)=9.74$, $p<.001$) and pride (LC: $t(39)=3.29$, $p<.001$; MC: $t(39)=4.41$, $p<.001$; HC: $t(39)=7.37$, $p<.001$, all *p*-values one-sided and Bonferroni-corrected for multiple comparisons). These differences were larger in HC than in MC (pride: $t(39)=6.97$, one-sided $p<.001$; happiness: $t(39)=4.64$, two-sided $p<.001$), and larger in MC than in LC for pride ($t(39)=3.03$, one-sided $p=.013$), but not happiness ($t(39)=2.24$, two-sided $p=.093$, all *p*-values corrected for multiple comparisons), showing that SPC drives affective dynamics in general. Importantly, the pride response (i.e. the difference [HC:WIN-HC:noWIN]-[MC:WIN-MC:noWIN]) increased more strongly from MC to HC than the happiness response ($t(39)=3.69$, one-sided $p<.001$), while

no difference was found when comparing pride and happiness responses between LC and MC ($t(39)=1.57$, one-sided $p=.124$, Bonferroni-corrected for multiple comparisons). These findings demonstrate that SPC depends on contexts in which behavior can be guided by internal models that explain how outcomes can be achieved through own actions. If such self-attribution is possible, SPC increases beyond having a choice or not, effectively increasing the self-relevance of outcomes and changing their affective valuation, driving pride more strongly than happiness. In contrast, merely choosing without any knowledge of how choices lead to outcomes may be rewarding in itself (Leotti & Delgado, 2011), but falls short of SPC as defined in classic theories and has little impact on self-related affect.

Study 2: The VMPFC Links SPC To Its Affective Consequences

In study 2 we replicated and extended study 1 by characterizing the neural correlates of SPC and its impact on affective dynamics in response to outcomes. Subjects (N=39) underwent fMRI scanning while performing the identical MC and HC conditions from study 1, which there showed strongest effects with regards to the affective response to SPC and should be contrasted for developing theory and the neuroscience of SPC. A total of 80 trials were presented, with ratings of either pride or happiness (24 each) acquired after every second to third outcome.

Subjectively perceived Control shapes affective Dynamics. The results of study 2 replicated those of study 1 (figure 3). Subjects experienced much higher SPC in HC than in MC (paired-sample t-tests: $t(37)=9.85$, $p<.001$, $d=1.60$, 90% $CI=[1.19; 2.00]$), and affect ratings differed between tasks with different levels of SPC (rmANOVA: main effect of condition: $F(1,38)=8.38$, $p=.006$, $\eta_p^2=.18$). Comparably to study 1, pride responses to task outcomes differed from those for happiness in dependence of SPC (condition*outcome valence*affect: $F(1,38)=9.08$, $p=.005$, $\eta_p^2=.19$). As before, we computed the affective responses separately for pride and happiness ([HC:WIN–HC:noWIN] – [MC:WIN–MC:noWIN]). The resulting pride response was significantly larger than the happiness response ($t(38)=3.01$, one-sided

183 *p*=.005), emphasizing how self-related positive affect hinges on the subjective belief that outcomes

184 depend on one's own actions (for full rmANOVA effects, see Supplement 1 – table S2).

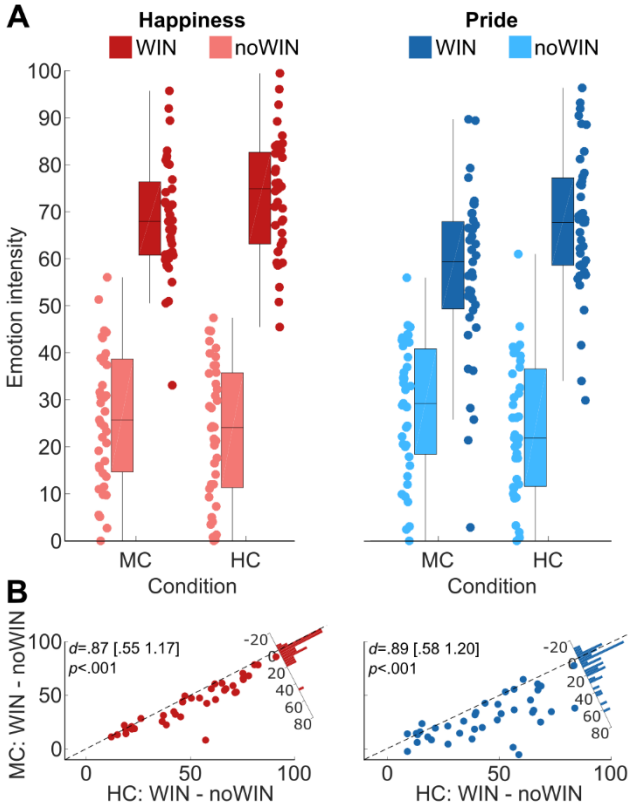

Figure 3. Task effects on emotion ratings in study 2 **A** Emotion ratings from study 2, separate for pride and happiness, high and medium control as well as outcome valence. **B** Scatterplots depict reactivity to WIN vs noWIN outcomes for happiness (left) and pride (right) in dependence of SPC condition (x-axis: HC; y-axis: MC). Histograms in top right corners visualize the differences in emotion reactivity between HC and MC. HC=high control. MC=medium control. *d*=Cohen's *d*. Values in brackets represent 90% confidence intervals for *d*.

185

186 **Neural Responses to SPC.** Receiving a positive outcome (WIN>noWIN) yielded significant

187 activations in regions associated with processing of value (as indicated by ROI-analyses using the

188 VALUE¬SELF mask, covering areas associated with the term "value", but not "self-referential"; created

189 using Neurosynth; Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011; see methods). Specifically, we

190 observed significant activation clusters with peaks in bilateral ventral striatum (VS; left: x,y,z (mm): -14,8,-

191 10, *t*(114)=8.18; *Z*=7.24, *k*=235; right: 16,4,-12, *t*(114)=7.69; *Z*=6.89, *k*=233; all coordinates in MNI space),

192 anterior cingulate cortex (ACC; -2,44,-6, *t*(114)=6.71; *Z*=6.15, *k*=108), superior medial frontal gyrus (-2,58,0,

193 *t*(114)=8.14; *Z*=7.21, *k*=61), and vmPFC (4,48,-2, *t*(114)=5.59; *Z*=5.24, *k*=12; all p-values <.05, FWE-

194 corrected within the VALUE¬SELF mask; for whole-brain effects see Supplement 2).

Receiving outcomes attributable to one's own actions (HC>MC) yielded significant activations in CMS (ROI-analysis using the SELF¬VALUE mask, covering regions associated with the term "self-referential" but not "value"; Yarkoni et al., 2011), with peaks in left vmPFC (-8,50,-12, $t(114)=6.34$; $Z=5.85$, $k=27$), and left ACC (-2,38,4, $t(114)=6.27$; $Z=5.80$, $k=108$). In addition, this contrast yielded significant effects in posterior CMS, specifically the left cuneus (-8,-58,20, $t(114)=6.61$; $Z=6.07$, $k=208$), extending to precuneus (-6,-50,6, $t(114)=5.60$; $Z=5.25$, $k=14$; all p-values <.05, small-volume FWE-corrected). These findings indicate, that, as expected, cortical regions associated with processing of self-relevant information are engaged when outcomes are obtained in task environments that are perceived as controllable and thus provide information about the subjects' capabilities (Northoff & Bermpohl, 2004; Tracy & Robins, 2007b).

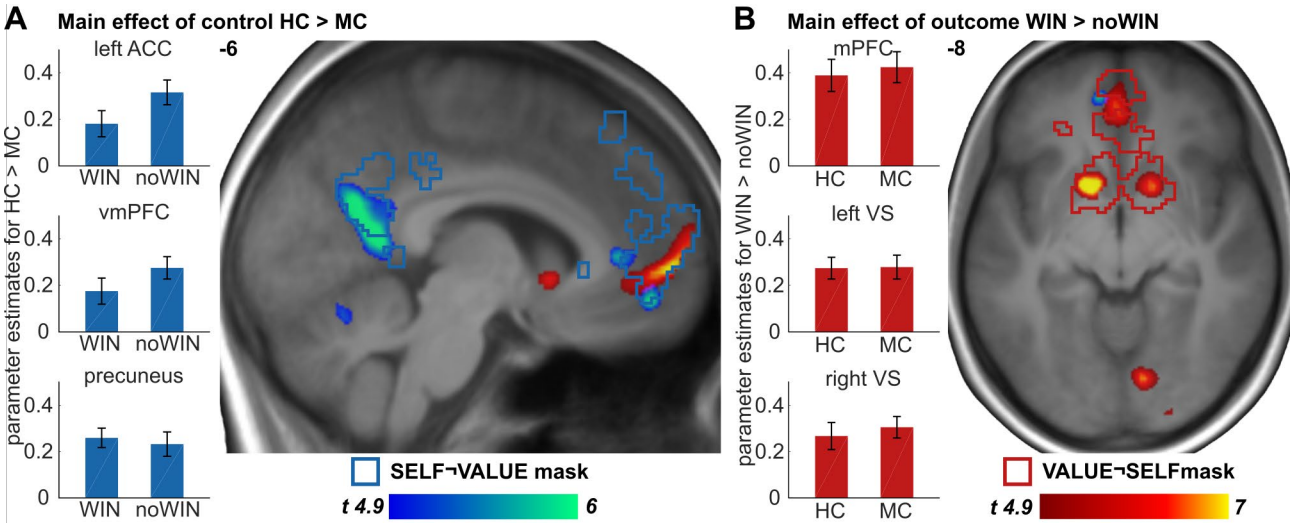

Figure 4. BOLD effects of the MRI task. **A** HC>MC (blue-green) and **B** WIN>noWIN (red-yellow) displayed at p<.05, whole-brain FWE-corrected. Blue and red outlines represent masks for SELF¬VALUE and VALUE¬SELF, respectively. Barplots on the left represent average effects across participants for all voxels inside HC>MC clusters. Barplots on the right depict average effects across participant s for all voxels inside WIN>noWIN clusters. Errorbars are +/- 1 standard error of the mean.

Next, we were interested in the additive effects of SPC and success, thus describing specific neural correlates of receiving positive outcomes under high SPC (three-way conjunction of [HC:WIN>HC:noWIN] ∩ [HC:WIN>MC:WIN] ∩ [HC:WIN>MC:noWIN]; figure 5). This analysis revealed that the left vmPFC, specifically, is more strongly engaged when subjects' successes are attributable to their own actions (-

4,48,-10, $t(114)=3.45$; $Z=3.36$, $k=11$, $p=.023$, FWE-corrected within the SELF∩VALUE mask, covering regions associated with both "self-referential" and "value", according to Neurosynth; Yarkoni et al., 2011). The additivity of the effect in this region is illustrated by the common of responses to winning (WIN>noWIN: -2,48,-4, t(114)=7.60; Z=6.82, k=193; p<.05, FWE-corrected) as well as task controllability (HC>MC; -8,48,-12, t(114)=6.13; Z=5.69, k=162, p<.05, small-volume FWE-corrected). The localization of this effect thus mirrors how the processing of value and self-reference converges in the vmPFC (D'Argembeau, 2013; Will et al., 2017).

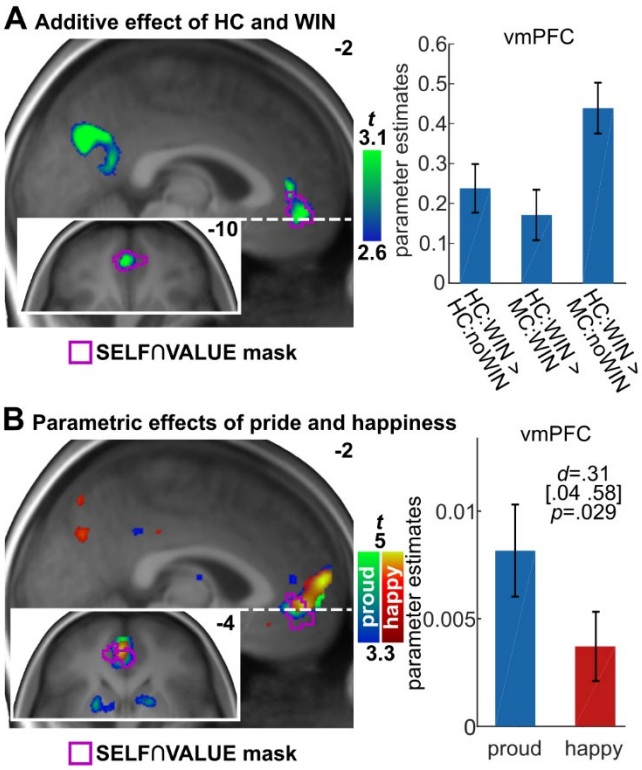

Figure 5. Additive effect of winning under high control and parametric effects of emotion ratings. **A** Activations show the specific effect of HC:WIN (i.e. 3-way conjunction [HC:WIN>HC:noWIN] ∩ [HC:WIN>MC:WIN] ∩ [HC:WIN>MC:noWIN], displayed at $p<.005$, uncorrected. The conjunction contrast survived small-volume FWE-correction at $p<.05$ inside the SELF∩VALUE mask in vmPFC. Bar plot represents differences of neural activation in vmPFC between HC:WIN and the other three outcomes. **B** Parametric modulation effect of happiness (red-yellow) and pride ratings (blue-green) at outcome presentation, displayed at $p<.001$, uncorrected for illustrative purposes. Bar plot shows group-level parameter estimates of the parametric modulations, averaged across all voxels inside the SELF∩VALUE mask. Violet outlines show SELF∩VALUE mask. Errorbars are +/- 1 standard error of the mean. *d*=Cohen's *d*. Values in brackets are lower and upper bound of of 90% confidence interval for *d*.

Parametric Effects of affective Dynamics. We next aimed to link BOLD responses of task outcomes to intra-individual dynamics in the experiences of pride and happiness. (figure 5). We found that within-subject dynamics in happiness were significantly correlated with neural activity within the VALUE¬SELF mask at outcome presentation (16,2,-12, $t(38)=4.55$, $Z=4.04$, $k=3$, $p=.022$), as well as the SELF∩VALUE mask (left vmPFC; -2,48,-4, $t(38)=4.60$, $Z=4.08$, $k=47$, $p=.002$). Within-subject variability in pride ratings showed

more extended significant effects in the SELF¬VALUE mask (dorsal medial prefrontal cortex dmPFC; -2,56,2, $t(38)=5.96$, $Z=4.98$, $k=122$, $p=.001$) and the VALUE¬SELF mask (dmPFC; -2,56,0, $t(38)=6.15$, $Z=5.09$, $k=22$, $p<.001$). In addition, variability in pride ratings correlated significantly with BOLD responses in the SELF∩VALUE mask (left vmPFC; -4,48,-6, $t(38)=4.83$, $Z=4.24$, $k=94$, $p=.001$; all p-values small-volume FWE-corrected; see Supplements 2). Notably, pride ratings covaried more strongly with neural activity in vmPFC than happiness ratings (paired-sample t-test on mean beta estimates for all voxels inside the SELF∩VALUE mask: $t(38)=1.951$, one-sided $p=.029$, $d=.31$, $CI=[.04\ .58]$), indicating that neural activity in vmPFC is more strongly linked to affective experience when the causes of such experiences allow self-evaluation and might bear implications for one's future behavior (Roy et al., 2012; Tracy & Robins, 2004).

Functional Connectivity in Dependence of SPC. Psychophysiological interaction (PPI) analysis demonstrated that when task outcomes were received in the HC condition, functional connectivity increased between the left VS and left vmPFC (6,48,-14, $t(37)=3.80$; $Z=3.47$, $k=48$, $p=.017$; small-volume-corrected within the SELF∩VALUE mask). Though much more spatially extended in the CMS, this effect partly converged with the additive effects of success and SPC reported above. Beyond that, the left VS BOLD signal was more strongly associated with responses in the left angular gyrus (left AG) during outcome presentation in the HC as compared to the MC condition (-46,-70,38, $t(37)=5.64$; $Z=4.76$, $k=24$, $p=.001$ small-volume FWE-corrected inside the SELF¬VALUE mask, surviving whole brain FWE-correction: -44,-70,40, $t(37)=5.67$, $Z=4.78$, $p=.035$). The equivalent analyses for the right VS showed significant effects in left superior frontal gyrus (-18,38,46, $t(38)=4.59$; $Z=4.07$, $k=4$, $p=.028$, small-volume FWE-corrected inside the SELF¬VALUE mask), but not in vmPFC (4,38,-4, $t(38)=3.23$; $Z=3.02$, $p=.069$, small-volume FWE-corrected inside the SELF∩VALUE mask). At a more lenient exploratory threshold, for both left and right VS, we observed spatially extended connectivity changes in regions covered by the SELF¬VALUE and SELF∩VALUE masks, such as the left AG, the dmPFC, ACC, and the vmPFC ($p<.001$; see Supplement 2). These findings align with the notion that outcome-related information processed in regions such as the

ventral striatum (Pagnoni et al., 2002) are more strongly integrated with self-related representations in high SPC contexts, allowing to relate one's own actions to ensuing outcomes.

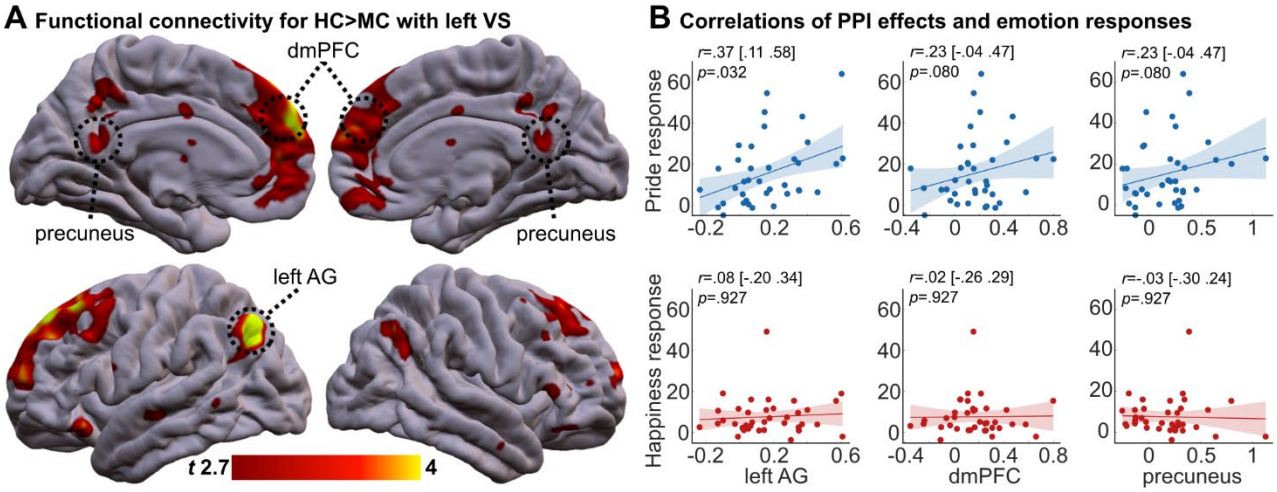

Figure 6. Increased functional connectivity with left VS in response to outcomes obtained under high subjectively perceived control tasks. **A** ROI analysis showed increased coupling between left VS and the left AG, the dmPFC and precuneus (small-volume FWE-corrected at $p<.05$). Effects in are displayed at $p<.005$, whole-brain, for illustrative purposes. See Supplement 2 for full connectivity coordinates. **B Top** Bivariate correlations between pride response (i.e. [HC:WIN - HC:noWIN] - [MC:WIN - MC:noWIN]) and estimates of functional connectivity from left AG, dmPFC and precuneus. Eigenvariates of clusters within the SELF¬VALUE mask consisting of voxels showing significantly increased functional connectivity with VS at $p < .0005$ (uncorrected) were computed for the three regions highlighted in A. *p-value*s are one sided and false-discovery-rate corrected. **Bottom** Analyses for happiness response equivalent to the ones performed for pride ratings. r = Pearson correlation coefficient. Values in brackets are 90% confidence intervals and shaded areas represent 95% confidence intervals.

Based on the assumption that stronger integration of self- and outcome-related processing should relate to more pronounced pride responses, we performed additional exploratory analyses on the SPC-dependent connectivity dynamics. These showed that the observed increases of connectivity with the VS correlated significantly with the behaviorally measured pride response, at least in the left AG (r=.37, p=.032; dmPFC: r=.23, p=.080; precuneus: r=.23, p =.080, FDR-corrected one-sided p-values; figure 6, see methods for details). This implies that pride dynamics relate to changes in functional coupling of the VS with brain regions associated with self-referential processes. The equivalent analyses for the happiness response did not show any significant effects (left AG: r=.08, p=.582; dmPFC: r=.02, p=.582; precuneus: r=-.03, p =.582; FDR-corrected one-sided p-values). However, we note that these correlations did not differ significantly between pride and happiness (left AG: Hotelling's $t(35)$ = 1.84, p=.088; dmPFC: Hotelling's

258 $t(35) = 1.29$, $p=.102$; precuneus: Hotelling's $t(35) = 1.60$, $p=.088$; FDR-corrected one-sided p-values). While
259 general positive affect has recently been shown to relate to neural activity also elicited by surprising and
260 uncontrollable task outcomes (Rutledge et al., 2016, 2014) these data demonstrate that positive affect is
261 also considerably shaped by perceived control over task outcomes. Precisely, SPC increases self-relevance
262 of task outcomes, driving activity in CMS and dynamics of self-related affect upon outcome reception
263 (D'Argembeau, 2013; Northoff & Bermpohl, 2004; Tracy & Robins, 2007b). These shifts in affective and
264 neural dynamics effectively display as increased reports of pride experiences (Lindquist, 2013), which
265 relate to activity in the vmPFC as shown above and are assumed to bear implications for future behavior
266 (Roy et al., 2012; Tracy & Robins, 2007b).
267
268 **Study 3: Pride As An Affective Marker For The Subjective Value Of Control**
269 In study 3 we aimed to predict behavior based on SPC-related affective experiences of pride. We
270 show that participants' preference for controllable tasks is related to their pride response, even at a
271 monetary cost. Subjects (N=50) completed a total of 64 trials of MC and HC (32 each), with pride ratings
272 acquired after 40 outcome presentations. Following the task presented in study 2 (hereafter: the main
273 task), we subsequently assessed whether subjects preferred HC or MC when different monetary amounts
274 were offered. We employed an adaptive staircase algorithm (Leek, 2001) thus varying the offers presented
275 for HC and MC on every trial in a fashion allowing to identify each subject's decision point. To increase the
276 relevance of the task, subjects were informed that at random intervals some trials were going to be
277 executed right after their choice. The chosen option, i.e. HC or MC with the associated potential payoffs,
278 could then be played and the sum earned through successful task completion was awarded at the end of
279 the experiment. Eight trials were pseudorandomly selected and presented to the subjects after the
280 respective choice, however without the presentation of task outcomes.

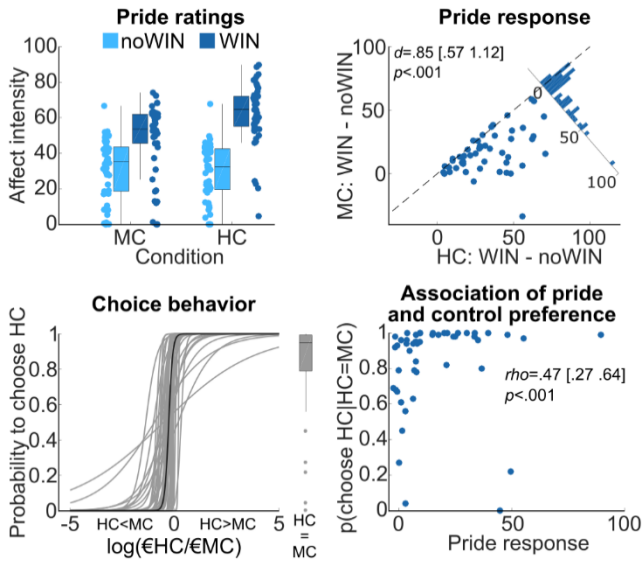

Figure 7. The experience of pride in response to high SPC affects subjective value of choices. **Top left** Pride ratings for study 3, separate for high and low control, as well as outcome valence. **Top right** Pride reactivity to WIN vs noWIN outcomes, separately for HC (x-axis) and MC (y-axis). Histogram depicts difference between HC and MC. *d*=Cohen's *d*. Values in brackets represent lower and upper bound of 90% confidence interval for *d*. **Bottom left** Probability to choose HC in choice task of study 3 as a logistic function of log-transformed relative option values (log(€HC/€MC)). More positive values on horizontal axis indicate higher monetary value of HC relative to MC. Thin grey lines represent individual participants' choice functions. Thick black line represents hypothetical choice behavior based on sample medians for β_0 and β_1. Boxplot represents participant' probabilities to choose HC, given that both options have equal values. **Bottom right** Relationship of pride response and choice behavior in study 3. *rho*=Spearman's rho. Values in brackets are lower and upper bound of 90% confidence interval for *rho.*

Confirming studies 1 and 2, subjects experienced higher SPC in HC than in MC ($t(49)=11.35$, $p<.001$, $d=1.61$, 90% *CI*=[1.25; 1.95]). Again, pride reactivity to outcomes differed between HC and MC (condition*outcome valence: $F(1,49)=35.98$, $p<.001$, $\eta_p^2=.42$; figure 7). Specifically, pride was rated higher for WIN than for noWIN outcomes (MC: $t(49)=7.15$, one-sided $p<.001$; HC: $t(49)=12.37$, one-sided $p<.001$, Bonferroni-corrected for multiple comparisons). In addition, the difference in affect ratings between WIN and noWIN outcomes was larger in the HC condition than in the MC condition ($t(49)=6.00$, one-sided $p<.001$; see table S3 for full results of rmANOVA).

In the choice task, the mean percentage of choices in favor of the HC option was 58.1% (*SD*=10.2 %), which was significantly higher than chance ($t(49)=5.62$, one-sided $p<.001$). The mean value of the chosen MC options was 1.19€ (*SD*=.09€) and that of the chosen HC options was 1.03€ (*SD*=.07€; paired *t*-test: $t(49)=8.20$, one-sided $p<.001$), indicating that participants had a preference for the HC task, despite having a 13.4% smaller payoff than for the MC options.

In order to better characterize the choice behavior, we assessed the model parameters of a logistic choice model fit to each participant's data (see methods). Across participants, the mean value of the

295 models intercept β_0 was significantly negative (*M*=-3.49, *SD*=4.18, *t*(49)=-6.00, one-sided *p*<.001)
296 indicating that participants preferred the HC option over the MC option, if both options offered equal
297 monetary payoffs. Similarly, β_1 was significantly negative (*M*=-17.21, *SD*=19.67; *t*(49)=-6.19, one-sided
298 *p*<.001), showing that across participants, as expected, the probability for choosing HC increased with
299 higher monetary gain for HC relative to MC (figure 7). Since β_0 is directly convertible into the probability
300 to select HC given equal monetary payoffs of the two options, we will base the following analyses on this
301 more intuitive measure. More specifically, if the nominal monetary offer for both options was equal, there
302 was a strong preference for HC, with over 90% of the participants preferring the controllable over the less
303 controllable option (*MD*=95.1 %, *IQR*=20.48, figure 7), which was significantly above 50% (Wilcoxon signed-
304 rank *W*=1182, one-sided *p*<.001). Importantly, the subjects' probability to choose HC given equal expected
305 values for HC and MC remained significantly above 50% (*MD*=65.98%, *IQR*=50.48, Wilcoxon signed-rank
306 *W*=863, one-sided *p*=.015) even when considering differences in expected outcome probabilities, by
307 controlling for differences in subjectively perceived winning histories, that deviated from the objectively
308 presented outcome rates of 50% for the two tasks (see Methods).
309 A further goal of study 3 was to demonstrate that participants' preference for HC over MC varies
310 in dependence of the affective dynamics during the main task. As expected, individuals who had a more
311 positive pride response showed a stronger preference for HC in the choice task, given equal values of the
312 two choice options (Spearman's *rho*=.47, one-sided *p*<.001; figure 7). This association remained significant
313 even after controlling for various control variables such as expended effort or perceived winning
314 probabilities (see Supplement 1 - table S4). This extends previous results showing that mere choice is
315 preferable to not having choices by highlighting the notion of instrumental control over the outcomes for
316 building preferences (Ly et al., 2019), and emphasizing that self-related positive affect is a relevant factor
317 for motivated behavior (Williams & DeSteno, 2008).
318

Studies 1 – 3: Interindividual Variability In SPC Predicts Pride Response

Aggregating data from all 129 participants, we finally tested whether interindividual differences in the degree to which the task could stimulate control beliefs were associated with self-related affective experiences. Across the three studies, participants who perceived more control in HC compared to MC also showed stronger pride responses (Spearman's *rho*=.25, one-sided *p*=.003; figure 8), supporting the notion of how individual differences in the experience of SPC drive self-conscious positive affect (Tracy & Robins, 2004, 2007b).

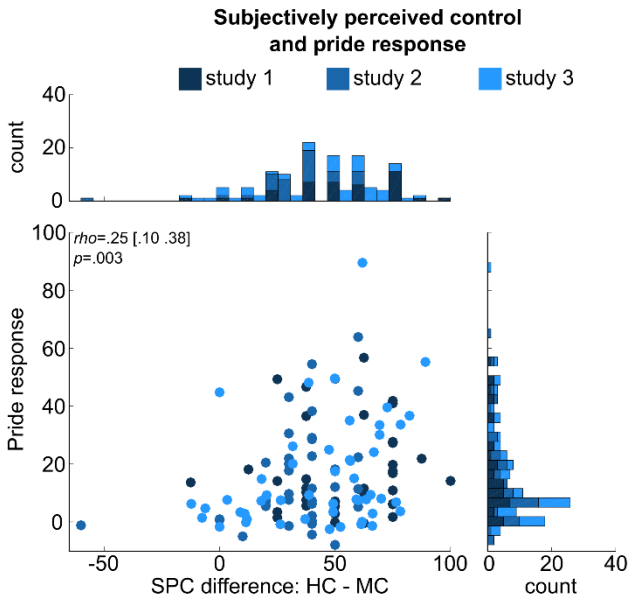

Figure 8. Association of pride response and individual differences in SPC. The scatterplot depicts the relationship between SPC and pride response across all three studies. Dark blue indicates data point belongs to study 1, intermediate blue to study 2, and light blue to study 3. Raw controllability ratings were transformed to a range between 0 and 100, across SPC conditions, before computing the difference between HC and MC in each study. For study 1, raw control and pride ratings were averaged across LC and MC. The pride response is the interaction term for pride ([HC:WIN–HC:noWIN] - [MC:WIN–MC:noWIN]). Histograms depict counts for difference in perceived control (top), and pride response (right). Values in brackets represent lower and upper bounds of the 90% confidence interval for *rho*.

Discussion

By employing a novel experimental paradigm, we demonstrate that the perception of control over task execution, i.e. its potential mastery, has intrinsic value and unique affective consequences. Precisely, subjectively perceived control (SPC) differentiates self-conscious positive affect – i.e. pride – from more unspecific positive affect – i.e. happiness – when receiving task outcomes. Using functional magnetic resonance imaging, we furthermore characterize brain regions involved in altered valuation of outcomes of controllable tasks. When outcomes are received in a high SPC task we see increased activity in brain regions of the cortical midline, such as the medial prefrontal cortex and precuneus, that are associated with self-related processing (D'Argembeau, 2013; Northoff & Bermpohl, 2004). Here, the vmPFC seems to play a key role in tracking both, reward value as well as self-relevance. In addition, these regions are functionally more strongly coupled to brain regions processing reward information, i.e. ventral striatum, when outcomes depend on one's own behavioral performance. In a final step, we highlight the subjective value of the emerging self-related affect, as people discount monetary gains to perceive control over task execution in dependence of their pride response during task execution.

Overall, our findings from three independent samples provide evidence for the link between SPC and the affective reaction of pride. This concords with psychological theories of self-conscious affect, stating that SPC allows attributing task outcomes to internal causes, such as one's abilities (Ryan & Deci, 2000; Tracy & Robins, 2004). As noted by Tracy and Robins (2007), self-evaluative processes are crucial to the understanding of self-conscious affect like pride, differentiating them from other affect constructs such as happiness. While positive affect was generally increased in response to successes under high SPC this was particularly the case for pride responses and less so for participants' reports of happiness which conceptually does not necessarily include evaluative process of self-worth (Tangney & Dearing, 2002; Tracy & Robins, 2004). Since in potentially controllable contexts outcomes are informative about one's abilities, participants can use these outcomes to infer to what extent they succeed at actually exerting control.

352 Regarding affective responses, this was reflected by the fact that pride was most prominent during high
353 SPC trials.

354 Importantly, individuals with stronger SPC-dependent pride responses preferred to partake in the
355 task offering high SPC over another, less controllable one. Concordant with earlier findings (Leotti &
356 Delgado, 2011; Weidman, Tracy, & Elliot, 2016; Williams & DeSteno, 2008), and substantiating the claim
357 that self-conscious affect is central in the guidance of future behavior (Tracy & Robins, 2007), this finding
358 underlines the motivational effects of pride (Leary, 2007). Strikingly, preferring to choose an opportunity
359 to exert control outweighed a monetary detriment entailed by this choice behavior. Collectively, this
360 indicates that the development of behavioral preferences is partially driven by the extent to which an
361 individual perceives contexts to be controllable and how succeeding in such contexts manifests in the
362 experience of self-related affect, such as pride. That is, the experience of mastering a task might elicit
363 feelings of pride and competence that increase the probability of choosing to perform the same or similar
364 behaviors later on, dovetailing nicely with theories linking experiences of competence to intrinsic
365 motivation (Ryan & Deci, 2000).

366 Guided by automated meta-analysis (Yarkoni et al., 2011), we show that these effects of SPC on
367 outcome processing are mediated via two distinctive, but connected brain networks associated with the
368 processing of value and self-related information. Outcomes from tasks with high SPC were associated with
369 activity in brain regions linked to self-related information processing, such as CMS (Northoff & Bermpohl,
370 2004), since outcomes in controllable tasks are informative about one's abilities and thus inherently self-
371 relevant. This is an important amendment to previous evidence and underscores that control beliefs need
372 to be understood beyond having a choice or not in order to understand how subjects develop self-esteem
373 (Tracy et al., 2009) and concepts of their own capabilities in acting on the environment (Ryan & Deci, 2000).
374 Our findings thus are in line with other studies showing that ACC is implicated in monitoring self-initiated
375 actions (Ullsperger & von Cramon, 2004) or vmPFC being involved in outcome monitoring, especially when
376 events are relevant to the individual (Denny et al., 2012). However, while paralleling these earlier findings,

377 our data also provide novel insights by relating these processes to the concept of self-conscious affect.
378 First, in the condition eliciting the strongest pride, i.e. when receiving outcomes indicating success in a
379 controllable task, the vmPFC was significantly more active than in any other condition. Second, under high
380 SPC, regions associated with processing self-related information such as left AG, vmPFC, and dmPFC, were
381 more strongly coupled to VS, which is implicated in the processing of reward information (Pagnoni et al.,
382 2002), and these effects correlated with behaviorally measured pride responses across subjects. Third,
383 intraindividual variability in pride covaried more strongly than happiness with neural activity in vmPFC.
384 Collectively, these findings support the notion that self-related positive affect might depend on the
385 integration of outcome information with self-representations, mediated via regions of the cortical midline
386 and AG, mirroring findings of studies investigating other types of self-conscious affect (Müller-Pinzler et
387 al., 2015).

388 Regarding the relationship of affect and neural processing, Rutledge et al. (2014) more recently
389 linked moment-to-moment variability of happiness to errors in reward prediction, which in turn is
390 associated with activity in the VS. In a follow-up study, the same authors highlighted the importance of
391 investigating "instrumental control" for a deeper understanding of well-being (Rutledge et al., 2016). Our
392 study takes a first step in this direction by manipulating SPC, underlining its importance for differentiated
393 affective experience and downstream motivational effects that manifest in behavioral preferences.
394 However, our study design does not allow explicit modeling of reward expectations and associated reward
395 prediction errors. While recent work suggests how SPC and prediction error processing might interact
396 (Cockburn et al., 2014; Huys & Dayan, 2009; Ly et al., 2019), explicit neuroscientific investigations of their
397 interplay are lacking. Thus, future studies should directly test how prediction error signaling relates to SPC
398 and affective dynamics and how these processes are mediated neurally (Rutledge et al., 2016; Seth, 2013).

399 Our findings replicate and extend previous work on the value of control (Leotti & Delgado, 2011;
400 Suzuki, 1997) by demonstrating that participants preferred a controllable task over an uncontrollable one,
401 reflecting differences in subjective value that are likely processed by vmPFC (Bartra et al., 2013). This is

402 supported by previous studies showing activation differences in vmPFC for the anticipation of choice vs.
403 non-choice (Leotti & Delgado, 2011). However, the core feature of our study was a condition supplying
404 participants with an internal model of how their behavior maps to outcomes, extending the concept of
405 SPC beyond merely having a choice (Ly et al., 2019). Rather, the high SPC condition in our task suggested
406 that the subjects' performance determined whether or not a goal was reached. This condition yielded the
407 strongest affective reactivity to outcomes, which was reflected in activity changes in the vmPFC within
408 subjects and increased functional coupling of the vmPFC with VS. Hence, vmPFC might serve the
409 integration of outcome information with representations of one's abilities (Chavez & Heatherton, 2013;
410 D'Argembeau, 2013; Kuzmanovic et al., 2016), potentially driving differences in behavioral preferences for
411 subjectively more or less controllable tasks (Bartra et al., 2013; Ly et al., 2019; Maier & Seligman, 2016).
412 Future research could follow this path by assessing directly how SPC-dependent outcome valuation
413 translates into behavioral preferences in subsequent choice situations and how this might be mediated
414 neurally by processing of subjective value in the vmPFC.

415 Pride experiences in response to outcomes that can be attributed to the self foster self-esteem.
416 Thereby they effectively shape meta-cognitive beliefs about oneself and estimates of one's social status
417 (Leary, Tambor, Terdal, & Downs, 1995; Tracy et al., 2009). A recent study investigated updating of state
418 self-esteem in response to evaluation through others (Will et al., 2017) and found these updates to be
419 positively correlated with activity in vmPFC. Comparably, in a study in which participants were asked to
420 imagine or remember pride-associated events, significant activations in the medial prefrontal cortex were
421 found that extended into vmPFC (Gilead, Katzir, Eyal, & Liberman, 2016). Furthermore, two recent studies
422 have supported this role of vmPFC in the updating of self-related beliefs (Kuzmanovic et al., 2016;
423 Kuzmanovic, Rigoux, & Tittgemeyer, 2018). In this perspective, the vmPFC activation and affective
424 dynamics we observed in response to outcomes from controllable tasks might reflect correlates of short-
425 term updating beliefs about one's abilities. If subjects experience pride this might contribute to updating
426 their concepts of their own capabilities in a specific environment. In the long run, such positive self-

427 evaluations support self-esteem and help individuals with developing an understanding of their worthiness
428 (Wigfield, Eccles, Mac Iver, Reuman, & Midgley, 1991).

429 From a broader perspective the findings described here have implications for learned helplessness
430 and psychiatric conditions, such as major depressive disorder (Maier & Seligman, 2016; Nolen-Hoeksema
431 et al., 1986). Our results emphasize that lower SPC is associated with reduced attribution of positive
432 outcomes to the self, relating to decreased pride experiences. Further, these reductions in self-related
433 affective responses align with diminished preferences for tasks offering opportunities for exerting control.
434 These dependencies might contribute to reduced self-esteem in the long run (Tracy et al., 2009) and
435 reduced motivation to show goal-directed actions (Nolen-Hoeksema et al., 1986; Ryan & Deci, 2000). Such
436 processes could therefore causally relate to depressive episodes, which are centrally defined by negative
437 views of the self and lack of motivation (World Health Organization, 1993). In contrast to states of reduced
438 SPC, other psychiatric phenomena such as pathological gambling are characterized by a marked increase
439 in SPC, even in contexts offering no objective evidence for action-outcome contingencies (L. Clark et al.,
440 2013; Joukhador, Blaszczynski, & Maccallum, 2004; Langer, 1975). In this regard, our data hint at a possible
441 role of affective reactions to (un)controllable events in mediating the development of gambling addictions
442 (Wickwire, Whelan, & Meyers, 2010). Individuals who perceive control over objectively uncontrollable
443 events might experience positive self-related affect once a desired outcome – such as cracking a one-
444 armed bandit – is obtained, and might thus be at greater risk of developing gambling addictions. Therefore,
445 the findings presented here provide a first hint for future clinical research to refocus on perturbed beliefs
446 of control over the environment to understand affective and motivational symptoms as well as altered
447 neural dynamics associated with psychiatric conditions.

448 In conclusion, the three studies provide unequivocal evidence that SPC over task execution
449 impacts the valuation of the respective outcomes, resulting in entangled positive self-conscious affect and
450 behavioral preference for environments with greater perceived control. While based on a classical
451 understanding of control beliefs (Ajzen, 2002; Bandura, 1977) the present studies add to our

452 understanding of how outcomes that have been achieved through one's own actions recruit neural
453 systems involved in computations of reward value and self-relatedness (D'Argembeau, 2013). Increased
454 interactions of the ventral striatum and cortical midline structures, as well as responses of the vmPFC that
455 track both SPC-dependent shifts in outcome processing and self-conscious positive affect thereby provide
456 first links to how the experience of SPC drives motivation and future behavior (Ly et al., 2019). On a more
457 general note, our studies underline the need for the neurosciences to consider how behavior and
458 subjective experiences are shaped by beliefs individuals hold, that regard how their actions relate to events
459 in the world they live in and constantly interact with. Taking further steps in this direction promises to
460 deepen our understanding of affect, motivation, and underlying neural dynamics with important
461 implications for scientific models of behavioral control, general well-being, and psychiatry (Huys & Dayan,
462 2009; Ly et al., 2019; Ryan & Deci, 2000; Ryff, 1989).

463 **Material and Methods**

464 **Participants**

465 A total of 154 participants took part in the three studies (mean age: 23.41 years; SD: 3.41; range,
466 18-37; 77 females). All experimental designs were approved by the ethics committee of the University of
467 Lübeck, Germany (AZ 16-133). Participants had to be right-handed, speak fluent German, have no deficits
468 in color vision, normal or corrected-to-normal vision, and no pre-existing psychiatric or neurological
469 conditions. Psychology students (study 1: in the second or later year of university) were not invited. In
470 study 2, contraindications for fMRI scanning (e.g. pregnancy, metal parts inside the body) were additional
471 exclusion criteria. All participants gave written informed consent prior to participation in the study, were
472 debriefed after completion of the experimental session, and received monetary compensation or partial
473 course credit for participation. See table 1 for details on the individual samples.

474

475 **Design and Procedure**

476 **Description of the main experimental Task.** In the main experimental task we manipulated SPC
477 over task outcomes across three levels (low, medium and high control; in the following LC, MC and HC).
478 The tile task displayed a grid-pattern of two halves of turquoise and yellow squares surrounding a single

Table 1. Descriptive statistics for study samples

		age in years			female/male
	n	*M*	*SD*	range	
Study 1	40	23.33	3.11	18-31	14/26
Study 2	39	23.31	3.87	18-37	32/7
Study 3	50	23.55	3.34	18-32	30/19
overall	129	23.41	3.41	18-37	77/52

Note. In study 1, the post-experimental interview indicated that 9 out of 49 tested participants did not believe the cover story (i.e. they informed us that they did not believe that feedback depended on their behavior but was manipulated), who were therefore excluded from further analysis. In study 2, 10 out of 49 tested participants had to be excluded due to various reasons (did not believe the cover story: 6 / excessive motion: 1 / technical problems: 3). For study 3, 6 out of 56 tested participants had to be excluded from the analysis (did not believe the cover story: 4 / could not fit choice function because subject chose only one option: 1 / already participated in fMRI study: 1). *M*=mean. *SD*=standard deviation.

479 grey square in the center (figure 1). On each trial, orientation of halves (left-right or upper-lower
480 arrangement) and brightness of squares within each half was pseudo-randomly defined. On each trial,
481 three, four or five squares on each half (targets) were assigned a brightness that was considerably higher
482 than the remaining ones (distractors). Targets never appeared side by side. Crucially, while there were
483 random differences in brightness of all distractor squares, the brightness of target squares was kept near
484 identical rendering a definite identification of the brightest square within one half impossible. The
485 brightness of the grey square in the center remained constant across the experiment.

486 Perceived controllability of task outcomes was manipulated in a within-participants design. In the
487 low control (LC) condition, participants were instructed to *click* on the central grey square. In 50% of trials
488 clicking the square was pseudo-randomly followed by a win and in the other 50 % by a no win outcome (in
489 the following: WIN and noWIN). In the medium control (MC) condition, participants were instructed to
490 *choose* one color (i.e. yellow or turquoise) by clicking on any square of that color. Again, in 50% of trials
491 choosing a half was pseudo-randomly followed by either a WIN or a noWIN outcome. In the high control
492 (HC) condition, participants were instructed to *identify* the brightest square of either the yellow or
493 turquoise half of the grid. Again, in 50% of trials the identification of the putatively brightest square was
494 pseudo-randomly followed by either a WIN or a noWIN outcome.

495 In each study, given that no mistakes were made (i.e., response was fast enough, and participant
496 did not click on background instead of a square, and a square of the correct color was clicked in the HC
497 condition), an equal amount of trials was presented for every combination of outcome valence (WIN,
498 noWIN) and control (LC, MC, HC in study 1; MC, HC in studies 2 & 3).The number of ratings was equally
499 distributed across combinations of outcome valence and SPC condition and the same for pride and
500 happiness. SPC regarding each condition (HC, MC, and LC; “How strongly could you influence / control the
501 outcome in the different tasks?”, ranging from “very strongly” to “not at all”; see below) was rated after
502 the main task using 5-point Likert-type scales in studies 1 & 2, while a continuous horizontal rating scale
503 was used in study 3.

All subjects in a given study were tested in the same laboratory room and lighting conditions were held constant by lowering the window blinds and setting the dimmable electric lights to the same level. Brightness of the 3-5 brightest squares was randomly set on each trial within these pre-defined limits in studies 1 & 2. In study 3, instead of creating a unique display by setting the previously described parameters randomly on each trial, a predefined pool of 100 grid stimuli was used, which was shuffled and therefore randomly assigned to each condition for each subject.

In each study, presentation of WIN and noWIN outcomes was manipulated, so that the overall probability of receiving each outcome would be fixed to 50% for every condition. In case a square was clicked that was not defined as belonging to the set of brightest squares on a given HC trial, a noWIN was presented in order to maintain credibility of the task. The predefined sequence of WIN and noWIN outcomes was designed in a way that no more than four WIN or noWIN trials appeared consecutively across conditions, and that no more than two WIN or noWIN trials appeared consecutively within conditions. Additionally, no condition appeared more than two times in a row. This was done in order to maintain an expectation of receiving a WIN (noWIN) outcome close to 50% across the course of the task.

All experimental stimuli were presented using the Psychophysics Toolbox (Brainard, 1997) for Matlab (Mathworks Inc, Natick, MA). Post-experimental interviews were administered using computerized questionnaires presented in Sosci Survey (Sosci Survey GmbH, München, Germany).

Association of perceived Control with the affective Experience of Pride (Study 1). Prior to the main experiment, and after a short demonstration of the three task conditions, participants completed a practice session (see below) so that they could learn a) the timing of the task, and b) that they would receive approximately 50% WIN and 50% noWIN feedbacks in all three conditions.

After the practice session and prior to the main task, participants completed two trials of every condition including one WIN and one noWIN outcome each, and ratings of pride and happiness in order to learn the timing of the complete trial structure. Subsequently, participants performed a total of 90 trials (figure 1B) of the experimental task. The sequence of conditions and outcome valence in each condition was

529 predefined, such that no condition appeared more than twice in a row. Additionally, no more than four
530 consecutive WIN or noWIN trials were presented across conditions, and no more than two repetitions of
531 the same outcome valence appeared within conditions. Ratings of pride and happiness were displayed
532 side-by-side after each trial and visualized as thermometers initiated at 0 and ranging to 100. Participants
533 could rate their subjective feelings of pride and happiness in any order by clicking on the corresponding
534 levels of the two thermometers and confirming their ratings using a *done*-button on the bottom of the
535 screen.

536 **Neural Foundations of processing Rewards in controllable Environments and Pride (Study 2).**
537 The procedure in the study 2 largely followed that of the study 1, with a few changes. First, the LC condition
538 was not presented in the fMRI in order to reduce scanning time and to perform a more conservative
539 comparison between the MC and HC conditions that both had a component of choice. A total of 80 trials
540 were presented, followed by a rating of either pride or happiness (figure 1B) on each or every second trial.
541 If no mistakes were committed, this yielded a total of 24 ratings each for pride and happiness, 12 for each
542 condition, and 6 for every combination of WIN/noWIN and condition. For approximately half of the
543 participants, the trials on which pride and happiness were rated were switched. In case a mistake was
544 committed, both the feedback and the rating on that trial were replaced by a warning and a prolonged
545 inter-trial-interval (ITI) until the planned onset time for the next trial was reached.

546 After a short explanation of the task outside the scanner, the practice session in the fMRI study
547 was done inside the fMRI scanner and followed the same structure as in the study 1, as did the post-
548 experimental interview and debriefing. Participants completed all tasks with an fMRI-compatible
549 computer mouse (NAtA TECHNOLOGIES, Coquitlam, Canada) and their right arm rested on a tilted
550 mousepad supported by an adjustable armrest. ITIs were pseudo-randomly jittered between 3-5 seconds
551 during which a fixation cross was presented in the center of the screen. Following a 1 second cue, the task
552 was presented for 4.75 seconds and after a 4 second delay, the outcome was presented for 3 seconds. On
553 each or every second trial, participants were asked to rate within 4 seconds either how proud or how

554 happy they felt regarding the preceding outcome. Ratings were given on a horizontal rating scale initiated
555 at an intermediate position ("somewhat") and ranged from "not at all" to "very" (figure 1), and converted
556 to values ranging from 0 through 100.

557 **Pride as an affective Marker for the SV of Control (Study 3).** Study 3 consisted of two behavioral
558 paradigms (figure 1B). After an initial demonstration of the task and a practice session, 64 trials of the
559 main task were presented, and pride ratings were collected on 40 pseudo-randomly selected trials.
560 Thereafter, participants completed a choice task in which on each of 96 trials they were given a choice
561 between performing either the MC or the HC condition. Importantly, each choice option was associated
562 with varying amounts of money (see below for details). For instance, a subject could have the choice
563 between participating in the MC condition for a potential gain of 1 € or, alternatively, participate in the HC
564 condition for a potential gain of 0.9 €. On eight pseudo-randomly selected trials, participants performed
565 the chosen task, and were informed that after the experiment they would receive the sum of all
566 successfully completed trials. No outcomes were presented during this part of the experiment to avoid
567 influencing the participants' expectation of succeeding.

568 The algorithm we used to determine the potential monetary gains of the choice options on each
569 trial followed the logic of an adaptive staircase algorithm for the detection of perceptual detection
570 thresholds as used in psychophysics (Leek, 2001). Specifically, on each trial, one of the two choice options
571 was selected as the *reference* and assigned a value of 1€, while the other option was assigned another
572 value that was either higher or lower than the reference value. E.g., if this *comparison value* was higher
573 than the reference value on a given trial and the participant picked the higher value, the comparison value
574 was decreased by a predefined fraction in the following trials until the participant changed her decision
575 and chose the option with the reference value. In this fashion we aimed to find the point at which each
576 individual participant valued both choice options equally. A description of the staircase-algorithm we
577 employed is detailed below.

Table 2. Reaction times and number of valid trials

	condition	Median reaction times (ms)		Number of valid trials		Number of trials planned
		M	*SD*	*M*	*SD*	
Study 1	LC	751	89	29.10	1.11	30
	MC	778	101	29.05	0.93	30
	HC	820	90	28.56	1.19	30
Study 2	MC	1428	380	38.80	1.30	40
	HC	2041	400	38.13	1.99	40
Study 3	MC	1223	325	30.76	1.24	32
	HC	1218	322	31.54	0.73	32

Note. ms = milliseconds; *M* = mean; *SD* = standard deviation; LC = low control; MC = medium control; HC = high control.

Between the main task and the choice task, participants gave a number of ratings regarding their experience of the task. These ratings included the participants' estimate of the percentage of WIN and noWIN outcomes they had received during the different conditions in the main task, or they thought they would receive if they continued to perform the same conditions in the future.

Practice Task (studies 1, 2, & 3). The practice task preceding the main experiment was conducted in order to minimize differences in outcome expectations between the three conditions. During the practice session, participants completed 15 trials of each condition without any feedback during the first twelve trials. Instead, subjects received manipulated feedback during the last three trials of the different conditions, indicating that they had "won" (LC), "chosen correctly" (MC), or "found the brightest square" (HC) in approximately 50% of the preceding trials. Precisely, there were three sets of feedback percentages (46, 50, 54 / 47, 50, 53 / 48, 50, 52), that were randomly assigned to the task condition based on the subject ID and the order of each set was randomized for each condition and every subject. In case a subject made too many mistakes (i.e. responded too slowly, clicked on the background, clicked a square of the incorrect color in the HC condition, or did not click on the grey square in the LC condition on more than ¼ of the completed practice trials) after the first eleven practice trials of a condition, the subject was informed about this by an on-screen message and the respective practice block was repeated. Before the start of the practice session, subjects were informed that depending on their performance in the practice blocks, they would be assigned to one of three groups gaining either 10, 15 or 20 €-cents on each correct

trial of the main task and that the better they performed the more money they could gain during the main task. After the practice session, all subjects were informed that they had been assigned to the 20-cent group (irrespective of their performance).

Description of Ratings. In study 1, ratings of both pride and happiness were administered after every outcome, using thermometer-like rating scales, ranging from 0 through 100, and initialized at 0 (see figure 1). Subjects could decide which affect to rate first and completed their rating by clicking a *done*-button. In study 2, either pride or happiness ratings were administered after a given trial, with a total of 24 ratings for each affect (6 for each combination of outcome valence (WIN, noWIN) and control (MC, HC). For 20 out of the 39 subjects included in the analyses in study 2, the predefined assignment of pride and happiness ratings to a given outcome was switched. In study 3, only pride was rated after a total of 40 trials, equally distributed over all combinations of outcome valence and control. In studies 2 and 3 ratings were administered using horizontal rating bars, asking subjects how strongly they felt a given affect with regard to the preceding outcome. Scales ranged from *not at all* through *somewhat* to *very* and were initialized at *somewhat*, i.e. a neutral position.

Ratings of subjectively perceived control (SPC) in studies 1 and 2 were assessed using a paper-pencil 5-point Likert scale asking participants "How strongly could you influence the outcome in the different tasks?", with the different options being: "very strongly", "strongly", "neutral", "weakly", "very weakly" (in German: 1. "Wie stark glaubst du konntest du das Ergebnis in den verschiedenen Bedingungen beeinflussen?"; „sehr stark", „stark", „mittel", „wenig", „sehr wenig"). In study 3, two items were used to assess SPC, with the first item asking the same question as in studies 1 and 2. The second item asked "How strongly could you control the outcome in the different tasks?" (German: "Wie stark konntest du das Ergebnis in den verschiedenen Aufgaben kontrollieren?"). In study 3, a horizontal rating bar ranging from "very weakly" through "somewhat" to "very strongly" was displayed after the main task, similar to the affect ratings and initialized at a neutral position (i.e. "somewhat"). In study 3, ratings from both items were averaged for each condition in order to measure SPC.

621 In addition to ratings measuring SPC, after the main task in study 3, a set of additional questions was
622 asked – separately for MC and HC – that was later used to statistically control the relationship between
623 the pride response and choice behavior (see tables 1 and 3). All questions were asked using a horizontal
624 rating bar like the ones used for the affect ratings and the SPC ratings in study 3 and all answers were
625 initialized at a neutral position and recoded to range from 0 to 100.

626 **Choice Task (Study 3).** The algorithm we used to determine the potential monetary gains of the
627 choice options on each trial followed the logic of an adaptive staircase algorithm for the detection of
628 perceptual detection thresholds as used in psychophysics (Leek, 2001). More specifically, on each trial,
629 one of the two choice options was selected as the *reference* and assigned a value of 1€, while the other
630 option was assigned another value that was either higher or lower than the reference value, called the
631 comparison value. This comparison value was changed on each trial by a certain step size in a specific
632 manner detailed below.

633 In the beginning of the task, two step sizes were used: 33 cents and 17 cents. Additionally, the
634 comparison value could either be smaller or larger than the reference value and was initially calculated by
635 3*step size, giving four sets of initial comparison values: 1.99€, 1.51€, 0.49€, 0.01€. Since either HC or MC
636 could be the reference value on a given trial, we obtained a total of 8 initial starting values, defining 8 so-
637 called comparison sets.

Table 3. Items regarding subjects' experience of the experimental task

Variable	Item
subjectively received %WIN	How often do you think that you guessed correctly / identified the brightest square in the different tasks? (in percent)
difficulty (inv.)	How easy were the different tasks for you?
effort	How much effort did you put into the different tasks?
fun	How much fun did you have doing the different tasks?
exciting	How exciting / thrilling do you think the different tasks were?
exhausting	How exhausting were the different tasks?

638 The task was programmed to contain four phases of 24 trials each that were not explicitly
639 conveyed to the participants. In the first phase, only those comparison sets were used that started with a
640 step size of 17 cents (i.e. comparison values starting at 1.51€ or 0.49€). In the second phase, two thirds of
641 the trials belonged to these sets, while one third were trials starting with comparison values of 1.99€ or
642 0.01€ (i.e. step sizes of 33 cents). In the third phase of the task, two thirds of the trials belonged to the
643 comparison sets with a step size of 33 cents and all of the trials in the fourth phase belonged to this set.
644 In each phase, 2 trials were randomly selected to be actually played by the subject (being HC or
645 MC, depending on the subject's choice), without showing an outcome. Subjects were informed that in the
646 end, they would receive the amount gained from those trials on which they succeeded (i.e. found the
647 brightest square in HC; selected the correct color In MC). However, they truly received 50% of the amounts
648 they chose and played for during the decision task.
649 If on a given trial the comparison value (e.g. HC = 1.99€) was higher than the reference value (e.g.
650 MC = 1€) and the subject picked the choice option with the (higher) comparison value, the comparison
651 value was decreased by the current step size (e.g. 33 cents) in the following trials of the same comparison
652 set until the subject changed her decision and picked the option with the reference value. As an example,
653 the MC condition could be defined as the reference (1 €), while the initial comparison value of HC could
654 be 1.99 €. Choosing HC for 1.99 € would lead to a decrease of the comparison value to 1.66 € on the next
655 trial of this comparison set. The comparison value would be decreasing as long as HC is preferred over MC.
656 At some point, e.g. when HC has a value of .67 €, the subject might prefer MC (having a value of 1€). Now,
657 the comparison value is *increased* until the subject's decision changes a second time, and the comparison
658 value starts to decrease again, this time by a smaller fraction than before (*previous step size*/1.25),
659 therefore iteratively approximating the point at which the subjective value of both options are subjectively
660 equal for this participant. On each trial, a random amount between -5 and 5 cents was added to the values
661 in order to decrease monotony of the task. The highest offered value was 1.99€ and the lowest was 0.01€.

FMRI Data Acquisition. Participants were scanned using a 3T Siemens MAGENTOM Skyra scanner (Siemens, München, Germany) at the Center of Brain, Behavior, and Metabolism (CBBM) at the University of Lübeck, Germany. After four dummy-scans allowing for equilibration of T1 saturation effects, 768 volumes with 39 near-axial slices in ascending order were acquired for each participant using echo-planar-imaging (voxel size=3*3*3 mm, 68*68 matrix, 20% interslice-gap, TR=2000 ms, TE=25 ms, 90° FA, iPAT=2). In addition, a high-resolution anatomical T1 image was acquired that was used for coregistration (voxel size=1*1*1 mm, 256*256 matrix, TR=1900 ms, TE=2.44 ms, 9°FA).

Statistical Analyses

The statistical analyses of subject ratings were performed using JASP version 0.9 (JASP Team, 2019). MRI data were analyzed using SPM12 (Ashburner et al., 2013), and the logistic choice models in study 3 were fitted using Matlab R2016a. The comparison of correlations between PPI-effects and affective responses in study 2, as well as FDR-correction of *p*-values regarding these correlations were performed in R (R Core Team, 2013; see below).

Manipulation Checks. In order to verify that subjects could not reliably detect the brightest square, we computed how many times in the entire experiment the brightest square of a given color would be found given a subject performed at chance level. For instance, if in a given trial three squares were defined to be the brightest squares, there was a chance of 1/3 to find the brightest square. We computed the level of chance performance for each subject individually, accounting for the fact that by chance, the number of trials in which 3, 4, or 5 squares were the brightest could vary between subjects (due to the design of the experimental task). We performed paired t-tests in each study, comparing the number of times each subject found the brightest square with the level of chance performance. These analyses indicated, that in no study performance exceeded chance level. In fact, in every study, subjects performed significantly worse than chance (study 1: $t(39) = -33.931$, $p < .001$; study 2: $t(38) = -2.311$, $p = .026$; study 3: $t(49) = -2.762$, $p = .008$).

The objective rates of receiving WIN and noWIN outcomes did not deviate significantly from 50% in any study (study 1: LC: *M*=50.45%, *SD*=1.78, *t*(39)=1.601, two-sided *p*=.117, *MC*: *M*=50.26%, *SD*=1.29, *t*(39)=1.272, two-sided *p*=.211, HC: *M*=50.01%, *SD*=2.20, *t*(39)=0.030, two-sided *p*=.977; study 2: MC: *M*=50.10%, *SD*=1.14, *t*(38)=0.556, two-sided *p*=.581, HC: *M*=49.88%, *SD*=1.70, *t*(38)=-0.437, two-sided *p*=.664; study 3: MC: *M*=50.55%, *SD*=1.42, *t*(49)=0.275, two-sided *p*=.784, HC: *M*=50.00%, *SD*=1.15, *t*(49)=0.0005, two-sided *p*=.999), nor were there any significant differences in outcome rates between conditions (study 1: *F*(2,78)=0.572, *p*=.567; study 2: *t*(38)=-0.703, two-sided *p*=.487; study 3: *t*(49)=-0.234, two-sided *p*=.839).

Participants' subjective reports of the perceived percentages of WIN and noWIN outcomes did not differ from 50% in studies 1 and 2 (study 1: LC: *M*=51.60%, *SD*=12.36, *t*(39)=0.818, two-sided *p*=.418, MC: *M*=48.23%, *SD*=6.60, *t*(39)=-1.70, two-sided p=.097, HC: *M*=50.70%, *SD*=14.78, *t*(39)=.300, two-sided *p*=.766; study 2: MC: *M*=48.13%, *SD*=6.37, *t*(37)=-1.808, two-sided *p*=.079, HC: *M*=52.07%, *SD*=10.29, *t*(37)=1.216, two-sided *p*=.232), nor were there any significant differences between conditions (study 1: *F*(2,78)=.982, two-sided *p*=.379; study 2: *t*(37)=-1.936, two-sided *p*=.061). Surprisingly, in study 3 subjects reported having received significantly less than 50% WIN outcomes in MC (*M*=46.66%, *SD*=11.75%, *t*(49)=-2.011, two-sided *p*=.049, *d*=-0.28, 90% *CI*=[-.57, -.0002]), and significantly more than 50% WIN outcomes in HC (*M*=54.51%, *SD*=12.07%, *t*(49)=2.640, *p*=.011, two-sided, *d*=0.37, 90% CI=[.09, .66]), contradicting the objective outcome rates. We therefore controlled the results of study 3 for differences between conditions regarding subjective outcome rates.

Analysis of affective Dynamics in Studies 1, 2, and 3. For each participant, we calculated the mean ratings of pride or happiness (study 3: only pride), separately for each combination of condition (LC (only study 1), MC, HC) and outcome valence (WIN, noWIN), for all valid trials (i.e. excluding those in which the participant either clicked on the background or did not respond fast enough). The resulting variables were then taken as dependent variables in repeated measures analyses of variance (rmANOVA), using the

711 factors condition, outcome valence, and affect (factor affect only in studies 1 & 2). Paired comparisons
712 were then used to disentangle significant effects of interest.

713 **Correlation of SPC and Pride Response across Studies.** In order to perform a more direct test
714 regarding the relationship between SPC and pride, we computed the pride response from the data of each
715 study ([HC:WIN–HC:noWIN] – [MC:WIN–MC:noWIN]). Hence, a positive pride response indicated that
716 participants reported greater outcome-dependent differences in pride under HC than under MC.
717 Additionally, after transforming the control ratings from each study to values between 0 and 100 across
718 HC and MC, we computed the difference between control ratings for the different levels of SPC. For this
719 analysis, control ratings and pride ratings from study 1 were averaged across LC and MC. Non-parametric
720 correlation analysis (Spearman's rho) was used to test the relationship between the pride response and
721 differences in SPC between HC and MC.

722 **Analysis of Choice Data in Study 3.** We predicted the probability for each subject to choose the
723 HC option on a given trial by fitting a logistic model to the choice data. We calculated the ratio of the
724 potential monetary gain for the HC option (e.g. 1.37 €) to the one for the MC option (e.g. 1.01 €) on each
725 of the 96 trials and transformed this ratio to log-space (e.g. log(1.37/1.01)=.3049). Thus, positive values of
726 the resulting predictor variable indicate a higher potential gain for HC than for MC on a given choice trial,
727 negative values indicate a relatively higher potential gain for MC, and a value of zero indicate equality of
728 gains for the two options.

729 Considering the general form of logistic models,

730 $$p(choose\ BRIGHTNESS|X = x_1) = \frac{1}{1 + \exp(\beta_0 + \beta_1 * X_1)}$$

731 participants with parameters β_0 and β_1 both equaling zero would have a 50% probability of choosing HC
732 on a given trial, regardless of the value of X_1 (X_1 being the log-transformed ratio of the monetary values
733 offered for HC and MC). Assuming equal offers for HC and MC, negative values of β_0 indicate that a
734 participant has a preference for HC over MC, while positive values of β_0 indicate a preference for MC over

735 HC. With more negative values of β_1, the probability of a participant choosing HC therefore increases more
736 steeply, the higher the potential gain in the HC option, relative to MC.

737 Participants reported having received WIN outcomes more often in HC than in MC (see
738 Supplement 1 - table S4), contradicting objective outcome rates. To control for differences in the
739 subjective outcome rates, we again fit the logistic functions to each subjects' choice data, now
740 incorporating subjective outcome probabilities in the prediction. First, each monetary amount offered for
741 either HC or MC on a given trial was multiplied with the subjectively rated percentage of WINs obtained
742 in the respective condition (e.g. 1.23€ * 52% WINs in HC = 0.64€). The ratio of these expected values on
743 each trial was then log-transformed and used to predict the subjects' choices on each trial. The subjects'
744 probability to choose HC given equal expected values for HC and MC remained significantly above 50%
745 (*MD*=65.98%, *IQR*=50.48, Wilcoxon signed-rank *W*=863, one-sided *p*=.015), i.e., even when controlling for
746 differences in subjective winning histories for the two tasks, a preference for HC remained.

747 **Analysis of FMRI Data (Study 2).** fMRI data were analyzed using SPM12 (Ashburner et al., 2013)
748 in MATLAB R2015a. All functional volumes were slice-time corrected, spatially realigned, and normalized
749 using the forward deformation fields as obtained using the unified segmentation approach by
750 coregistration of the anatomical T1-image to the mean functional image of each individual participant
751 (Ashburner et al., 2013). Normalized images were resliced with a voxel size of 2*2*2 mm and smoothed
752 with an 8-mm full-width-at-half-maximum isotropic Gaussian kernel. To remove drift, functional images
753 were high-pass-filtered at 1/128 Hz.

754 Statistical analyses were performed in a two-level, mixed-effects approach. The first-level general
755 linear model (GLM) for each participant included a total of 8 regressors defining the onsets and duration
756 of the two task phases (MC, HC), the four feedback phases (MC:WIN, MC:noWIN, HC:WIN, HC:noWIN),
757 and two regressors modelling the phases for pride and happiness ratings. In addition, the six realignment
758 parameters from the preprocessing as well as their first derivatives were included as regressors of no
759 interest to account for noise due to head movement.

760 For the analyses at the second level, we focused on the outcome phase of the task by
761 implementing a within-participants ANOVA including the individual first-level contrast images for MC:WIN,
762 MC:noWIN, HC:WIN, and HC:noWIN. Using this approach we computed main effects of condition (HC>MC)
763 and outcome valence (WIN>noWIN), as well as their interaction ((HC:WIN>HC:noWIN) >
764 (MC:WIN>MC:noWIN)).

765 **GLM Analysis including Pride and Happiness Ratings as parametric Modulators.** We performed a
766 second GLM analysis which included two predictors modelling the onsets and durations of the MC and the
767 HC task on each trial, three different predictors for the task outcomes, and two predictors modelling the
768 onsets and durations of the pride and happiness ratings. The first of the three outcome predictors
769 modelled those task outcomes after which pride was rated. The second one modelled those task outcomes
770 after which happiness was rated. For each of these predictors the respective affect ratings on each trial
771 were included as parametric modulations to model variability in neural responses related to the subjective
772 ratings of pride or happiness on each trial. The third outcome regressor modelled those trial outcomes
773 that were not followed by any affect rating, and thus was not parametrically modulated. As before, the six
774 realignment parameters as well as their first derivatives were included to account for noise due to head
775 movement. The first-level contrast images for the parametric modulations of pride and happiness were
776 then taken to a group-level within-subjects ANOVA in SPM12 (Ashburner et al., 2013).

777 **Psychophysiological Interactions (PPI).** In addition to the standard GLM approach, we additionally
778 performed psychophysiological interaction (PPI) analyses on the first level and aggregated the resulting
779 contrast images for the PPI effect on the second level using one-sample t-tests in order to investigate
780 changes in functional connectivity between brain regions identified in the within-participants ANOVA.
781 Precisely, we investigated whether functional connectivity of regions activated more strongly for WIN than
782 for noWIN would differ between outcomes of a HC as compared MC. For each individual participant, we
783 defined 4-mm radius spherical ROIs, centered at the nearest local maximum for the contrast WIN>noWIN
784 and located within 6 mm from the group maximum for the same contrast, separately for the left and right

785 VS, which is a central structure associated with the processing of rewarding outcomes (Delgado, 2007;
786 Pagnoni et al., 2002). By computing the first eigenvariate for all voxels within each of the two individual
787 spheres that showed a positive effect for WIN>noWIN, we extracted the time course of activations and
788 constructed PPI terms using the contrast HC>MC (Ashburner et al., 2013). One participant was excluded
789 from the PPI analysis for right VS, because no voxels survived the predefined threshold for eigenvariate
790 extraction. The PPI term, along with the activation time course from the (left or right) VS and a regressor
791 modelling the effect of HC>MC was included in a new GLM for each participant that additionally modelled
792 the two task phases (grids for HC or MC) and rating phases (pride and happiness) as well as the six
793 realignment parameters from preprocessing and their first derivatives. First level contrast images of the
794 (left or right) VS PPI analyses were aggregated for all participants in order to test for changes in functional
795 connectivity on the group level using one-sample t-tests.

796 **Rationale for Masking Procedures.** We created a set of masks used for region-of-interest (ROI)
797 analyses by performing automated meta-analyses using Neurosynth (Yarkoni et al., 2011) for the terms
798 *self referential* and *value*, comprising activation foci of 166 and 470 studies, respectively. Using the SPM12
799 image calculator (Ashburner et al., 2013), we created three mutually exclusive image masks, showing brain
800 regions associated with a) the term *self referential*, but not *value* (SELF¬VALUE), b) with the term *value*,
801 but not *self referential* (VALUE¬SELF), and c) the conjunction of both terms (SELF∩VALUE, covering regions
802 where both meta-analyses showed overlapping effects). This rationale is in line with a recent meta-analysis
803 showing substantial overlap between regions associated with processing of SV and self-referential
804 processes (Acikalin, Gorgolewski, & Poldrack, 2017). These masks were then limited to include only clusters
805 with 5 or more contiguous voxels. For a given contrast, we first tested whether there were significant
806 activations within the regions covered by the masks of interest. Subsequently, we tested whether the same
807 contrast showed significant activations on the whole-brain level in order to detect regions activated that
808 were located outside of our a-priori masks.

809 **Linking SPC-dependent Neural Connectivity to interindividual Variability in affective Responses.**

810 We hypothesized that individuals showing stronger functional connectivity between VS and regions
811 associated with self-related processing when receiving HC outcomes than when receiving MC outcomes,
812 should display larger pride responses. We obtained an estimate of individual functional connectivity
813 strengths by computing the eigenvariate across participants from the three largest clusters inside the
814 SELF¬VALUE mask showing significant PPI effects at $p<.0005$ (uncorrected at peak level). These three
815 clusters were located in left AG (k=50 voxels), dmPFC (k=89) and precuneus (k=33; figure 6). Next, we
816 correlated pride responses with estimates of functional connectivity in each of the three clusters, applying
817 FDR correction for multiple comparisons on the resulting p-values (using the *p.adjust* function in R; R Core
818 Team, 2013). An equivalent analysis was performed for the happiness responses. We then compared these
819 correlations between pride and happiness using the *cocor* package (Diedenhofen, 2016) in R, again
820 applying FDR-correction for multiple comparisons.

Acknowledgements

We thank Janine Baumann, Finn Lübber, Timo Schlesinger, and Johanna Schulz for their help with data collection.

Competing Interests

All authors declare no conflicts of interest.

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