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Power Effects on Instrumental Learning: Evidence From the Brain and Behavior

Petra C. Schmid
Swiss Federal Institute of Technology,
Zurich, Switzerland

Leor M. Hackel
Stanford University

David M. Amodio
New York University

We investigated whether high power facilitates instrumental learning relative to low power—an effect that would support power effects on goal-pursuit and decision-making. Because power is known to increase instrumentality in action, we expected that high power would enhance instrumental learning involving both approach and avoidance responses, relative to low power. Studies 1 and 2 revealed that manipulated power modulated instrumental learning, such that relative to low power, high power facilitated the learning of approach and avoidance responses through reinforcement. Furthermore, Study 2 revealed stronger neural processing of valid versus invalid feedback, indexed by the feedback-related negativity (FRN) component of the event-related potential (ERP), among high-power participants, but not low-power or control participants. These results suggest higher power engaged more strategic processing of goal-relevant feedback—a finding that illuminates the links between power, goal pursuit, and social behavior.

Keywords: power, learning, feedback, event-related potential (ERP), brain

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Whether for good or ill, the psychological experience of power is known to promote action and the effective pursuit of goals (Galinsky, Gruenfeld, & Magee, 2003; Guinote, 2007c, 2017; Harada, Bridge, & Chiao, 2013; Schmid, Kleiman, & Amodio, 2015; Schmid & Schmid Mast, 2013). For example, people in high-power roles are more likely to initiate goal-directed action and win in negotiations compared with those in low-power roles (Galinsky et al., 2003; Guinote, 2007c). At the same time, high-power participants exhibit greater cognitive and behavioral flexibility relative to low-power subjects (Guinote, 2007b, 2008). These effects suggest that power influences not just behavioral outcomes, but also the way in which people interpret and learn information that is relevant to one's goal. To investigate this proposal, we examined whether power modulates instrumental reinforcement learning—the process of learning approach/avoidance action tendencies based on positive (rewarding) or negative (nonrewarding) feedback. Evidence for this effect would suggest that power facilitates basic cognitive processes that are key to initiating and guiding goal pursuit. An additional aim was to shed light on a theoretical debate about whether high power sensitizes individuals primarily to

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Petra C. Schmid, Department of Management, Technology, and Economics, Swiss Federal Institute of Technology (ETH Zurich), Zurich, Switzerland; Leor M. Hackel, Department of Psychology, Stanford University; David M. Amodio, Department of Psychology, New York University.

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Correspondence concerning this article should be addressed to Petra C. Schmid, Department of Management, Technology, and Economics, Swiss Federal Institute of Technology (ETH Zurich), Weinbergstrasse 56/58, 8092 Zurich, Switzerland, or to David M. Amodio, Department of Psychology, New York University, 6 Washington Place, New York, NY 10003. E-mail: petraschmid@ethz.ch or david.amodio@gmail.com

rewarding feedback (Keltner, Gruenfeld, & Anderson, 2003), or whether power sensitizes individuals to all goal-related feedback, regardless of its valence (Guinote, 2017; Magee & Smith, 2013).

Power and Instrumentality

In past research, high power has been associated with greater goal focus (Guinote, 2007b; Schmid, Kleiman, et al., 2015; Smith, Jostmann, Galinsky, & van Dijk, 2008) and goal pursuit (Galinsky et al., 2003; Guinote, 2007c), relative to low power. This pattern appears to reflect a broader effect on instrumentality, such that the experience of high power, relative to low power, induces a more instrumental mindset regarding one's social and physical environment.

Initial research on power and instrumentality examined this relationship in the context of social perception and memory. Compared with powerless subjects, powerful subjects formed more individuated impressions of others, but only to the extent that the other people were relevant to the subjects' personal goals (Overbeck & Park, 2006). In another series of studies, Gruenfeld, Inesi, Magee, and Galinsky (2008) found that the experimental induction of high power led subjects to view other people in an objectified manner, as a means to an end. Moreover, Overbeck and Park (2001) found that participants assigned to the role of a high-power person (e.g., a professor, or a judge) in an email exchange remembered more goal-relevant information from the exchange than in a low-power role. Although this effect likely represented a form of episodic memory that is fundamentally different in nature from the action-based reinforcement learning processes examined presently, their finding of stronger goal-relevant memory is broadly consistent with our hypothesis that power should enhance instrumental learning and memory. Together, these studies demonstrate that power enhances instrumentality across a range of social situations and outcomes.

Instrumental Learning

In cognition and the brain, learning occurs through multiple mechanisms (e.g., Pavlovian fear conditioning, conceptual association, episodic encoding, etc.; Squire & Zola, 1996), with different learning systems having distinct implications for social cognition and behavior (Amodio & Ratner, 2011). Most relevant to the present hypothesis is the process of instrumental learning (see also, procedural or skill learning). In contrast to other forms of learning, instrumental learning involves the encoding of value and action through repeated positive or negative feedback on one's behavior. As such, this form of learning comports closely with theoretical models of power that emphasize an enhancement of goal pursuit through goal focus and behavioral adaptation (e.g., Guinote, 2007a).

In the brain, a network of structures contributes to instrumental learning, including the anterior cingulate cortex (ACC), which tracks uncertainty and is involved in behavioral adaptation processes (Behrens, Woolrich, Walton, & Rushworth, 2007; Hauser et al., 2014), as well as the striatum (Knowlton, Mangels, & Squire, 1996; O'Doherty et al., 2004). The ACC is highly interconnected with motor regions, as well as the dorsolateral prefrontal cortex (dlPFC), the ventromedial prefrontal cortex (vmPFC), the amygdala, and the striatum (Hauser et al., 2014). The interconnectivity of these regions allows for behavioral adjustments following negative reinforcement signals (Holroyd & Coles, 2002), thereby guiding a goal-directed pattern of behavior.

Importantly, both positive and negative performance feedback are considered instrumental because both provide information on how to further pursue a goal (e.g., Finkelstein & Fishbach, 2012). From positive feedback following a response, one learns what behavior should be maintained. From negative feedback, one learns what behavior should be changed. However, neural pathways for positive (Go) and avoidance (NoGo) learning are somewhat distinct (Frank & Claus, 2006; Maia & Frank, 2011). Positive outcomes increase striatal dopamine, associated with D1 dopamine receptor activity, which promotes learning to repeat the reinforced action. Negative outcomes decrease striatal dopamine, associated with D2 dopamine receptor activity, which promotes learning to avoid that action in the future. Through these distinct pathways, positive feedback leads to an incremental increase in the value of an instrumental action, whereas negative feedback leads to an incremental decrease in this value (Frank, Moustafa, Haughey, Curran, & Hutchison, 2007). Since dissociable pathways support learning from positive and negative feedback, this model raises the possibility that power could have differential effects on learning from positive and negative outcomes.

Theoretical Views on Instrumental Learning and Its Relation to Power

Interestingly, major psychological theories of power offer contradicting views on how power should affect instrumental learning. The Social Distance Theory of Power (Magee & Smith, 2013), the Situated Focus Theory of Power (Guinote, 2007a), and Guinote's (2017) recent framework propose that high power increases goal focus and goal-directed behavior relative to low power, independent of whether goals relate to reward or punishment. This view is also consistent with appraisal theories of emotion that associate power with coping potential (e.g., Scherer, 2001), which suggest that power should further facilitate goal pursuit by increasing self-efficacy. Thus, according to this *goal-focus account*, high power should increase learning to approach rewards as well as to avoid nonrewards, relative to low power.

An alternative prediction is suggested by the Approach–Inhibition Theory of power (Keltner et al., 2003), which proposes a *reward-focus account* to predict power effects on learning. Specifically, this theory states that high power induces approach orientation and, by extension, greater attention to rewards. Low power, in turn, induces inhibition and greater attention to punishments. If high power indeed increases people's sensitivity to reward and decreases sensitivity to nonreward, then high power should enhance approach learning and impair avoidance learning relative to low power.

By examining the effect of power on reinforcement learning, we may clarify existing theoretical models of social power and determine whether power influences basic forms of learning and memory that may contribute to a wide range of behaviors.

Overview of Research

In two studies, the present research explored the relative effects of high and low power on feedback-based reinforcement learning. To do so, we used a probabilistic stimulus selection task (Frank, Seeberger, & O'Reilly, 2004; Frank, Woroch, & Curran, 2005), which permitted us to compute indices representing learning to approach or, independently, to avoid a stimulus through repeated positive and negative feedback. In Study 2, we also examined the neurocognitive processes associated with power effects on reinforcement learning to gain further insight into the process through which power influences instrumental learning.

Although our focus was on the relative effects of high and low power, a control condition was included in each study. However, few prior studies of power included control conditions (Schaerer, du Plessis, Yap, & Thau, 2016). Moreover, power dynamics are often complex and difficult to completely avoid in control conditions. Because little is known regarding the relative impact of high and low power on power-related outcomes relative to a baseline control, we did not have strong predictions regarding control groups. Finally, to capitalize on the data included across studies, a meta-analysis was conducted to test the strength of the effects with greater statistical power.

Study 1

Study 1 examined whether manipulated power affects learning from feedback. Building on recent theories of power (Guinote, 2017; Magee & Smith, 2013), and given research showing that power increases instrumentality in action (Chen, Lee-Chai, & Bargh, 2001; Côté et al., 2011; Gruenfeld et al., 2008; Overbeck & Park, 2001, 2006), we tested the hypothesis that high power would enhance instrumental learning involving both approach and avoidance learning, relative to low power. This goal-focus hypothesis stands in contrast to the idea that high power should enhance the learning of approach responses (to rewarding stimuli), whereas low power should enhance the learning of avoidance responses (to nonrewarding stimuli).

Method

Participants. Participants were 113 undergraduate psychology students (69% females; $M_{\text{age}} = 19.81$, $SD_{\text{age}} = 1.29$) who participated in this study for course credit. We aimed to include a minimum of 30 participants per cell

(90 participants in total). Once this number was achieved, we continued data collection until the end of the semester and only then analyzed our data. Participants were randomly assigned to one of three conditions (high power, low power, or a neutral control).

Procedure. Participants were run in individual sessions. After providing consent, participants' level of power was manipulated based on their assigned condition. Participants then performed one or more blocks of the reinforcement learning task until they reached performance criteria, after which they completed test phase trials. The task was programmed using DMDX software (Forster & Forster, 2003) and run on a PC. Finally, participants completed a set of questionnaires including manipulation compliance checks and demographic information, were then probed for suspicion, and were debriefed. All measures and manipulations are described below. This procedure was approved by the institutional review board.

Power manipulation. To manipulate power, participants were asked to imagine themselves in high-power, low-power, or power-neutral situations. This role imagination task has been used successfully in past research (e.g., Dubois, Rucker, & Galinsky, 2010). Following Cesario and MacDonald (2013), participants were further instructed to simultaneously hold body postures corresponding to their assigned power role. None of these poses were strenuous, and each required a similar (minimal) degree of attention and effort. Holding these poses allowed participants to embody their imagined role. The exact instructions and poses that were used to manipulate power are described in the Appendix. The strength of our manipulation is that it combines a more explicit power manipulation (role imagination task) with one that is arguably more implicit (posing), and thus activates a broad construct of power.

It is notable that the effectiveness of "power poses" as a power manipulation has been recently debated. However, this debate concerns manipulations that are based on body postures alone and do not include an imagination exercise. Importantly, when poses were put in a social context (e.g., with an imagination exercise), they have successfully induced power in participants (Cesario & McDonald, 2013). Thus, it is likely that congruent postures reinforce the power-inducing effects of the imagination exercise and likely broaden the scope of the manipulation's effect on behavior, through both implicit and explicit processes (Huang, Galinsky, Gruenfeld, & Guillory, 2011, although a recent meta-analysis of preregistered studies suggests that posing may affect people's subjective feeling of power more so than their behavior Jonas & Cesario, 2017).

Learning phase. Each learning block included 60 trials that were presented in randomized order. On each trial, a fixation cross was first presented for 800 ms, followed by a pair of Japanese pictographs (similar to Frank et al., 2005). Participants' task was to choose one of the two pictographs. Feedback was given immediately following choice in the form of a schematically drawn face that was either green and smiling (correct), or red and frowning (incorrect). Feedback faces were presented for 1500 ms together with the labels "correct" or "wrong" respectively. If no response was given within 4s, a "Too Slow" message appeared in the center of the screen. The next trial began immediately after the feedback (see Figure 1, panel A for a sample trial sequence).

The learning phase included three different trial types (see Figure 1, panel B), each consisting of a fixed pair of Japanese stimuli (i.e., pictograph A paired with pictograph B, pictograph C paired with pictograph D, pictograph E paired with pictograph F). Importantly, the reward/nonreward feedback was probabilistic, and these probabilities varied as a function of pair type. On AB trials, pictograph A was the correct choice on 80% of trials and the pictograph B on 20% of trials; on CD trials, pictograph C was correct on 70% of trials and the pictograph D on 30% of trials; and on EF trials, pictograph E was correct on 60% of trials and pictograph F on 40% of trials. Following past research (e.g., Frank et al., 2005), participants were told that they will see these pictographs repeatedly and that one of the pictographs will be correct and one incorrect on each trial. Participants were further informed that there is no absolute correct answer, but that some pictographs have a higher chance of being correct, and that they should choose the pictograph they believe is

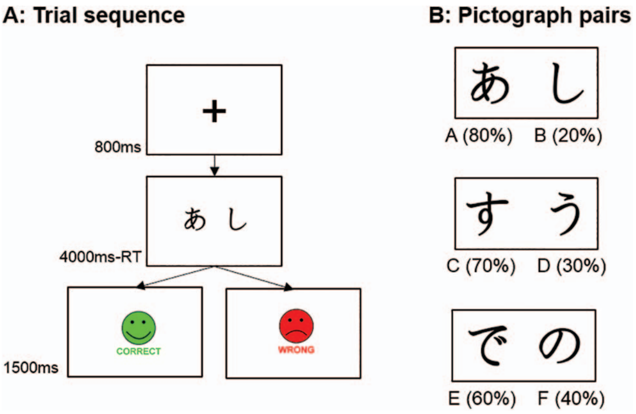

Figure 1. Reinforcement learning task. Panel A represents a trial sequence in the probabilistic reinforcement task. Panel B shows the different pictograph pairs as they were presented during the learning blocks. See the online article for the color version of this figure.

more likely to be correct. Several features make this task well-suited for the assessment of instrumental learning. First, responses are goal-driven (for accuracy). Indeed, although our task included positive and negative feedback and no extrinsic incentives, past research has shown that learning tasks with accuracy feedback produce prediction errors and striatal activity consistent with instrumental learning, comparable to tasks that use money rewards (e.g., Foerde & Shohamy, 2011; Seger & Cincotta, 2005). Second, learning occurs through immediate feedback on an action. This is the hallmark of instrumental learning, as opposed to passive observational or associated learning tasks used commonly in other research. Third, the probabilistic nature of the feedback specifically affords striatal-based learning associated with implicit instrumental memory and dissociated from more declarative forms of memory (Foerde, Knowlton, & Poldrack, 2006; Knowlton et al., 1996; Poldrack et al., 2001).

Following past research (Frank et al., 2005), an accuracy criterion of 65% was set for AB trials, 60% for CD trials, and 50% for EF trials. When these criteria were met, participants moved on to the testing phase. If these criteria were not met, participants repeated the learning block up to six times. If participants failed to meet the criteria after six blocks, they moved on to the test phase.

Test phase. The goal of the test phase was to determine the extent to which participants learned to approach A and, independently, to avoid B based on the feedback they received in the learning phase. The test phase contained 90 trials. On each trial, a fixation cross was presented for 800 ms, followed by a pair of pictographs. All pictographs from the learning phase were paired with one another, resulting in 15 different combinations of pictographs, including novel pairings participants had not viewed previously. Participants' task was again to choose the pictograph that they believed was more likely correct. Pictographs stayed onscreen until a response was given. If no response was given within 4s, a "Too Slow" message appeared on the center of the screen. No accuracy feedback was given. Intertrial intervals were 1500 ms. Participants were instructed to apply what they learned from the learning blocks, and if they were unsure, to go with their gut feelings.

This phase produces separate estimates of approach (i.e., choose) and avoidance (i.e., do not choose) learning: A and B were each paired with more neutral stimuli (C, D, E, and F), providing a test of whether participants approached A over the more neutral stimuli and avoided B relative to the more neutral stimuli. Following Frank et al. (2005), the percentage of choosing A over all other stimuli in these novel pairings was calculated as an index of approach learning. In addition, the percentage of *not* choosing B over all other stimuli novel pairings was calculated as an index of avoidance learning.

These indices of approach and avoidance learning were computed based only on novel pairings, and thus did not include AB trials. During the learning phase, participants saw A and B paired only with one another, and therefore could choose the correct answer by learning to approach A or avoid B. However, the novel pairings in the test phase reveal the strength of each form of learning. These measures of approach and avoidance learning have been found to correlate differentially with genetic markers of striatal D1 and D2 function, which are believed to support positive versus negative feedback-based learning, respectively (Cockburn, Collins, & Frank, 2014; Doll, Hutchison, & Frank, 2011; Frank et al., 2007). Moreover, dopaminergic manipulations impact test phase performance on novel pairings, further supporting the notion that these trials assess instrumental associations between actions and outcomes, developed incrementally through feedback (Frank et al., 2004; Jocham, Klein, & Ullsperger, 2011). In other words, upon receiving positive feedback after choosing A during the learning phase, participants may form a positive instrumental association, which supports choosing A over more neutral stimuli in the test phase (i.e., an approach response). Conversely, upon receiving negative feedback after choosing B during learning, participants may form a negative instrumental association, which supports avoiding B relative to more neutral stimuli in the test phase.

Manipulation compliance check. To assess compliance with the power manipulation procedure, participants indicated whether they completed the imagination exercise when holding each of the two poses, as instructed (1 = *yes, until the experimenter came back*, 2 = *yes, but I stopped after a while*, 3 = *no, I was thinking about something else*); whether they held the poses during each of the two imagination exercises (1 = *yes, until the experimenter came back*, 2 = *no, I stopped after a while*); and whether they were holding the pose during the reinforcement learning task (1 = *yes, the whole time*, 2 = *no, I stopped after a while*). To ensure that participants were comfortable in their poses, participants further indicated how comfortable and painful each pose was on a 7-point scale (1 = *not at all*, 7 = *very much*).

Subjective experiences (self-reports). Although not central to our hypotheses, participants completed a short questionnaire assessing their subjective feelings and experiences at the conclusion of the session. Specifically, participants reported their subjective power-related feelings on the items *independent, dominant, influential, strong, in authority, powerful, responsible, dependent, powerless, constrained,* and *submissive,* using a 5-point Likert scale (1 = *not at all*, 5 = *very much*) and indicated their mood on a 7-pont scale (1 = *very negatively*, 7 = *very positively*). In addition, to indicate their task-related motivations and feelings, participants rated to what extent they felt *irritated, tired, content, distressed, bothered, angry, relaxed, calm, frustrated, interested, motivated, confident*, and *bored* on a 7-point scale (1 = *does not apply at all*, 7 = *applies very much*).

Exclusions. Twelve participants were excluded from analysis for the following reasons: The participant failed to understand the task even after multiple clarification attempts (3); outlying scores (i.e., values exceeded the 1.5 interquartile range, indicating unusually poor performance) on the primary test-phase outcome variables (7); the computer program crashed (1); or the experimenter miscalculated the participant's accuracy rates in the learning task such that the participant completed more learning blocks than needed (1).

Results

Participants performed significantly above chance accuracy (.50) in the test phase, for approach learning, $M = .86$, $SD = .16$, $t(100) = 22.77$, $p < .001$, 95% CI [.83, .89], $d = 4.55$, and for avoidance learning, $M = .85$, $SD = .17$, $t(100) = 21.18$, $p < .001$, 95% CI [.82, .88], $d = 4.24$. Twenty participants did not reach performance criteria within six learning blocks. However, in the test phase, their performance did not significantly differ from other participants (i.e., participants with performance outliers were excluded), suggesting that they nevertheless successfully learned the probabilities and were able to apply this knowledge to the test phase.

Manipulation compliance check. Overall, participants complied with the power manipulation procedure. Five participants reported that they had stopped holding the pose after a while; however, because they also engaged in the imagination exercise, it is likely that the power manipulation was still effective. Indeed, excluding these participants did not significantly affect results.[1]

Learning task. To test effects of power on learning, test phase performance scores were submitted to a 3 (Power Condition: high vs. low. vs. control) × 2 (Learning Type: approach A vs. avoid B) mixed-model ANOVA. This analysis produced only a main effect of power condition, $F(2, 98) = 5.84$, $p = .004$, $\eta_p^2 = .11$. Neither the learning type main effect, $F(2, 98) = 0.70$, $p = .404$, $\eta_p^2 = .01$, nor the interaction, $F(2, 98) = 0.32$, $p = .724$, $\eta_p^2 = .01$, were significant (Figure 2, panel A).[2]

Planned contrasts revealed that high-power participants were more accurate ($M = .90$, $SE = .02$) than low-power participants ($M = .80$, $SE = .02$), $t(98) = 3.18$, $p = .002$, 95% CI [−.17, −.04], $d = .77$, across learning types. Control group accuracy was intermediate ($M = .88$, $SE = .02$); control participants were significantly more accurate than low-power participants, $t(98) = 2.45$, $p = .016$, 95% CI [−.14, −.02], $d = .59$, but not significantly different from high-power participants, $t(98) = 0.77$, $p = .441$, 95% CI [−.04, .09], $d = .19$.[3]

We further tested whether power condition influenced how many learning blocks were required for participants to reach criteria in the learning phase. The power condition effect was not significant, $F(2, 98) = 2.00$, $p = .141$, $\eta_p^2 < .04$. It is also notable, however, that the power main effect on test phase performance remained significant when controlling for the number of blocks needed in the learning phase, $F(2, 97) = 5.70$, $p = .005$, $\eta_p^2 = .11$.

Posttask subjective experiences. An ANOVA testing the effect of condition (high power, low power, and control) on a composite measure of subjective feelings of power ($\alpha = .843$) was not significant, $F(2, 98) = 0.84$, $p = .436$, $\eta_p^2 = .02$. The power manipulation also did not significantly affect participants' mood, $F(2, 98) = 0.23$, $p = .793$, $\eta_p^2 < .01$. None of the one-way ANOVAs testing for effects of the power condition on the 13 task experience items reached significance, $F\text{s} < 2.18$, $p\text{s} > .119$, $\eta_p^2 < .05$. These results suggest that power effects on learning were likely not due to participants' explicit subjective feelings during the task (see supplemental materials for additional descriptive and exploratory analyses).

Discussion

In Study 1, we tested whether power, previously linked to instrumentality in social judg-

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[1] We tested participants' experienced comfort during their poses. Ratings of pain and comfort correlated significantly (in Study 1 for the sitting pose, $r(99) = -.44$, $p < .001$, and for the standing pose, $r(99) = -.52$, $p < .001$, and in Study 2, $r(79) = -.43$, $p < .001$). We then tested whether power condition affected the aggregated ratings of comfort and pain for each of the poses. In Study 1, the power condition effect was marginal for the standing pose, $F(2, 98) = 2.88$, $p = .061$, $\eta_p^2 = .06$, and significant for the sitting pose, $F(2, 98) = 9.89$, $p < .001$, $\eta_p^2 = .17$. Simple effect analyses showed that high-power and low-power participants did not significantly differ in how comfortable they experienced the standing pose, $t(98) = 4.45$, $p = .183$, or the sitting pose, $t(98) = 3.14$, $p = .171$. Thus, effects were solely driven by the control group, who tended to feel more comfortable in both poses. In Study 2, power did not significantly affect participants' comfort, $F(2, 78) = 0.11$, $p = .897$, $\eta_p^2 < .01$.

[2] Bayesian analyses were conducted to provide further support for our hypothesis that high power increases approach and avoidance in a similar way. Indeed, in Study 1, $BF_{10} = .012$, and in Study 2, $BF_{10} = .144$ (a BF_{10} between 0 and 1 indicates that it is closer to a null model), providing strong (Study 1) to moderate (Study 2) evidence against a Power × Learning Type interaction effect.

[3] To determine whether the effect of power on learning was evident for both approach and avoidance learning, we examined simple effects of power on each learning type. An analysis of approach learning revealed a significant power effect, $F(2, 98) = 4.44$, $p = .014$, $\eta_p^2 = .08$, such that high-power participants were more accurate ($M = .90$, $SE = .03$) than low-power participants ($M = .80$, $SE = .03$), $t(98) = 2.66$, $p = .009$, 95% CI [−.17, −.03], $d = .59$, with the control group ($M = .89$, $SE = .03$) differing from low-power participants, $t(98) = 2.40$, $p = .018$, 95% CI [−.16, −.02], $d = .53$, but not high-power participants, $t(98) = 0.26$, $p = .798$, 95% CI [−.07, .09], $d = .08$.

For avoidance learning, the power condition effect was also significant, $F(2, 98) = 4.30$, $p = .016$, $\eta_p^2 = .08$; high-power participants were more accurate ($M = .91$, $SE = .03$) than low-power participants ($M = .79$, $SE = .03$), $t(98) = 2.86$, $p = .005$, 95% CI [−.19, −.04], $d = .69$. Control participants ($M = .86$, $SE = .03$) showed marginally better avoidance learning than the low-power group, $t(98) = 1.80$, $p = .075$, 95% CI [−.15, .01], $d = .38$, but did not differ from the high-power group, $t(98) = 1.05$, $p = .295$, 95% CI [−.01, .15], $d = .33$. Hence, high-power participants showed better approach and avoidance learning than low-power participants, and the pattern of power effects were similar for both forms of reinforcement learning.

Although participants were not instructed to respond quickly in the test phase, we computed exploratory analyses on RTs in the test phase. In Study 1, the main effect of learning type (approach vs. avoidance learning) was significant, $F(2, 98) = 29.80$, $p < .001$, $\eta_p^2 = .23$; participants were faster when choosing A ($M = 827.08$, $SE = 35.06$) compared to when avoiding B ($M = 919.77$, $SE = 34.59$) in the test phase. Neither power condition nor the interaction effect were significant, $F\text{s} < 2.03$, $p\text{s} > .137$, $\eta_p^2 < .04$. Study 2 showed similar results, a significant learning type effect, $F(2, 78) = 13.54$, $p < .001$, $\eta_p^2 < .15$, indicating again that participants were faster at choosing A ($M = 9.3.19$, $SE = 32.71$) than at avoiding B ($M = 996.00$, $SE = 34.35$). No significant power main or interaction effects were found for RTs, $F\text{s} < 0.64$, $p\text{s} > .528$, $\eta_p^2 < .02$.

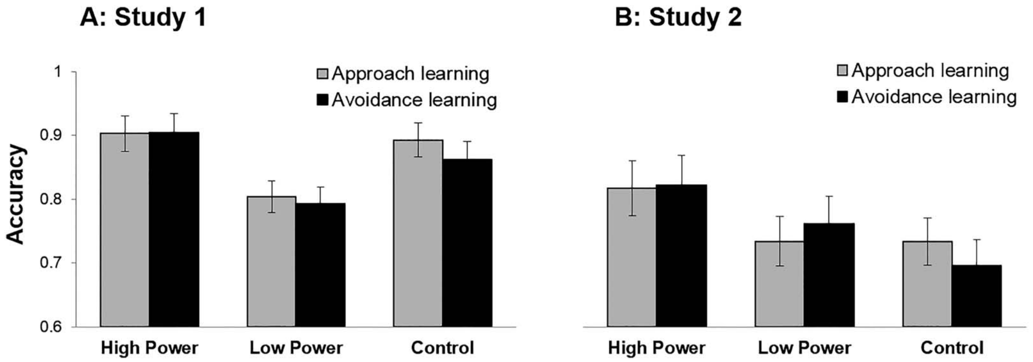

Figure 2. Test phase accuracy rates for approach and avoidance learning as a function of power condition for Study 1 (panel A) and Study 2 (panel B).

ments, also affects more basic processes of feedback-based reinforcement learning. Results showed that relative to low power, high power increased both approach and avoidance forms of learning—a pattern that supported our hypothesis, in line with a goal-focus account of power. By contrast, this pattern is inconsistent with a reward-focus account, which would predict that high power increases learning to approach good options and reduces learning to avoid bad options, relative to low power. Although we did not observe power to significantly affect the number of blocks required to reach learning criterion, this index of learning is not considered to be a pure measure of striatal-based instrumental learning given the additional role of working memory during learning (Collins & Frank, 2012; Frank et al., 2007). By contrast, test phase performance provides a more direct test of striatal instrumental learning because it relies less on working memory processes. Thus, this pattern of results is consistent with our hypotheses that power increases instrumental learning.

Although our theoretical interests concern the relative effects of high and low power, it is notable that in this study, control participants performed more similarly to high-power than to low-power participants. This pattern suggests the possibility that the low-power manipulation produced the observed differences; that is, a low-power mindset may reduce instrumentality in learning. However, we consider this particular inference tentative, given the difficulty in obtaining a true "neutral" mindset for control participants and the inconsistent effects observed for control conditions in previous research (cf. Schmid, Kleiman, et al., 2015; Smith et al., 2008). Nevertheless, inclusion of a control group may help identify the factors that influence whether effects are driven primarily by the high-power or low-power manipulation (e.g., nature of dependent variables, experimental settings, sample properties).

Study 2

The goal of Study 2 was to further probe the processes involved in power effects on instrumental learning by examining how power influences feedback processing. In addition, our aim was to replicate our central finding that power modulates instrumental learning.

Prior theorizing suggests two different ways in which power could affect the processing of reinforcement feedback. One possibility is that power sensitizes an individual to reward and punishment, thereby increasing responsivity to positive and negative feedback and leading to greater behavioral adjustments following negative feedback. According to this hypothesis, power would increase sensitivity to the valence of feedback, consistent with theories of power that emphasize its effect on reward processing. A second possibility, however, is that power increases one's focus on the task goal (i.e., to learn instrumental associations), such that feedback is processed according to expectancy based on prior learning. According to this hypothesis, power tunes sensitivity to the *validity* of feedback rather than to its valence, such that subjects are more responsive to feedback that represents a guide to task behavior. This second possibility is consistent with theories of power that emphasize its effect on goal pursuit.

In Study 2, participants completed the same task used in Study 1. In order to examine the effects of power on the processing of feedback valence and feedback validity during the reinforcement learning task, we also included event-related potential (ERP) measures that tracked participants' neural processing of feedback unobtrusively and trial-by-trial. Following past research on probabilistic reinforcement learning (e.g., Eppinger, Mock, & Kray, 2009; Pietschmann, Endrass, Czerwon, & Kathmann, 2011), feedback was considered "valid" when it rewarded the choice of the option that had a higher likelihood of being correct, which was the case for the majority of trials. A subset of feedback was considered "invalid" because it rewarded the low-probability choice option. That is, on AB trials, feedback was "valid" when participants received positive feedback when choosing A and negative feedback when choosing B. This was the case on 80% of all AB trials. However, on 20% of all trials, participants received opposite, "invalid" feedback (negative feedback if they chose A, and positive feedback if they chose B). On CD trials, participants received "valid" feedback on 70% of all trials, that is, when receiving positive feedback for choosing C and negative feedback for choosing D. Feedback was "valid" on 60% of all EF trials, when participants received positive feedback for choosing E and negative feedback for choosing F.

Our predictions focused on the feedback-related negativity (FRN) component of the ERP, which has been used in much research to examine neural processing of reinforcement feedback (e.g., Frank et al., 2005; Gehring & Willoughby, 2002; Hajcak, Moser, Holroyd, & Simons, 2006, 2007; Yeung & Sanfey, 2004). The FRN is part of a larger family of medial frontal negativities (e.g., the N2 and the error-related negativity) that reflect conflict processing and are putatively generated in the ACC (Amodio, Bartholow, & Ito, 2014). Prior research suggests evidence for the FRN's sensitivity to the valence of feedback, such that it is typically stronger in response to negative than to positive feedback (Frank et al., 2005; Nieuwenhuis, Holroyd, Mol, & Coles, 2004; Yeung & Sanfey, 2004). The FRN is also believed to support the adjustment of behavior so that the error is not repeated in the future (Cohen & Ranganath, 2007; Frank et al., 2005; Holroyd, Krigolson, Baker, Lee, & Gibson, 2009). Supporting this interpretation, larger FRNs to negative feedback are associated with greater subsequent behavioral adjustment (Cohen & Ranganath, 2007).

Given these characteristics, the FRN provided an ideal method for testing our question of how power affects the processing of feedback valence or feedback validity. If power increases the processing of feedback valence, high-power participants should show stronger FRN responses to negative feedback, relative to positive feedback, compared with low-power participants. However, if high-power participants' feedback processing is more strongly guided by prior learning vis-à-vis their task goals, then their FRNs would be more sensitive to the validity of feedback—particularly when it signals the need for behavioral adaptation (i.e., valid negative feedback)—than to its valence. In this case, valid negative feedback should elicit a stronger FRN than invalid negative feedback. It is also possible that FRNs of high-power participants would be more responsive to both valence and validity of feedback.

Method

Participants. Ninety-five undergraduate students (68% female, $M_{\text{age}} = 19.82$, $SD_{\text{age}} = 1.41$) participated in the study for course credit. Our recruitment goal was 90 participants, as in Study 1; upon reaching it, we continued data collection until the end of the semester.

Procedure. After providing consent, participants were prepared for EEG recording. Following baseline EEG measures, power was manipulated (high power vs. low power vs. control). Participants then completed a first set of 1–6 learning blocks, depending on how quickly they reached the performance criteria. They then applied their knowledge in the testing phase. If time allowed, participants learned a second stimulus set with different pictographs and then did a second application task, in order to increase the number of trials as suggested by Frank et al. (2005). Finally, they completed a set of questionnaires that included a manipulation compliance check and demographics. All measures and manipulations are described below. This procedure was approved by the institutional review board.

Power manipulation. The same power manipulation was used as in Study 1. However, because of the restriction of the EEG, participants only held the sitting posture while imagining the power-related situations. Participants remained in the manipulated sitting pose during the learning tasks.

Learning and testing phases. The same learning and testing tasks were used as in Study 1, except that intertrial intervals in both tasks were longer (between 2000 and 3000 ms) and jittered to facilitate ERP scoring and interpretation. The session time was restricted to 2h. For participants who only needed 1–3 learning blocks to reach performance criteria, this was enough time to proceed with the learning of the second stimulus set after they have learned and been tested on the first set (49 participants did so). However, many participants needed more learning blocks and had no time left to learn the second set. All analyses therefore focused on the first set of stimuli only from the full sample.

Manipulation compliance check. Participants were probed regarding their compliance with instructions as in Study 1.

Subjective experiences (self-reports). The same self-report measures of subjective experiences were used as in Study 1.

Personality questionnaires. Three additional trait measures were included: the 10-item personality inventory (Gosling, Rentfrow, & Swann, 2003), the minisocial phobia inventory (Connor, Kobak, Churchill, Katzelnick, & Davidson, 2001), and the Generalized Sense of Power Scale (Anderson, John, & Keltner, 2012). These questionnaires were included for reasons unrelated to the present research and are thus not discussed here; moreover, 11 participants did not have enough time left to complete these questionnaires.

EEG recording and processing. EEG was recorded from F7, F3, Fz, F4, F8, FCz, Cz, CPz, P7, P3, Pz, P4, P8, Oz, and the two earlobes (with the left earlobe serving as the active reference) with tin electrodes embedded in a nylon cap (ElectroCap, Eaton, OH; $\Omega < 5$k). Eye movements were recorded for use in artifact correction. Signals were amplified with a Neuroscan Synamps2 (El Paso, TX) with AC coupling, digitized at 1000 Hz and passed through a 0.15–100 Hz online filter. Offline, EEG was rereferenced to average earlobes, submitted to regression-based blink correction, and lowpass filtered at 30 Hz (Amodio et al., 2014).

Analyses focused on individuals' responses to feedback in the learning phase. To compute the ERPs from the learning phase, we extracted 800 ms epochs locked to the feedback starting 200 ms before stimulus onset. Average voltage during a baseline period (200 ms prior to stimulus onset) was subtracted from the entire epoch, and epochs were averaged as a function of both feedback valence (positive or negative) and validity (valid or invalid, with respect to the more probable stimulus–outcome association). The FRN was scored as the average negative amplitude between 190 and 300 ms after feedback onset, following past work (e.g., Bellebaum & Daum, 2008; Potts, Martin, Burton, & Montague, 2006). Visual inspection of the waveform indicated that the FRN was strongest at FCz, consistent with past research (e.g., Cavanagh, Frank, Klein, & Allen, 2010).

It is notable that this task necessarily yielded unequal numbers of trials to be included in FRN scores associated with positive versus negative feedback—an issue also present in much past ERP research on probabilistic reinforcement learning. This concern was mitigated, in part, by the use of an average amplitude score, rather than peak amplitude (Luck, 2005), and the inclusion of adequate numbers of trials, on average, for each FRN index of interest (Marco-Pallares, Cucurell, Münte, Strien, & Rodriguez-Fornells, 2010). In addition, our theoretical and analytical focus on interactive effects between manipulated power and FRNs further mitigated the potential problems associated with unequal variances.

Exclusions. Data from 14 participants were excluded from analyses. As in Study 1, one participant had outlying data (i.e., the value exceeded the 1.5 interquartile range) on performance accuracy in the testing phase. Moreover, 11 participants showed extensive EEG artifacts, one participant did not hold the assigned pose, and one participant was noncompliant. Due to these exclusions, our final sample size was slightly smaller than planned (i.e., 81 instead of the 90 participants).

Results

Participants' performance was above chance (.50) in the test phase for approach learning, $M = .76$, $SD = .20$, $t(80) = 11.33$, $p < .001$, 95% CI [.71, .80], $d = 2.53$, and for avoidance learning, $M = .75$, $SD = .23$, $t(80) = 9.99$, $p < .001$, 95% CI [.70, .80], $d = 2.23$. Five participants did not reach the performance criteria within six learning blocks. However, their test phase performance did not differ significantly from participants who reached these criteria, suggesting they successfully learned and applied the knowledge.

Manipulation compliance checks. All included participants reported that they were compliant with the power manipulation exercise (see Footnote 1).

Behavioral analyses. Accuracy rates in the test phase were submitted to a 3 (Power Condition: high vs. low vs. control) × 2 (Learning Type: approach A vs. avoid B) mixed-factor ANOVA. Replicating Study 1, and further supporting our hypothesis, this analysis produced a main effect of power condition, $F(2, 78) = 3.39$, $p = .039$, $\eta_p^2 = .08$. Pairwise group comparisons indicated that high-power participants learned better from feedback ($M = 0.82$, $SE = .03$) than both low-power participants ($M = 0.75$, $SE = .03$), $t(78) = 1.74$, $p = .085$, 95% CI [−.15, .01], $d = .49$ (marginal effect), and control participants ($M = 0.72$, $SE = .03$), $t(78) = 2.56$, $p = .012$, 95% CI [.02, .19], $d = .71$. Accuracy among low-power participants and controls did not differ significantly, $t(78) = 0.86$, $p = .397$, 95% CI [−.04, .11], $d = .23$. As in Study 1, the learning type main effect was not significant, $F(1, 78) = 0.00$, $p = .955$, $\eta_p^2 < .001$, nor was the Power Condition × Learning Type interaction effect, $F(2, 78) = 0.32$, $p = .726$, $\eta_p^2 < .01$. Thus, as in Study 1, high-power participants showed better feedback-based learning across approach and avoidance forms of learning than low-power participants (see Footnotes 2 and 3).

In an additional analysis it was tested whether power condition affected the number of learning blocks participants needed to reach criteria. As in Study 1, this was not the case, $F(2, 78) = 0.91$, $p = .405$, $\eta_p^2 = .02$. Moreover, the power main effect on test phase performance was still significant when controlling for number of blocks needed in the learning phase, $F(2, 77) = 3.76$, $p = .028$, $\eta_p^2 = .09$.

FRN validation. The FRN amplitude is typically larger (i.e., in a negative-polarity direction) to negative feedback than to positive feedback, in line with the idea that it is sensitive to negative prediction errors. Indeed, this difference was significant in our sample, $t(80) = 13.37$, $p < .001$, $d = 0.99$, with larger FRN amplitudes in response to negative feedback, $M = 2.41$, $SE = 0.69$, than to positive feedback, $M = 8.74$, $SE = 0.72$ (although both peaks were positive relative to the prestimulus baseline; see Figure 3).

Power effects on valence-based FRNs. Next, we tested whether the power manipulation moderated the FRN to positive versus negative feedback. On average, FRN waveforms comprised 122 epochs for positive feedback and 51 epochs for negative feedback. FRN scores were submitted to a 3 (Power Condition: high vs. low. vs. control) × 2 (Feedback Valence: positive vs. negative) mixed-model ANOVA on FRN responses. The feedback valence main effect was again evident, $F(1, 78) = 172.54$, $p < .001$, $\eta_p^2 = .69$, with stronger FRN responses to negative than to positive feedback. However, we did not observe significant effects for power, $F(2, 78) = 1.02$, $p = .364$, $\eta_p^2 = .03$, or the interaction, $F(2, 78) = 0.01$, $p = .993$, $\eta_p^2 < .001$. Thus, power did not significantly affect the FRN response to the valence of feedback.

Power effects on validity-based FRNs. We next turned to the novel question of whether power affects feedback-related neural activity depending on the validity of the feedback; that is, whether the feedback was valid given its prevailing probability. Analyses focused on negative feedback trials only, because, as shown in Figure 3, positive feedback did not elicit a discernable FRN. On average, FRN waveforms comprised 33 epochs for valid negative feedback and 37 epochs for invalid negative feedback, and were thus roughly equivalent. A 3 (Power Condition: high vs. low. vs. control) × 2 (Feedback validity: valid vs. invalid) mixed-model ANOVA was conducted on FRN responses to negative feedback. Main effects were nonsignificant for power condition, $F(2, 78) = 0.97$, $p = .384$, $\eta_p^2 = .02$, and feedback validity, $F(1, 78) = 0.53$, $p = .532$, $\eta_p^2 < .01$. However, the Power Condition × Feedback Validity in-

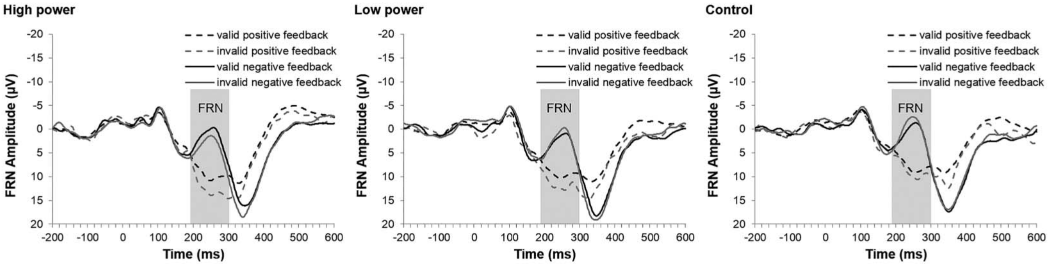

Figure 3. FRN waveforms as a function of power condition, feedback valence, and feedback validity in Study 2.

teraction was significant, $F(2, 78) = 3.47$, $p = .036$, $\eta_p^2 = .08$ (see Figure 4).

Analysis of simple effects revealed that high-power participants had significantly greater (i.e., more negative) FRN responses to valid ($M = 2.29$, $SE = 1.44$) than to invalid negative feedback ($M = 4.10$, $SE = 1.30$), $F(1, 78) = 5.65$, $p = .020$, 95% CI [−3.32, −0.29], $\eta_p^2 = .07$, in line with our hypothesis. As expected, for low-power participants, FRN responses to valid feedback ($M = 3.44$, $SE = 1.31$) and invalid feedback ($M = 3.13$, $SE = 1.18$) did not differ significantly, $F(2, 78) = 0.20$, $p = .655$, 95% CI [−1.06, 1.68], $\eta_p^2 < .01$. Similarly, in the control condition, FRNs to valid ($M = 1.58$, $SE = 1.26$) and invalid negative feedback ($M = 0.85$, $SE = 1.14$) did not differ significantly, $F(2, 78) = 1.21$, $p = .275$, 95% CI [−.59, 2.06], $\eta_p^2 = .02$.[4]

Correlations between FRN responses and performance indices. In order to test whether sensitivity to valid versus invalid feedback was related to performance indices, we computed FRN difference scores in which FRNs to valid feedback were subtracted from FRN responses to invalid feedback, separately for positive and negative feedback trials. FRN difference scores were not significantly correlated with test phase performance (i.e., approach and avoidance learning) or the number of learning blocks that were necessary to reach criterion in the learning phase, rs $< .161$, ps $> .151$.

Posttask subjective experiences. As in Study 1, subjective feelings of power ($\alpha = .86$) did not differ significantly between conditions, $F(2, 78) = 1.19$, $p = .309$, $\eta_p^2 = .03$; nor did mood, $F(2, 78) = 0.80$, $p = .454$, $\eta_p^2 = .02$. Power condition also did not significantly affect the 13 task-related feelings, Fs < 3.04, ps $> .053$, $\eta_p^2 < .07$ (see supplemental materials for additional descriptive and exploratory analyses).

Discussion

Study 2 was conducted to replicate the effect of power on instrumental learning observed in Study 1, while further probing the way that power influences the processing of instrumental feedback. Overall, the behavioral results of Study 2 replicated those of Study 1. High-power participants learned better relative to low-power participants, although the effect was marginal in this study, and this effect did not depend on the approach or avoidance nature of the learning. In this study, high-power participants also learned significantly better than control participants, who, in turn, did not differ significantly from low-power partici-

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[4] It has been argued that the FRN may be influenced by the superimposition of a slow positive potential (e.g., Hajcak et al., 2007; Luck, 2005). Although our FRN waveforms looked clean and did not show evidence of such a superimposition at first sight, we followed previous research and also computed difference scores between the FRN and the preceding positive potential (e.g., Frank et al., 2005; Holroyd & Coles, 2002; Yeung & Sanfey, 2004). Difference between average waveforms were computed rather than the peak-to-peak difference, given the unequal number of valid and invalid trials and the resulting potential problems to evaluate peak values (Luck, 2005). Results based on these difference scores generally mirrored those found for FRN average amplitudes to negative feedback. That is, a 3 (Power Condition: high vs. low. vs. control) × 2 (Feedback Validity: valid vs. invalid) mixed-model ANOVA revealed the expected Power Condition × Feedback Validity interaction, $F(2, 78) = 3.03$, $p = .054$, $\eta_p^2 = .07$. The main effects were not significant for feedback validity, $F(1, 78) = 0.25$, $p = .621$, $\eta_p^2 < .01$, or for power condition, $F(2, 78) = 0.37$, $p = .695$, $\eta_p^2 = .01$.

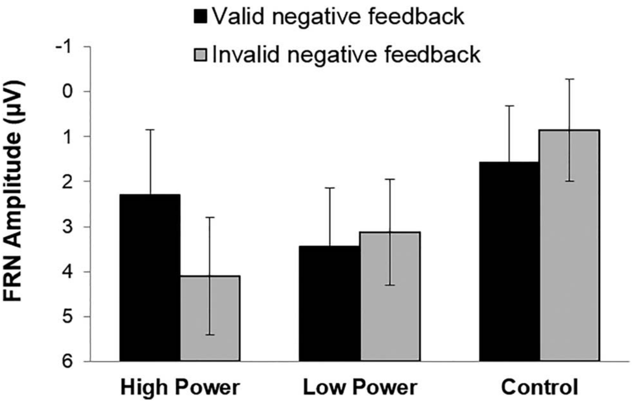

Figure 4. Mean FRN amplitude scores for valid and invalid negative feedback (Study 2), as a function of power condition and feedback validity.

pants. We discuss our interpretation of the control condition in the General Discussion.

In Study 2, we also examined how power affected the neural processing of feedback depending on its valence (i.e., positive vs. negative feedback) and its validity (i.e., valid vs. invalid feedback). Findings from the ERP data revealed that power condition influenced the way participants processed valid as opposed to invalid feedback: High-power participants were significantly more sensitive to valid relative to invalid negative feedback, whereas low-power and control participants did not show a significant differentiation between the processing of valid and invalid negative feedback. Analyses of FRNs to positive versus negative feedback did not reveal significant power condition effects, despite that we observed the typical increase in FRN amplitude to negative compared with positive feedback across conditions.

The finding that high-power participants showed greater FRN responses to valid than to invalid feedback suggests these participants processed feedback in light of their prior experience and learning goals, and not merely in response to signals of reward or punishment. This pattern of feedback processing supports the idea that power enhances goal-directed processing. Validity did not significantly modulate the FRN among low-power and control participants, and therefore it appears that participants in these conditions did not process feedback in terms of prior experience to the same extent as high-power participants.

FRN responses to valid versus invalid feedback were not correlated with test phase performance or the number of learning blocks required to meet criterion. This lack of correlation was observed in prior research using this task (Frank et al., 2005; Schmid, Hackel, Jasperse, & Amodio, 2017), and it may reflect the fact that additional processes, such as working memory, contribute more strongly during learning than in test phase performance (Collins & Frank, 2012; Frank et al., 2007). Thus, it remains unclear whether such effects should be expected.

Meta-Analysis

To assess the effect of power on reinforcement learning with increased statistical power and to further refine our conclusions (Goh, Hall, & Rosenthal, 2016), we conducted a meta-analysis on the behavioral results of Studies 1 and 2, using Comprehensive Meta-Analysis (CMA) software (Biostat Inc, Version 3). This analysis indicated that high-power participants learned better from feedback than low-power participants, $d = .65$, $Z = 3.44$, $p(Z) = .001$, 95% CI [.28, 1.02]. Data from the two studies were homogenous, $Q = 0.54$, $p(Q) = .461$, indicating that the effect was comparable in both studies.

Additional contrast analyses revealed that high-power participants learned better than control participants, $d = .42$, $Z = 2.21$, $p(Z) = .027$, 95% CI [.05, .79], and data were relatively homogeneous, $Q = 1.67$, $p(Q) = .095$. Thus, the high-power manipulation appears to have increased learning. Low-power participants did not significantly differ from controls, $d = .21$, $Z = 1.17$, $p(Z) = .242$, 95% CI [−.56, .14]. However, the data were heterogeneous, $Q = 5.19$, $p(Q) = .023$, meaning that this contrast was dissimilar in the two studies, possibly due to differences in task procedures, such as the use of EEG in Study 2, which also placed restrictions on participants' movement and lengthened session time. These factors may have made the control group feel more powerless in Study 2.

A contrast was also computed to test whether power (high vs. low) affected approach versus avoidance learning differently across studies. Similar to the individual study results, no significant difference emerged (contrast $Z = 0.003$, $p = .956$).

General Discussion

In two studies, we found that manipulated power influenced feedback-based reinforcement learning—a core component of instrumental cognition. Specifically, high power enhanced the learning of both approach- and avoidance-related associations, relative to low power. Using a neural index of feedback processing, Study 2 further revealed that high power facilitated the processing of valid relative to invalid feedback. This finding suggests that high-power participants were more likely to process feedback in terms of goal relevance and prior learning rather than mere reward value. By comparison, low-power and control participants responded to feedback only in terms of its reward value, suggesting that their learning was not as strongly guided by prior knowledge and task goals. Together, these findings demonstrate that high power increases instrumental learning relative to low power, and that it does so by increasing goal focus and the processing of goal-relevant information.

Power and Instrumentality

Our findings link power to a specific mechanism of goal-directed, action-based learning. Although the idea that power enhances goal focus and instrumental behavior has been suggested in much prior work (Galinsky et al., 2003; Guinote, 2007b, 2007c; Schmid, Kleiman, et al., 2015), research has not previously examined the link between power and core mechanisms of instrumental processing in the mind. A key feature of instrumental learning is that it supports the learning of behaviors based on their repeated associations with a particular outcome, and as such, this form of learning is most directly expressed in behavior. Previous research has examined effects of power in judgments and self-reported expressions of learning. For example, past research examined power effects regarding explicit recollection of information (Overbeck & Park, 2001, 2006). In that work, high power facilitated participants' recall of information about other people and segments of conversation when these were instrumental to participants' goals, relative to low power. These studies addressed the incidental learning of information in declarative memory—a form of memory that, while important for social behavior, is not directly tied to mechanisms of instrumentality and action. By comparison, our research links power to a specific mechanism of goal-directed, action-based learning, thereby establishing a more direct association between power and instrumentality.

Although manipulated high power increased performance on a task that is specifically designed to assess a specific instrumental, striatal-dependent form of learning (Frank et al., 2007), it is notable that, in past research, high-power participants have been found to outperform low-power participants in a variety of tasks involving attentional control, cognitive control, or planning (e.g., Schmid, Kleiman, et al., 2015; Smith et al., 2008). Thus, it is possible that the effect of power on instrumental learning could be driven, in part, by the effect of power on other cognitive processes that could promote performance. Nevertheless, the observed effect of power on the probabilistic selection task, as well as the FRN, suggests that, in addition to more general effects of power, high power specifically enhances dopamine-dependent feedback-based reinforcement learning. In future research, neuroimaging could be used to more precisely demonstrate the theorized role of the striatum in power effects on instrumental learning.

It is possible that other factors that have been linked to power, such as action orientation (Galinsky et al., 2003), may also relate to instrumental learning processes. Similarly, other processes known to engage approach-related motivation may also promote instrumental learning, such as emotions like anger and desire (Gable & Harmon-Jones, 2010; Harmon-Jones, 2003) and neurophysiological states (Amodio, 2010; Gendolla & Silvestrini, 2010; Tomaka, Blascovich, Kelsey, & Leittena, 1993). With the current evidence that high power promotes instrumental learning processes, it is possible that a broad range of approach motivational states and emotions have their effects on behavior through the kind of instrumental processes described here (but see Schmid et al., 2017). This possibility suggests a promising direction for future research.

It may also be interesting to investigate the role of working memory in this effect. Working memory plays an important role in reinforcement learning (Collins & Frank, 2012; Frank et al., 2007). Moreover, there is some evidence that lack of power may decrease working memory (Smith et al., 2008), although other research did not replicate this effect (Schmid, Schmid Mast, & Mast, 2015). Power could also affect other processes that are relevant for reinforcement learning, such as model-based versus model-free learning strategies, which could be differentiated in sequential tasks (Doll, Simon, & Daw, 2012).

Implications for Contemporary Theories of Power

Our findings help to inform an important theoretical debate in the power literature regarding the way power affects people's sensitivity to reward versus punishment. Theories of power that emphasize its effect on goal focus and goal-directed behavior predict that high power should increase learning to approach good choices *and* to avoid bad choices, relative to low power (Guinote, 2007a, 2017; Magee & Smith, 2013; see also Schmid, Kleiman, et al., 2015), because both learning processes are instrumental for their goal. In contrast, theories that emphasize power effects on reward processing (Anicich & Hirsh, 2017; Keltner et al., 2003) posit that high power increases approach motivation and sensitivity to rewards, whereas low power increases avoidance motivation and sensitivity to punishments. Based on this rationale, one may argue that high power should boost approach learning and low power should facilitate avoidance learning.

Our findings were most consistent with the goal-focused perspective: High power increased approach- and avoidance-based forms of instrumental learning, relative to low power. The neural data from Study 2 further clarified the effect of power on goal focus as opposed to reward sensitivity. That is, high-power participants relied more on their prior experiences to guide their choices and were sensitive to the validity of feedback relative to prior learning, whereas low-power and control participants' responses did not reflect their prior learning. In contrast, power did not significantly moderate participants' neural processing of feedback valence within FRN amplitudes. Taken together, these results suggest that the power effect on reinforcement learning reflected differences in goal-relevant processing rather than in the processing of rewards versus nonrewards.

It is notable, however, that while our results more clearly support a goal focus model of power, it may nevertheless be possible to interpret our findings in terms of a reward focus account. That is, one may argue that achieving a learning goal (i.e., performing well on the task) is rewarding itself. Power could thus have increased focus on a rewarding end state (i.e., a better learning outcome), without enhancing focus on rewarding relative to nonrewarding information during the learning process. This interpretation is complicated, however, because it would suggest that power enhances focus on long-term reward outcomes but not on immediate reward/punishment feedback.

A High Power or a Low Power Effect?

Schaerer et al. (2016) noted that it remains difficult to determine the independent roles of high and low power from the current literature due to the infrequent inclusion of a control group. Interestingly, it is not unusual for power studies to produce inconsistent results with regard to control groups, even when methods are comparable. This suggests that ambiguity regarding the role of high versus low power may relate to methodological differences and their influence on power manipulations, as well as baseline experiences in the control condition.

Our results were also mixed in this regard: In Study 1, control participants performed more similarly to high-power participants, suggesting an effect of low power, whereas in Study 2, control participants performed more similarly to low-power participants, suggesting an effect of high power. We conducted a meta-analysis to gain clarity on the relative influences of high and low power vis-à-vis the control condition. This analysis suggested that, on average, the effect was driven primarily by the high-power manipulation; the high-power group learned better than the control group. The low-power group did not differ significantly from the control group. However, the meta-analysis indicated that the two studies produced heterogeneous results with regard to the low-power versus control group comparisons, such that an effect of low power cannot be ruled out.

In the present research, a potentially meaningful difference between studies was the use of EEG recording in Study 2, which placed substantial restraint on participants' movements during the task. This alone could have led participants to experience relatively lower power at baseline. We did not find significant differences in explicit reports of power feelings, but these measures were obtained at the conclusion of the session. It will be useful to more directly assess such methodological effects on experienced power in future research.

Conclusion

Power is known to profoundly affect judgments and decisions. Here, we examined the hypothesis that power affects a more basic form of processing—instrumental learning from positive and negative feedback—which likely underlies many effects of power. The finding that high power enhances both approach and avoidance forms of instrumental learning, relative to low power, supports a goal-based theory of power, whereby power facilitates strategic forms of goal-directed learning and decision making. Together, these findings advance general theories of social power and begin to illuminate the cognitive processes through which power influences a range of instrumental behaviors.

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(*Appendix follows*)

Appendix

Power Manipulation Procedure

Here, we present the exact procedures and instructions for the power manipulations, separately for the high-power, low-power, and control conditions.

High-power condition. The experimenter demonstrated the first standing pose, which corresponded to the standing pose suggested by Cesario & McDonald (Cesario & McDonald, 2013; see p.266 for a picture). Thus, the experimenter stood at the desk, with hands on the desk slightly spread apart, leaning forward. The experimenter gave the following instruction to the participant (note: "PAUSE" indicates where the experimenter makes a break to give the participant time to imagine the situation):

> *Please take this exact same position and hold it for the following task. It is very important that you hold this position. While you're holding this position, I'd like you to do an imagination task. PLEASE try to really put yourself in the role I'm going to tell you about, and really experience what it would feel like to be the person described. Please close your eyes now and imagine that you're at work (PAUSE) and you're standing at your executive desk (PAUSE). You're looking out over the worksite and overseeing the progress that's being made on the job you're in charge of. (PAUSE) I will leave the room now, so that you can concentrate on this. It is very important that you hold this pose and imagine this situation until I come back, which will be in about 1 min.*

After one minute, the experimenter returned to the room and instructed the participant to sit down in a chair in front of the computer. Here, the pose diverged from the pose suggested by Cesario and MacDonald, because recent research suggests that putting the feet on the desk does not induce the experience of high-power in all cultures (Park, Streamer, Huang, & Galinsky, 2013). Instead, the experimenter gave the participant the instruction to hold a sitting pose. Specifically, the experimenter said,

> *Now I'd like you to keep your legs a little bit spread, upper and lower leg in a 90 degrees angle. Keep your upper body upright. And please place your hands on the table spread apart. Again, it is very important that you hold this pose and do the imagination task that I am going to tell you about. Please close your eyes now and imagine that you're at work (PAUSE) and you're sitting at your desk (PAUSE). You're the head of one of the divisions at the company and you have several teams of subordinates working for you. (PAUSE) You've just gone over the latest performance data from the last quarter that one of your workers has given to you. (PAUSE) You're evaluating this person's performance on the report. (PAUSE) I will leave the room now, so that you can concentrate on this. Please hold this pose and imagine this situation until I come back, which will be in about 1 min.*

Low-power condition. In the low-power condition, the poses were the exact same as suggested by Cesario & McDonald (Cesario & McDonald, 2013; see p.266 for a picture). The experimenter demonstrated the standing pose by leaning against the wall with arms and feet crossed. The experimenter gave the following instruction to the participant:

> *Please take this exact same position and hold it for the following task. It is very important that you hold this position. While you're holding this position, I'd like to do an imagination task. PLEASE try to really put yourself in the role I'm going to tell you about, and really experience what it would feel like to be the person described. Please close your eyes now and imagine that you're a freshman in high school (PAUSE) and you're leaning up against a set of lockers (PAUSE). A group of older students are around you, making fun of you. (PAUSE) I will leave the room now, so that you can concentrate on this. It is very important that you hold this pose and imagine this situation until I come back, which will be in about 1 min.*

(*Appendix continues*)

After one minute, the experimenter returned to the participant room and asked the participant to sit down on a chair in front of the computer. The experimenter said,

> *Now I'd like you to keep your feet close to each other. Keep your upper body relaxed. And please keep your elbows close to your torso and hold your hands in your lap. Again, it is very important that you hold this pose and do the imagination task that I am going to tell you about. Please close your eyes now and imagine that you're at work and you're sitting in front of your boss. Imagine your boss is standing across from you, on the other side of his desk (PAUSE), facing you leaning with his hands on the desk (PAUSE). He's making it clear to you that he isn't satisfied with your latest job performance (PAUSE). I will leave the room now, so that you can concentrate on this. Please hold this pose and imagine this situation until I come back, which will be in about 1 min.*

Control condition. In the control condition, the experimenter gave the following instruction for the standing pose:

> *I would like you to stand up and take on a neutral position. It is very important that you hold this position. While you're holding this position, I'd like to do an imagination task. PLEASE try to really put yourself in the role I'm going to tell you about, and really experience what it would feel like to be the person described. Please close your eyes now and imagine that you're standing in a waiting line for a museum. I will leave the room now, so that you can concentrate on this. It is very important that you hold this pose and imagine this situation until I come back, which will be in about 1 min.*

After receiving this instruction, most participants had their arms hanging down next to their bodies. If this was not the case (e.g., if hands were on the hips or the arms crossed), the experimenter corrected the pose. After one minute, the experimenter returned to the participant room and asked the participant to sit down on a chair in front of the computer. The experimenter said,

> *I'd like you to sit down on this chair in a neutral position. Again, it is very important that you hold this pose and do the imagination task that I am going to tell you about. Please close your eyes now and imagine that you're watching a fairly interesting television program. I will leave the room now, so that you can concentrate on this. Please hold this pose and imagine this situation until I come back, which will be in about 1 min.*

Participants' "neutral" pose was corrected if it was clearly expansive (e.g., arms on the armrest) or restricted (e.g., arms or legs crossed). To keep participants in their respective mindsets, participants of all three conditions were instructed to hold the sitting pose during the learning task as far as possible.

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