Please cite as “Galang, C.M. & Obhi, S.S. (In Press). Social Power and Frontal Alpha Asymmetry. *Cognitive Neuroscience*.”

Social Power and Frontal Alpha Asymmetry

Carl Michael Galang^{1*} & Sukhvinder S. Obhi^{1*}

¹Social Brain, Body and Action Lab

Department of Psychology, Neuroscience and Behaviour

McMaster University, Canada

***correspondence to Carl Michael Galang (galangc@mcmaster.ca) or Sukhvinder S. Obhi (obhi@mcmaster.ca)**

Address:

Psychology Building (PC), Room 102

McMaster University

1280 Main Street West

Hamilton Ontario L8S 4K1

Canada

Phone: 905-525-9140 x26755 (CMG) x23030 (SSO)

Fax: 905-529-6225

Abstract

Recent studies have shown that the states of high and low social power (the ability to control or influence another's thoughts, feelings, or behaviours) are related to left and right frontal hemisphere activity, respectively, suggesting a connection with two neurobiological motivational systems – the Behavioural Activation and Inhibition Systems. However, an important and outstanding question is which state of social power is associated with differences in hemispheric activity. In the current study, we addressed this outstanding issue by examining differences in frontal alpha asymmetry while participants engaged in an established episodic recall task, priming states of high, low, or neutral social power. Results show that that it is the low social power state that is associated with hemispheric differences; that is, the low social power state was associated with significantly less left-frontal cortical activity relative to both the high and neutral social power states, while the latter two states did not differ. We discuss our results considering previous work on social power and the notion that different social power states are associated with different cognitive and behavioural tendencies.

Keywords: Social Power, Frontal Alpha Asymmetry, Behavioural Activation System, Behavioural Inhibition System, Approach-Inhibition Theory of Power

1. Introduction

1.1 Social Power

The past fifteen years has seen an explosion of social psychological research on the effects of social power (i.e., the ability to control or influence another's thoughts, feelings, or behaviours) on cognition and behaviour (see Guinote, 2017 for a recent review). Keltner et al. (2003) provided a theoretical framework that has guided recent research (although see Fiske's functionalist theory of social power; Fiske, 1993). This framework is often referred to as the 'approach-inhibition' theory of social power, which asserts that the powerful are approach-oriented and the powerless are more withdrawal-oriented. Inherent to this view is that the powerful are more attendant to reward cues and positive emotions, whereas the powerless are more attendant to threats and negative emotions. On a behavioural level this means that the powerful are more driven to act, whereas the powerless are more likely to inhibit their behaviours.

Using the approach-inhibition theory to guide their research, Galinsky et al. (2003) showed that high levels of social power leads to greater motivation to act, especially in a goal-consistent manner. To manipulate power, they developed an easy-to-use method that involves participants recalling an episode during which they felt powerful (i.e., had control over the outcomes of others) or powerless (i.e., where others had control over their outcomes). In a neutral condition, they simply asked participants to recall the events of the previous day. This 'episodic recall task' (Galinsky et al, 2015) has been widely used in research. For example, it has been used to show that a state of high social power reduces the tendency to take the perspective of others (Galinsky et al., 2006), increases the tendency to focus on task demands as opposed to information that is peripheral to the task (Guinote, 2007), and increases (perceptual) objectification of sexualized images of the opposite sex (Civile and Obhi, 2016). Other studies have shown specific effects of

low social power — Dubois et al. (2010) found that low social power leads to biased representations of the size of valued objects (e.g. money), and Obhi et al. (2012) found that being primed to a state of low social power reduces the sense of agency. Lastly, the episodic recall task has also been used to show that different social power states are associated with differences at the neurophysiological level. Specifically, Hogeveen et al. (2014) showed that high social power reduces motor resonance as indexed via motor evoked potentials (MEPs) induced with transcranial magnetic stimulation (TMS). Motor resonance refers to the automatic activation of the motor cortex during observation of another person's actions. In contrast to high social power participants, participants primed to low social power exhibited relatively high levels of motor resonance (also see Varnum et al., 2016).

Overall, using a host of manipulations (for a methodological overview see Galinsky et al., 2015), psychologists have convincingly shown that social power can have profound effects on cognition and behaviour. Whereas the psychology of social power is quite voluminous and well established, there has been relatively less work on uncovering its neurobiological underpinnings. However, Keltner et al. (2003) speculated that their theory of social power connected to two posited neurobiological systems of motivation - the Behavioural Activation System (BAS) and the Behavioural Inhibition System (BIS) (e.g., Gray, 1990).

1.2 The BAS and BIS

The traditional model of the BAS and BIS stem from Gray's (e.g., 1990) reinforcement sensitivity theory which states that the BAS is sensitive to rewards and acts to facilitate behaviours that lead to positive outcomes (regardless if the behaviour is approach or withdrawal oriented), whereas the

BIS is sensitive to punishment and acts to inhibit behaviours that lead to harmful outcomes. In contrast, the revised model of the BAS and BIS (Gray & McNaughton, 2000) suggests that the BAS controls approach motivation and rewards, while the BIS acts as a conflict monitor that interrupts or inhibits behaviours depending on contextual factors. Furthermore, a third system was postulated, the flight-fight freezing system (FFFS), which controls withdrawal motivations to aversive stimuli.

Given the above definitions, it is easy to see why Keltner et al. (2003) speculated that the BAS and BIS underlie feeling powerful and powerless, respectively; after all, powerful people are more likely to be able to carry out plans relatively unimpeded (leading to positive outcomes), whereas the powerless must continually monitor their environment for factors (e.g. more powerful people) that might impede their progress (which otherwise might lead to negative outcomes). However, strong evidence for this connection, at least at the neurophysiological level, did not arise until a study conducted by Boksem et al. (2012) using frontal alpha asymmetry (FAA).

1.3 Frontal Alpha Asymmetry

FAA refers to a significant difference in alpha activity (i.e., 8-12 Hz frequency band) between the frontal left and right hemispheres and is assessed via Electroencephalography (EEG). Given that alpha activity has been shown to be *inversely related* to cortical activity (jointly measured using fMRI and EEG; Laufs et al., 2003), if there is *less* alpha activity in one hemisphere compared to the other, it is assumed that there is *more* cortical activity in that same hemisphere compared to the other. To avoid confusion, and following standard nomenclature, we specifically refer to differences in cortical activity when referring to the effects of FAA.

127

128 It is important to note that there are multiple models detailing the relationship between FAA and
129 the BAS, BIS, and FFFS (for a detailed overview of these models, see: Rodrigues et al., 2018).
130 Following the traditional model of the BAS and BIS, the *Motivational Direction Model* suggests
131 that, given certain contexts, greater left-frontal cortical activity is associated with approach
132 motivated behaviours (governed by the BAS), while greater right-frontal cortical activity is
133 associated with withdrawal motivated behaviours (governed by the BIS; e.g., Sutton and Davidson,
134 1997). Likewise, the *Bilateral BAS Model* suggests that greater left and right frontal cortical
135 activity is related to approach and withdrawal motivated behaviours, respectively; however, these
136 two systems are part of a behavioural activation system linked to bilateral frontal brain activation
137 (Hewig et al., 2004; 2005; 2006).

138

139 In contrast to both models, Wacker et al.'s (2008) *Behavioural Activation – Behavioural Inhibition*
140 *Model* explicitly connects itself to the revised model of the BAS, BIS, and FFFS. The model
141 suggests that greater left-frontal cortical activity is related to behavioural activation in general
142 (with approach motivated behaviours governed by the revised BAS and the withdrawal motivated
143 behaviours governed by the FFFS), while greater right-frontal cortical activity is related to
144 behavioural conflicts and inhibition (governed by the revised BIS). It is also important to note that
145 research by Harmon-Jones and Allen (1997) and Coan and Allen (2003) suggests that the
146 relationship between right-frontal cortical activity and the BIS is not as strong as the one between
147 left-frontal cortical activity and the BAS. This relationship may be due to the complex role the
148 (revised) BIS plays in conflict monitoring and inhibition of behaviours, as opposed to active
149 avoidance (see Amodio et al., 2008).

Past research has linked FAA to a variety of different cognitive and behavioural processes, along with an emphasis of using FAA as a biomarker for psychopathologies (for reviews, see: Coan and Allen, 2004; Harmon-Jones et al., 2010; Reznik and Allen, 2017; Harmon-Jones and Gable, 2018). For example, previous research has linked less relative left-frontal cortical activity with depression (e.g., Nusslock et al., 2011; Nelson et al., 2018), with more recent research showing that this relationship is moderated by levels of comorbid anxiety (Nusslock et al., 2018). Less left-frontal cortical activity has also been linked to post traumatic stress disorder (Meyer et al., 2018) and aggression (Peterson et al., 2008), while stronger relative left-frontal cortical activity has recently been linked to callousness (Keune et al., 2018) and attention deficit hyper activity disorder (Hale et al., 2009; Keune et al., 2015).

1.4 Social Power and Frontal Alpha Asymmetry

To investigate Keltner et al.'s (2003) proposed connection between social power and the BAS and BIS, Boksem et al. (2012) used EEG to record electrical activity over the scalp while participants completed the episodic recall task (i.e., the power priming procedure described earlier). Boksem et al. (2012) found the expected results — participants in the high social power condition showed more left-frontal cortical activity compared to those in the low social power condition (who tended to show more right-frontal cortical activity). More recently, Li et al. (2016) found the same pattern of results using a modified episodic recall task (inducing anger along with states of social power). It is important to note, however, that neither Boksem et al. (2012) nor Li et al. (2016) directly measured BAS/BIS, and therefore the proposed connection between social power and the BAS/BIS is *assumed* via FAA results recorded during the episodic recall task. Specifically,

Boksem et al. (2012) proposed that the differences in high and low social power are the result of activity in two separate neural pathways that project from the limbic system to the PFC. They suggested that powerful people have more activation of a mediodorsal pathway that projects bilaterally to the dorsolateral PFC, whereas the powerless have more activation of a ventrolateral pathway that projects to the right ventral PFC and orbitofrontal cortex; the dorsal stream stimulates approach and goal-directed behaviours, while the ventral stream down-regulates approach behaviours depending on environmental factors (Corbetta & Shulman, 2002).

This potential account of differences in neural processing between high and low social power makes sense given the previously discussed relationship between FAA and the BAS/BIS. However, it is important to note that neither Boksem et al. (2012) nor Li et al. (2016) had a neutral social power condition in their experiments. As such, it is unclear which social power condition is associated with this apparent difference in FAA (or if both are); in other words, it is unclear if priming high or low social power leads to more left or right frontal cortical activity compared to neutral social power, respectively (or if both effects are shown).

Given that left-frontal cortical activity and the BAS seem to be more robustly associated than right-frontal cortical activity and the BIS, it is possible that left-frontal cortical activity and high social power are more robustly associated than right-frontal cortical activity and low social power. If this were true, we could infer that high social power is solely associated with the observed FAA effect. On the other hand, it may be that feeling powerless is more associated with (the previously proposed) inhibitory processes in the right hemisphere, and an argument could be made that it is the low social power condition that is solely associated with the observed effects on FFA. Support

for this possibility comes from a study by Wilkinson et al. (2010), where they found that participants induced to a state of low social power (via the episodic recall task), compared to both high and neutral social power, were more likely to bisect horizontal lines to the left of centre and bump into the right-hand side of a narrow passage — both of which indicate right-hemisphere dominance. Of course, an equally viable alternative is that both high and low social power conditions could contribute to the difference in FAA previously reported by Boksem et al. (2012). In any case, if we are to seriously consider the BAS and BIS (indexed by FAA) as plausible neurobiological systems underlying the psychological and behavioural effects of differing levels of power, then it is critical that we perform the necessary experiment(s) to determine whether it is high social power, low social power, or both states that contribute to observed differences in FAA. We address this outstanding and important issue in the present study via a careful experiment investigating FAA in three conditions; high social power, low social power, and a neutral condition.

1.5 The Current Study

To better understand the relationship of the previously observed differences in FAA between high and low social power states, we conducted a more complete experiment via the addition of a neutral social power condition. By comparing patterns of FAA in this condition to those in the high and low social power conditions, we can discern more completely the origins of the previously observed FAA differences. If the high social power condition is solely associated with the observed FAA differences, then participants in the neutral social power condition should show a similar pattern of FAA as those in the low social power condition. If the low social power condition is solely associated with the observed FAA differences, then the neutral social power condition

should not differ from the high social power condition. Again, it is also possible that both high and low social power contribute to the effect, in which case, the neutral social power condition should be associated with a pattern of FAA that is in-between the FAA observed in the high and low social power conditions. Given the results of Boksem et al. (2012) and Li et al. (2016), we can also make a strong prediction that high social power will be associated with more left-frontal cortical activity compared to low social power.

2. Methods

2.1 Participants

54 right-handed undergraduate volunteers (mean age = 18.6; male = 25) from the McMaster University psychology pool participated in this study for course credit and/or monetary compensation (\$5 or \$10). Each social power condition (High, Low, Neutral) was assigned an equal number of participants ($n = 18$; High male = 8; Low male = 8; Neutral male = 9). Sample size was determined based on Boksem et al. (2012) who only had a high and low social power condition with 18 participants per condition. In addition to this, we added an additional 18 participants in the control condition, resulting in a total of 54 participants in this study¹. Prior to participation, participants provided written informed consent. The study was approved by the McMaster Research Ethics Board (MREB).

2.2 Procedure

¹ A *post-hoc* sensitivity analysis using G*Power 3.1 (Faul et al., 2007; 2009) suggests that the smallest effect size that can be found with 80% power with the current design is Cohen's $F = 0.44$. This suggests that our study is underpowered for finding medium and small effects.

Participants first read over a letter of information going over the tasks in the study. If they were comfortable with the procedures, they were asked to sign a consent form. Afterwards, participants were fitted with a 64-channel EEG cap (Compuscan, Neuromedics). This experiment formed part of a larger study that consisted of a second phase that will not be discussed here. This experiment was always run as the first part of the larger study, and as such, we present it here as a single standalone experiment (although, for completeness, we briefly allude the “second” part of the larger study below). At the beginning of this first experiment, participants were required to complete the episodic recall task using Microsoft Word to type their episodic recollections. Participants were assigned to one of three Social Power groups: High, Low, or Neutral. As described in the introduction, the episodic recall task requires participants to write about a time when they felt powerful, powerless, or to recount what happened the previous day. Exact instructions were as follows (based on Galinsky et al., 2003):

- **High Social Power:** Please recall a particular incident in which you had power over another individual or individuals. By power, we mean a situation in which you controlled the ability of another person or persons to get something they wanted, or were in a position to evaluate those individuals. Please describe this situation in which you had power - what happened, how you felt, etc.
- **Low Social Power:** Please recall a particular incident in which someone else had power over you. By power, we mean a situation in which someone had control over your ability to get something you wanted, or was in a position to evaluate you. Please describe this situation in which you did not have power - what happened, how you felt, etc.

- **Neutral Social Power:** Please recall your day yesterday. Please describe your experiences yesterday - what happened, how you felt, etc.

The participants were informed that they would have 10 minutes to complete the task, and that they should write as much as possible within that time window. After making sure that the participants understood the task, the experimenter started the EEG recording, instructed the participant to begin the task and promptly left the room (it should be noted that we did not record EEG data for resting states before the task, see limitations section). After the allotted time limit was up, the experimenter came back into the room and saved the EEG dataset. In the second part of the experiment (again, not discussed in detail here), the participants were tasked with watching videos of hands being pierced with needles or touched by Q-tips. The second part of the larger study addresses a different research question than the first part, and as such, we do not present any further description or the results of the second part of the study here.

2.3 EEG Acquisition and Processing

EEG was recorded using a 64 channel Neuroscan Quik-Cap. We recorded vertical eye movements using two electrodes placed above and below the left eye (VEOG). The EEG and VEOG were sampled at 1000Hz and referenced to an electrode near CZ during recording (the data was later re-referenced to the average of the mastoids). The following processing steps followed Boksem et al. (2012) as much as possible to fairly test the hypothesis that high power leads to more left-frontal cortical activity compared to low power. Using the CURRY 7 Neuroimaging Suite (Compumedics USA, Inc., Charlotte, NC, USA), the raw data was offline re-referenced to the average of the mastoids, filtered with a 0.53 high-pass filter and a 40Hz low-pass filter (IIR Butterworth, Order

4), and re-sampled to 100Hz. The data was then transferred to EEGLab (Delorme and Makeig, 2004). In EEGLab, bad channels were visually identified and interpolated. Conspicuously bad parts of the EEG recording were identified and removed using EEGLab's *pop_rejcont* function (threshold 12, all other settings default). The data was segmented into 5.12 seconds epochs with 50% overlap, and ocular artifacts were corrected using the Gratton et al. (1983) method. Afterwards, the data was submitted to a Fast Fourier Transformation (FFT) using a 100% Hanning Window (see Allen et al., 2004, for a discussion on signal processing and FAA). Finally, the first 50 segments were averaged for analysis.

Following established methods of computing FAA, we calculated an 'FAA Index' by taking the log difference of alpha activity (8-12Hz; extracted using FFT) between pairs of homologous electrodes (e.g. Log(F4)-Log(F3); this approach also deals with individual differences from non-neural sources such as skull thickness; see Allen et al., 2004). The data is first log transformed for normalization, as alpha asymmetry data is often skewed. Since the right-sided electrodes are subtracted from the left-sided electrodes (and due to the inverse relationship between alpha and cortical activity), a *positive* FAA Index refers to more left-frontal cortical activity while a *negative* FAA Index refers to more right-frontal cortical activity. Boksem et al. (2012) note that the effects of power on FAA are not completely symmetrical between the left and right hemispheres; as such, we follow their advice of using an aggregate measure by pooling together electrode pairs. We opted to use the same electrode pairings — AF4-AF3, F4-F3, F6-F5 — and have also included FP2-FP1, FC4-FC3, and FC6-FC5 to have more coverage of the anterior region of the scalp (see Figure 1). We pooled these electrode pairs by averaging the logged right (FP2, AF4, F4, F6, FC4, FC6) and left (FP1, AF3, F3, F5, FC3, FC5) electrodes before taking their difference. This method

has the additional benefit of avoiding a possible inflation of Type 1 error by having only one FAA Index per condition, rather than testing each pair of electrodes between conditions separately.

Figure 1 about here

2.4 Primary Analysis Approach

FAA Indices were entered into a One-Way ANOVA, with Power as the between-subjects factor. Assuming a significant result, follow-up t-tests comparing each condition to one another were conducted. Given that the results of Boksem et al. (2012) and Li et al. (2016) enables a strong directional prediction (high social power leads to more a more positive FAA Index (more left-frontal cortical activity) compared to low social power), we conducted a one-tailed t-test for High vs. Low Social Power. However, two-tailed t-tests were used for the other pairings (i.e. High vs. Neutral and Low vs. Neutral). Given that the t-tests involving the Neutral Social Power condition were *post-hoc*, p-values have been corrected for multiple comparisons in these tests (Holms-Bonferroni method). However, since the comparison between High and Low Social Power is based on an *a priori* directional hypothesis, we report the uncorrected p-value.

3. Results

3.1 Frontal Alpha Asymmetry

The one-way ANOVA yielded a significant effect of Power ($F(2,51) = 4.244$, $p = 0.02$, $\eta^2 = 0.143$). The follow up t-tests shows that the High Social Power condition ($M = 0.051\mu V2$, $SE = 0.022$) showed a larger FAA Index relative to the Low Social Power condition ($M = -0.027\mu V2$, $SE = 0.028$) ($t(34) = 2.22$, $p = 0.016$, $d = 0.74$). Furthermore, the Neutral Social Power condition ($M = 0.08\mu V2$, $SE = 0.031$) also showed a larger FAA Index relative to the Low

Social Power condition ($t(34) = 2.6$, $p = 0.027$, $d = 0.87$). High and Neutral Social Power did not significantly differ from each other ($t(34) = 0.76$, $p > 0.4$). See Figure 2.

One sample t-tests were also conducted to determine if cortical activity significantly differed between each hemisphere; or in other words, if the FAA Index is significantly different from 0. One tailed t-tests were conducted for High (FAA Index > 0) and Low Social Power (FAA Index < 0) based on previous results (Boksem et al., 2012). A two-tailed t-test was conducted for Neutral Power (FAA Index *does not* = 0). Results indicate that the FAA Index for High Social Power is significantly greater than 0 ($t(17) = 2.326$, $p = 0.016$, $d = 0.55$), the FAA Index for Neutral Social Power is significantly different from 0 ($t(17) = 2.618$, $p = 0.018$, $d = 0.617$), and the FAA Index for Low Social Power is *not* significantly less than 0 ($t(17) = 0.99$, $p = 0.17$).

Figure 2 about here

3.3 Region Specificity

To check whether the effect of Social Power found is specific to the frontal regions, we calculated the pooled Parietal Alpha Asymmetry (PAA) Index of two pairs of parietal electrodes (P4-P3, P6-P5). We entered the FAA and PAA indices into 3x2 mixed-design ANOVA, where Social Power is the between-subjects factor. The results indicate a main effect of Region (FAA vs. PAA) ($F(1,51) = 7.56$, $p = 0.008$, partial-eta-squared = 0.129), which suggests that there were significantly larger alpha asymmetry indices in the parietal region ($M = 0.11\mu V^2$, $SE = 0.027$) compared to the frontal region ($M = 0.035\mu V^2$, $SE = 0.017$). No main effect of Social Power was found ($p = 0.22$). Importantly, the results indicate a significant Region x Social Power interaction ($F(2,51) = 3.86$, $p = 0.028$, partial-eta-squared = 0.131). This interaction was decomposed by

conducting separate one-way ANOVAs on each region. No effect of Social Power was found in the parietal region ($F(2,51) = 2$, $p = 0.145$), while the frontal region yielded the results reported above.

Figure 3 about here

3.4 Gender

We further tested if participant Gender interacted with Social Power. As such, we entered participant gender as a between-subjects factor (along with Social Power) into a 3x2 ANOVA. There was no significant Social Power x Gender interaction ($F(2,48) = 1.08$, $p = 0.348$). We again found the main effect of Social Power along with an interesting main effect of Gender ($F(1, 48) = 5.72$, $p = 0.021$, partial-eta-squared = 0.106). Males ($M = 0.074\mu V2$, $SE = 0.019$) had a more positive FAA Index compared to females ($M = 0.00015\mu V2$, $SE = 0.023$).

Figure 4 about here

4. Discussion

4.1 Clarifying the Relationship Between Social Power and FAA

Inspired by Keltner et al.'s (2003) approach-inhibition theory of social power and Galinsky et al.'s (2003) methodological innovations, the past decade and half has seen an explosion of social power related research (Galinsky et al., 2015; Guinote, 2017). Such research has focused on exploring the effects of social power on cognition and behaviour. In contrast, relatively little work has focused on uncovering the neurobiological underpinnings of social power (but see Hogeveen et al., 2014; Boksem et al., 2012). Keltner et al. (2003) posit a link between their approach-inhibition theory of social power and two neurobiological systems of motivation — the BAS and BIS. Using

376 FAA, affective neuroscientists have linked the BAS and BIS to hemispheric differences in activity,
377 with BAS linked to left-frontal cortical activity and BIS linked to right-frontal cortical activity
378 (Coan and Allen, 2004). Boksem et al. (2012) and Li et al. (2016) showed that states of high and
379 low social power led to *relative* differences in left- and right- frontal cortical activity, respectively,
380 providing empirical evidence for the link between states of power and the BAS and BIS. The
381 current study sought to specify the direction of this effect by utilising a more complete
382 experimental design including a neutral condition. We successfully replicated Boksem et al. (2012)
383 and Li et al. (2016) by finding that participants in the high social power condition do indeed show
384 more left-frontal cortical activity relative to those in the low social power condition (indexed by a
385 larger FAA Index in the high social power condition relative to low). However, and importantly,
386 we found no difference between the high and neutral social power conditions, and a significant
387 difference between the low and neutral social power conditions.

388
389 This pattern of results suggests that the framing used previously (e.g., by Boksem et al, 2012), that
390 high social power is associated with greater FAA, and in turn that high social power is associated
391 with brain activity that reflects greater activation of the BAS, may be only partially correct. This
392 is because, when a neutral condition is included, it is the low social power condition that is
393 associated with FAA that significantly differs from the neutral condition, whereas the high social
394 power condition is associated with FAA that is not statistically different from the neutral condition.
395 Furthermore, our results indicate that, rather than low social power leading to more right-frontal
396 cortical activity, it is more appropriate to state that low social power leads to *less* left-frontal
397 cortical activity relative to the other conditions. This interpretation is bolstered by the one-sample
398 t-tests – low social power did not lead to an FAA index significantly less than 0, and as such, we

cannot conclude that low social power leads to more right-frontal cortical activity.

4.2 Social Power and the BIS/BAS

Although we do not directly measure the BIS/BAS, we follow Boksem et al. (2012) and Li et al. (2016) in assuming that the obtained FAA results index the BIS and BAS. Given that the (traditional) BIS is sensitive to punishment and acts to inhibit behaviours that lead to harmful outcomes and the (revised) BIS acts as a conflict monitor that interrupts or inhibits behaviours depending on contextual factors, then the fact that our data shows that low social power leads to less left-frontal cortical activity relative to high and neutral fits well with research that suggests that feeling powerless is associated with increased threat vigilance (Willis et al., 2011) and inhibited behaviours (e.g. loss aversion; Inesi, 2010). This interpretation fits well with Wacker et al.'s (2008) *Behavioural Activation – Behavioural Inhibition Model*, wherein low social power may be associated with an increased need for monitoring for potential conflicts and inhibiting certain behaviours when conflicts arise; although we hesitate to say more given that the current study did not directly measure the BIS/BAS.

Furthermore, it is important to note that less relative left-frontal cortical activity does not imply more right-frontal cortical activity (exemplified by the one-sample t-tests); although, as noted above, the relationship between the BIS and right-frontal cortical activity is not as robust compared to the BAS and left-frontal cortical activity. More work will be needed to fully elucidate how less left-frontal cortical activity leads to increased threat vigilance and disinhibited behaviours as found in behavioural studies of social power.

It is also important to note that the BAS and BIS scales used in previous studies measure trait differences between participants, which are then compared to resting-state FAA. In contrast, the episodic recall task induces a state, and it is this state that is of interest rather than a pervading trait. It is possible that social power related differences in frontal alpha asymmetry might be dependent on the context the person is in (e.g., recalling a time when they felt powerful/powerless). An interesting question then is whether trait measures of power (e.g. Anderson et al., 2012) correlate with BAS/BIS scores and FAA, or if context specific conditions need to be met to see the relationship. An answer to this question would be very useful in further connecting the approach-inhibition theory of social power to the BAS and BIS.

An important question that needs to be addressed is why the FAA index of the high and neutral social power condition did not differ from one another. As noted in the introduction, Boksem et al. (2012) proposed that the differences in high and low social power are the result of two separate neural pathways that project from the limbic system to the PFC. Specifically, high social power may be more associated with activity in a mediodorsal pathway that projects bilaterally to the dorsolateral PFC, whereas low social power may be more associated with activity in a ventrolateral pathway that projects to the right ventral PFC and orbitofrontal cortex. As such, while the left ventromedial PFC was likely active during the recall task, extra activations in the right hemisphere in the low power condition may have led to more right-hemisphere activity that was then reflected in the FAA. Regarding the high social power condition, it is possible that activation of both the left dorsolateral and ventromedial PFC, while complementary, did not lead to an additive effect that was reflected in the FAA (perhaps due to a ceiling effect). This may account for the fact that there was no difference in FAA between the high and neutral power group. More work will be

needed to clarify this issue; given the current results, however, the evidence suggests that states of high social power do not lead to relatively more approach motivated behaviours compared to a neutral state.

Another important issue is why participants in the neutral condition showed more left-frontal cortical activity compared to the low social power condition. Research exploring the neural correlates of autobiographical memory suggests that the left ventromedial PFC is primarily involved when one is re-experiencing a past event (Gilboa, 2004). While the episodic recall task is meant to induce states of social power, it necessarily requires the activation of stored memories of past events. As such, in the neutral power condition, when one is merely asked to recount the events of the previous day, the left ventromedial PFC may have been especially active, thus leading to more left-frontal cortical activity indexed via FAA. Further evidence comes from the fact that left PFC is more involved with semantically guided information processing, of which the episodic recall task arguably involves (Cabeza, 2006).

4.3 Motor Actions and FAA

It could be argued that the above interpretation is confounded by the fact that we recorded brain activity during a task that requires motor action. For example, Harmon-Jones (2006) found that right and left handed contractions causes contralateral alpha suppression. However, since our task involved typing, a task which involves both hands, contralateral effects should be balanced. Furthermore, since participants in all conditions were typing, the subsequent noise in data should be evenly spread throughout the conditions. Lastly, the word count between each condition did not significantly differ, which suggests that one group did not write more or less than any other.

4.4 Gender, Social Power, and FAA

Another intriguing aspect of our results is the finding that FAA is different for males and females — males tended to show more left-frontal cortical activity compared to females, as indexed by a more positive FAA Index (females hovered around 0 suggesting balanced activity). This may not be surprising given that males are reported to show more approach-oriented tendencies (e.g. risk-assessment; Harris et al., 2006), and that at the societal level, it may be that males enjoy generally higher levels of power than females. We draw attention to this result as it opens up an interesting question regarding social power and gender. However, as male-female differences were not the focus of this study, we refrain from further comment on this aspect of results.

4.5 Limitations

There are a few limitations that should be kept in mind considering the above discussion.

4.5.1 Participant Recruitment

The first limitation of the current study is that participants assigned to the neutral social power condition were recruited first – further participants were then randomly assigned to high and low power conditions. This was done to address prior work on the behavioural task that formed the second part of this study (note, we do not report that experiment in this paper). Specifically, in that second task, we were aiming to replicate previous reports on the effects of pain observation on EEG activity. As such, we exclusively assigned the first eighteen participants into the neutral power condition to clearly see whether, in the absence of a power manipulation, similar results on the pain observation task were found. We raise this assignment to groups issue in the interests of

being thorough in our reporting, but we do not think that it is likely to have affected our results (i.e., it is unlikely that the first eighteen participants specifically differed on left hemisphere bias, for example, compared to participants who were recruited later). However, on balance, it would have been more ideal to use random assignment in all three conditions throughout the study.

4.5.2 *Lack of Resting State Baseline*

As mentioned above, we did not record resting state EEG. This limits our results as we cannot compare changes in FAA that may be specifically due to the episodic recall task. We can (and have done so), at best, compare the FAA index obtained in each group *relative* to one another. Future studies will need to include a resting state condition to better elucidate the relationship between the effects of priming states of social power and FAA.

4.5.3 *Lack of Direct Measure of BAS/BIS*

A final noteworthy limitation is that we, along with Boksem et al. (2012), did not record direct measures of self-reported BAS/BIS. Doing so would have allowed for more direct comparisons between Keltner et al.'s (2003) posited connection between the approach-inhibition theory of power and the BAS/BIS. As such, future studies should not only record self-reported BAS/BIS, but also trait measures of social power in order to better understand the relationship between social power, FAA, and the BAS/BIS.

4.6 *Conclusion*

In conclusion, the current study has found that inducing a state of low social power is associated with less left-frontal cortical activity relative to inducing a state of high social power or a state of

neutral social power. This clarifies previous results (Boksem et al., 2012; Li et al., 2016) by showing that it is low social power that is associated with differences in hemispheric activity between social power conditions. We have discussed various interpretations of these results and their consequences. Overall, more research is needed to clarify the relationship between social power, FAA and the BAS and BIS — including the need to measure and compare resting state FAA with state induced FAA, obtaining direct measures of BAS/BIS, and comparing trait measures of social power with FAA and the BAS/BIS. While more work needs to be done on this topic, our results nevertheless provide the clearest picture to date of how states of social power affects frontal alpha asymmetry and the BAS/BIS, which will help guide future research on this emerging topic.

535 **Acknowledgements**

536 This work was supported by an Ontario Graduate Fellowship awarded to CMG, a SSHRC Insight
537 grant and infrastructure funding from the Canada Foundation for Innovation, held by SSO. We
538 thank Dr. Ciro Civile, along with two anonymous reviewers, for valuable comments and
539 discussion.

540 **Conflicts of Interest**

541 The authors declare no conflicts of interest.

542

543

544

545

546

547

548

549

550

551

552

553

References

- Allen, J.J.B., Coan, J.A., and Nazarian, M. (2004). Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. *Biological Psychology*, 67, 183-218.
- Amodio, D.M., Devine, P.G., and Harmon-Jones, E. (2008). Individual Differences in the Regulation of Intergroup Bias: The Role of Conflict Monitoring and Neural Signals for Control. *Journal of Personality and Social Psychology*, 94, 60-74.
- Anderson, C., John, O.P., and Keltner, D. (2012). The Personal Sense of Power. *Journal of Personality*, 80(2), 313-44.
- Boksem, M.A.S., Smolders, R., and De Cremer, D. (2012). Social power and approach-related neural activity. *Social Cognitive and Affective Neuroscience*, 7, 516-20.
- Cabeza, R. (2006). *Prefrontal and medial temporal lobe contributions to relational memory in young and older adults*. In D. Zimmer, A. Mecklinger, & U. Lindenberger (Eds.), *Binding in human memory: A neurocognitive approach* (pg. 595-626). New York: Oxford University.
- Coan, J.A. and Allen, J.J.B. (2003). Frontal EEG Asymmetry and the behavioural activation and inhibition systems. *Psychophysiology*, 40, 106-14.
- Coan, J.A. and Allen, J.J.B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, 67, 7-49.
- Corbetta, M. and Shulman, G.L. (2002). Control of Goal-Directed and Stimulus-Driven Attention in the Brain. *Nature Reviews: Neuroscience*, 3, 201-215.

- 575 Civile, C. and Obhi, S.S. (2016). Power, Objectification, and Recognition of Sexualized Women
576 and Men. *Psychology of Women Quarterly*, 40(2), 199-212.
- 577 Delorme, A. and Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial
578 EEG dynamics including independent component analysis. *Journal of Neuroscience*
579 *Methods*, 134, 9-21.
- 580 Dubois, D., Rucker, D.D., and Galinsky, A.D. (2010). The Accentuation Bias: Money Literally
581 Looms Larger (and Sometimes Smaller) to the Powerless. *Social Psychological and*
582 *Personality Science*, 1(3), 199-205.
- 583 Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using
584 G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*,
585 41, 1149-1160.
- 586 Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power
587 analysis program for the social, behavioral, and biomedical sciences. *Behavior Research*
588 *Methods*, 39, 175-191.
- 589 Fiske, S.T. (1993). Controlling Other People: The Impact of Power on Stereotyping. *American*
590 *Psychologist*, 48(6), 621-28.
- 591 Galinsky, A.D., Gruenfeld, D.H., and Magee, J.C. (2003). From Power to Action. *Journal of*
592 *Personality and Social Psychology*, 85(3), 453-66.
- 593 Galinsky, A.D., Magee, J.C., Inesi, M.E., and Gruenfeld, D.H. (2006). Power and Perspectives
594 Not Taken. *Psychological Science*, 17(12), 1068-74.
- 595 Galinsky, A.D., Rucker, D.D., and Magee, J.C. (2015). Power: Past Findings, Present

- 596 Considerations, and Future Directions. In M. Mikulincer & P.R. Shaver (Ed.), *APA*
 597 *handbooks in psychology: APA handbook of personality and social psychology, Vol. 3.*
 598 *Interpersonal relations* (pg. 421-460).
- 599 Gilboa, A. (2004). Autobiographical and episodic memory – one and the same? Evidence from
 600 prefrontal activation in neuroimaging studies. *Neuropsychologia*, 42, 1336-1349.
- 601 Gratton, G., Coles, M.G.H., and Donchin, E. (1983). A New Method for Off-Line Removal of
 602 Ocular Artifact. *Electroencephalography and Clinical Neurophysiology*, 55, 468-84.
- 603 Gray, J.A. (1990). Brain Systems that Mediate both Emotion and Cognition. *Cognition and*
 604 *Emotion*, 4(3), 269-88.
- 605 Gray, J. A. and McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the*
 606 *functions of the septo-hippocampal system* (2nd ed.). Oxford, UK: Oxford University
 607 Press.
- 608 Guinote, A. (2007). Power affects basic cognition: Increased attentional inhibition and flexibility.
 609 *Journal of Experimental Social Psychology*, 43, 685-97.
- 610 Guinote, A. (2017). How Power Affects People: Activating, Wanting, and Goal Seeking. *Annual*
 611 *Review of Psychology*, 68, 353-81.
- 612 Hale, T.S., Smalley, S.L., Hanada, G., Macion, J., McCracken, J.T., McGough, J.J., Loo, S.K.
 613 (2009). *Neuropsychologia*, 47, 2082-2088.
- 614 Harris, C.R., Jenkins, M., and Glaser, D. (2006). Gender Differences in Risk Assessment: Why do
 615 Women Take Fewer Risks than Men?. *Judgement and Decision Making*, 1(1), 48-63.
- 616 Harmon-Jones, E. (2006). Unilateral right-hand contractions cause contralateral alpha power

- 617 suppression and approach motivational affective experience. *Psychophysiology*, 43, 598-
618 603.
- 619 Harmon-Jones, E. and Allen, J.J.B. (1997). Behavioural Activation Sensitivity and Resting Frontal
620 EEG Asymmetry: Covariation of Putative Indicators Related to Risk for Mood Disorders.
621 *Journal of Abnormal Psychology*, 106(1), 159-63.
- 622 Harmon-Jones, E., Gable, P.A., and Peterson, C.K. (2010). The role of asymmetric frontal cortical
623 activity in emotion-related phenomena: A review and update. *Biological Psychology*, 84,
624 451-462.
- 625 Harmon-Jones, E. and Gable, P.A. (2018). On the role of asymmetric frontal cortical activity in
626 approach and withdrawal motivation: An updated review of the evidence.
627 *Psychophysiology*, 55, 1-23.
- 628 Hewig, J., Hagemann, D., Seifert, J., Naumann, E., and Bartussek, D. (2004). On the selective
629 relation of frontal cortical asymmetry and anger-out versus anger-control. *Journal of*
630 *Personality and Social Psychology*, 87(6), 926–939.
- 631 Hewig, J., Hagemann, D., Seifert, J., Naumann, E., and Bartussek, D. (2005). The relationship of
632 cortical activity and personality in a reinforced go-nogo paradigm. *Journal of Individual*
633 *Differences*, 26(2), 86–99.
- 634 Hewig, J., Hagemann, D., Seifert, J., Naumann, E., and Bartussek, D. (2006). The relation of
635 cortical activity and BIS/BAS on the trait level. *Biological Psychology*, 71(1), 42–53.
- 636 Hogeveen, J., Inzlicht, M., and Obhi, S.S. (2014). Power Changes How the Brain Responds to
637 Others. *Journal of Experimental Psychology: General*, 143(2), 755-62.

- 638 Inesi, M.E. (2010). Power and loss aversion. *Organizational Behavior and Human Decision*
639 *Processes*, 112, 58-69.
- 640 Keltner, D., Anderson, C., and Gruenfeld, D. (2003). Power, Approach, and Inhibition.
641 *Psychological Review*, 110(2), 265-84.
- 642 Keune, P.M., Mayer, S.V., Jusyte, A., and Schonenberg, M. (2018). Frontal alpha asymmetry and
643 callous-unemotional traits in imprisoned violent offenders: A pilot study.
644 *Psychophysiology*, 55, 1-10.
- 645 Kuene, P.M., Wiedemann, E., Schneidt, A., and Schonenberg, M. (2015). Frontal brain asymmetry
646 in adult attention-deficit/hyperactivity disorder (ADHD): Extending the motivational
647 dysfunction hypothesis. *Clinical Neurophysiology*, 126, 711-720.
- 648 Laufs, H., Kleinschmidt, A., Beyerle, A., Eger, E., Salek-Haddadi, A., Preibisch, C., and Krakow,
649 K. (2003). EEG-correlated fMRI of human alpha activity. *NeuroImage*, 19, 1463-76.
- 650 Li, D., Wang, C., Yin, Q., Mao, M., Zhu, C., and Huang, Y. (2016). Frontal Cortical Asymmetry
651 May Partially Mediate the Influence of Social Power on Anger Expression. *Frontiers in*
652 *Psychology*, 7(73), 1-12.
- 653 Meyer, T., Quaedflieg, C.W.E.M., Weijland, K., Schruers, K., Marckelbach, H., and Smeets, T.
654 (2018). Frontal EEG asymmetry during symptom provocation predicts subjective
655 responses to intrusions in survivors with and without PTSD. *Psychophysiology*, 55, 1-21.
- 656 Nelson, B.D., Kessel, E.M., Klein, D.N., and Shankman, S.A. (2018). Depression symptom
657 dimensions and asymmetrical frontal cortical activity while anticipating reward.
658 *Psychophysiology*, 55, 1-14.

- 659 Nusslock, R., Shackman, A.J., Harmon-Jones, E., Alloy, L.B., Coan, J.A., and Abramson, L.Y.
 660 (2011). Cognitive Vulnerability and Frontal Brain Asymmetry: Common Predictors of
 661 First Prospective Depressive Episode. *Journal of Abnormal Psychology*, 120(2), 497-503.
- 662 Nusslock, R., Shackman, A.J., McMenamin, B.W., Greischar, L.L., Davidson, R.J., and Kovacs,
 663 M. (2018). Comorbid anxiety moderates the relationship between depression history and
 664 prefrontal EEG asymmetry. *Psychophysiology*, 55, 1-9.
- 665 Obhi, S.S., Swiderski, K.R., and Brubacher, S.P. (2012). Induced power changes the sense of
 666 agency. *Consciousness and Cognition*, 21, 1547-50.
- 667 Peterson, C.K., Shackman, A.J., and Harmon-Jones, E. (2007). The role of asymmetrical frontal
 668 cortical activity in aggression. *Psychophysiology*, 44, 86-92.
- 669 Reznik, S.J. and Allen, J.J.B. (2017). Frontal asymmetry as a mediator and moderator of emotion:
 670 An updated review. *Psychophysiology*, 55, 1-32.
- 671 Rodrigues, J., Muller, M., Muhlberger, A., and Hewig, J. (2018). Mind the movement: Frontal
 672 asymmetry stands for behavioral motivation, bilateral frontal activation for behavior.
 673 *Psychophysiology*, 55, 1-19.
- 674 Sutton, S. K., & Davidson, R. J. (1997). Prefrontal brain asymmetry: A biological substrate of the
 675 behavioral approach and inhibition systems. *Psychological Science*, 8(3), 204–210.
- 676 Varnum, M. E., Blais, C., and Brewer, G. A. (2016). Social class affects Mu-suppression during
 677 action observation. *Social neuroscience*, 11(4), 449-454.
- 678 Wacker, J., Chavanon, M.-L., Leue, A., and Stemmler, G. (2008). Is running away right? The
 679 behavioral activation-behavioral inhibition model of anterior asymmetry. *Emotion*, 8(2),

680 232–249.

681 Wilkinson, D., Guinote, A., Weick, M., Molinari, R., and Graham, K. (2010). Feeling socially
682 powerless makes you more prone to bumping into things on the right and induces leftward
683 line bisection error. *Psychonomic Bulletin & Review*, 17(6), 910-14.

684 Willis, G.B., Rodriguez-Bailon, R., and Lupianez, J. (2011). The Boss is Paying Attention: Power
685 Affects the Functioning of the Attentional Networks. *Social Cognition*, 29(2), 167-182.

686

687

688

689