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Fractionating negative and positive affectivity in handedness: Insights from the Reinforcement Sensitivity Theory of personality

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ABSTRACT

The Annett Hand Preference Questionnaire (AHPQ), as modified by Briggs and Nebes [(1975). Patterns of hand preference in a student population. *Cortex*, *11* (3), 230–238. doi:10.1016/s0010-9452(75)80005-0], was administered to a sample of 177 participants alongside the Reinforcement Sensitivity Theory of Personality Questionnaire [RST-PQ; Corr, P. J., & Cooper, A. (2016). The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ): Development and validation. *Psychological Assessment*. doi:10.1037/pas000], which measures two factors of defensive negative emotion, motivation and affectivity—the Behavioural Inhibition System (BIS) and the Fight–Flight–Freeze System (FFFS)—and one positive-approach dimension related to reward sensitivity, persistence and reactivity—the Behavioural Approach System. We sought to clarify the nature of negative, and positive, affectivity in relation to handedness. ANOVAs and multiple regression analyses converged on the following conclusions: left-handers were higher on the BIS, not the FFFS, than right-handers; in right-handers only, strength of hand preference was positively correlated with the FFFS, not the BIS. The original assessment method proposed by Annett was also used to assess handedness, but associations with RST-PQ factors were not found. These findings help us to clarify existing issues in the literature and raise new ones for future research.

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Introduction

For as long as can be determined, modern humans (*Homo sapiens*) along with Neanderthals (*Homo neanderthalis*) and other early hominin species (*Homo heidelbergensis*) have been predominantly right-handed (Coren & Porac, 1977; Dominguez-Ballasteros & Arrizabalaga, 2015; Frayer et al., 2012; Steele, 2000; Steele & Uomini, 2009). This strongly suggests that within an

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evolutionary context handedness has been, and is, of psychobiological significance.

For research purposes, hand preference is usually measured by specially developed questionnaires. One's preference for a particular hand may be strong or weak. Thus *direction* of hand preference can be distinguished from the *strength* of preference. The issue of how handedness should be assessed and measured is not straightforward and has given rise to controversy and discussion in the literature (see Annett, 1985, 2002; Beaton, 1995, 2003; Christman & Prichard, 2016; Christman, Prichard, & Corser, 2015; Fagard, Chapelain, & Bonnet, 2015; Groen, Whitehouse, Badcock, & Bishop, 2013; McManus, 2002; Prichard, Propper, & Christman, 2013). This point will be elaborated in the results and discussion sections of this paper.

However assessed, there is a long-standing tradition of research investigating handedness in relation to some aspect or other of cognition (e.g., Nicholls, Chapman, Loetscher, & Grimshaw, 2010; Somers, Shields, Boks, Kahn, & Sommer, 2015). Similarly, though of somewhat less well-established pedigree, there are studies examining handedness in relation to personality or other features of behaviour (see Beaton, 1985). On the face of it, which hand a person prefers to use would not be expected to relate to individual differences in cognitive ability or to aspects of personality. Yet in practice, it appears to do so, albeit subtly.

One particular feature of personality/behaviour to attract the attention of researchers has been anxiety (Beaton & Moseley, 1984, 1991; Hicks & Pellegrini, 1978; Lyle, Chapman, & Hatton, 2013; Wienrich, Wells, & McManus, 1982; Wright & Hardie, 2012). The findings, however, have been inconsistent (for review, see Beaton, Kaack, & Corr, 2015).

Orme (1970) reported that a greater proportion of 23 left-handed adolescent girls (defined by writing hand) showed high levels of emotional instability when compared with 277 right-handers. This study was criticized by Hicks and Pellegrini (1978) who themselves reported that 12 mixed-handed and 23 left-handed college students (sex composition not given) assessed using the Briggs and Nebes (1975) modification of Annett's (1970) Hand Preference Questionnaire (AHPQ) and a modified version of the Taylor Manifest Anxiety Scale (TMAS; Taylor, 1953) were significantly less anxious than 35 right-handers. Wienrich et al. (1982) used the TMAS with 35 male and 35 female students (28 right-handers, 23 left-handers and 19 mixed-handers) and found no linear relationship between handedness, as measured by the Briggs–Nebes (BN) version of the AHPQ, and anxiety. However, they reported a quadratic relationship between handedness and anxiety such that extreme scores in both directions were associated with greater anxiety scores. Females were significantly more anxious than males, but there was no sex-by-anxiety interaction.

The question of a relationship between handedness and anxiety was taken up by Beaton and Moseley (1984), who gave the Trait Scale (Spielberger, Gorsuch, & Lushene, 1970) of the Spielberger State-Trait Anxiety Inventory (STAI) to 247 university students of both sexes (see also Beaton & Moseley, 1991). Beaton and Moseley (1984) found no relationship between handedness and trait anxiety. In their study, handedness was assessed using the AHPQ and the method of classification advocated by Annett (1970). This method stands in contrast to the method of assessing handedness adopted by Briggs and Nebes (1975) (and used in almost all other hand inventories), whereby each participant is assigned a total handedness score calculated by summing the scores obtained on individual test items, with each item being treated as of equal weight. Using Annett's method, the study by Beaton and Moseley (1984) was replicated and extended by French and Richards (1990), who tested 392 participants (293 of whom were female) using both the Trait and State (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) sub-scales of the STAI. French and Richards (1990) also failed to find any relationship between scores on either sub-scale of the STAI and handedness. There was no significant difference between males and females in mean score for either state or trait anxiety.

Mueller, Grove, and Thompson (1993) distinguished between "basal" levels of anxiety and the impact of any such anxiety while undertaking written or other tests. The results of their study gave little support for the view that handedness, treated dichotomously as the response to a single question—"Are you (a) left-handed or (b) right-handed?"—is related to basal levels of anxiety. Women worried more than men but there was no interaction of sex/gender with handedness. Dillon (1989) reported a significant correlation among 34 male but not 44 female college students between scores on a questionnaire assessing students' worries and scores on a General Laterality Scale. Using the Edinburgh Handedness Inventory (EHI; Oldfield, 1971), Merkelbach, de Ruiter, and Olff (1989) compared the handedness of 77 anxiety disorder patients of both sexes with handedness in a healthy control group and found no evidence of a relationship between left-handedness and clinically diagnosed anxiety.

Wright and Hardie (2012) measured state and trait anxiety in 50 right-handers (25 males, 25 females) and 50 left-handers (25 males, 25 females). Left-handers had significantly higher state anxiety scores than right-handers even after statistically controlling for state anxiety but there was no difference in trait anxiety. Wright and Hardie (2012) argued that their deliberate use of a novel experimental situation expected to be mildly anxiety-provoking is what led to their findings for state anxiety. There was no significant sex difference for either measure of anxiety and no sex-by-handedness interaction.

In a recent study, Lyle et al. (2013) administered the Beck Anxiety Inventory (BAI) and both state and trait sub-scales of the STAI to 74 left-handers and 91 right-handers (106 females), with direction of handedness being categorized in terms of negative (left) and positive (right) scores on a modified version of the EHI. Within each handedness group, a further sub-division was made between consistent (scores less than −80 or greater than +80) and inconsistent handedness (scores between 0 and −80 or between 0 and +80). Inspection of the figures provided by Lyle et al. (2013) suggests that females were more anxious than males, but there was no interaction with handedness. For both trait and state anxiety, inconsistent right-handers (of both sexes) showed less anxiety than consistent right-handers; among left-handers there was no significant effect of consistency of hand use. Inconsistent right-handers were significantly less anxious than inconsistent left-handers in both state and trait anxiety.

The contradictory findings reported in the literature may derive in part from uncontrolled or unexplored sex differences and/or from different ways of measuring and classifying both handedness and anxiety. The discrepancies may also reflect conceptual limitations. As Lyle et al. (2013) put it, "Anxiety is not a monolithic construct and there is unshared variance between questionnaires" (p. 529). The same might be said of handedness.

A novel approach to the issue was introduced by Wright, Hardie, and Wilson (2009), who administered a questionnaire developed by Carver and White (1994) to measure the constructs proposed by Reinforcement Sensitivity Theory (RST) as originally conceived by Gray and his colleagues. Gray (1982) postulated that behaviour is driven principally by two independent motivating systems: the Behavioural Inhibition System (BIS) and the Behavioural Approach System (BAS). Using the Carver and White (1994) questionnaire, Wright et al. (2009) reported that left-handers had higher BIS scores than right-handers while BAS scores did not differ between the handedness groups, a finding replicated by Hardie and Wright (2014) in an extension of their earlier study. Similar results were obtained by Beaton et al. (2015), who also used the Carver and White (1994) questionnaire but a different measure of handedness to that used by Wright and her colleagues.

Since the publication of Carver and White's (1994) questionnaire, RST has seen a number of theoretical advances. The BIS was conceived originally as underlying anxiety and avoidance, whereas the BAS was thought to underlie impulsivity and other factors related to approach behaviour. These systems were modified in subsequent formulations (revised Reinforcement Sensitivity Theory—rRST) and a third system, the Fight–Flight–Freeze System (FFFS), relating to an individual's response to aversive stimuli motivated by fear, was highlighted and more clearly differentiated from the BIS (Corr & McNaughton, 2008; Gray & McNaughton, 2000). The FFFS updates the original Fight–Flight System to include freezing and is held to mediate all reactions to aversive stimuli of whatever kind.

In contrast to the original formulation, the BIS is not now considered to mediate responses only to stimuli for which there is an innate reaction of fear; rather, it is held to mediate goal conflict in general (for example, between BAS-approach and FFFS avoidance) and between other forms of conflict. BIS generates anxiety (as in "Look out for danger!"). In the most recent formulation of RST (see Corr & McNaughton, 2012), the BAS is activated by all forms of appetitive stimuli (including omission/termination of expected punishment) and the BIS by all forms of goal conflict.

In addition to distinguishing between BIS/anxiety and FFFS/fear, there have been developments in regard to BAS. Revised RST contends that the BAS mediates reactions to all appetitive stimuli (conditioned and unconditioned) and generates anticipatory pleasure. As described by Corr and Cooper (2016), the BAS is the "Let's go for it!" system. Its primary function is to move an organism along a spatio-temporal gradient towards a final biological reinforcer. There are a number of distinct but related BAS processes. "Reward Interest" and "Goal-Drive persistence" that characterize the early stages of approach can be distinguished from "Reward Reactivity" and "Impulsivity" as the final reinforcer is approached and captured.

In addition to recent theoretical revisions in rRST, several questionnaires that purport to measure the constructs proposed by rRST have been developed (for summary and evaluation of these questionnaires, see Corr, 2016). The Carver and White (1994) questionnaire used by Wright and her colleagues and by Beaton et al. (2015) was devised at a time when RST emphasized only BIS and BAS; consequently it conflates fear and anxiety. It is now widely recognized, however, that the latter are conceptually and psychometrically separable constructs (Corr, 2011; Gray & McNaughton, 2000; Perkins, Kemp, & Corr, 2007; for review, see Corr, 2016; Corr & Cooper, 2016).

A limitation of the Beaton et al. (2015) study was that FFFS scores were not separated from BIS scores. Their main finding, that non-right-handers had higher BIS scores than right-handers, thus leaves open the possibility that BIS is related to handedness through FFFS/fear rather than BIS/anxiety. However, Wright et al. (2009; see also Hardie & Wright, 2014) differentiated between BIS and FFFS by identifying the two items of the Carver and White (1994) questionnaire that were said to reflect FFFS and they, too, reported effects similar to those of Beaton et al. (2015). This form of psychometric differentiation has significant limitations and much better factors for the FFFS and BIS exist now (e.g., Corr & Cooper, 2016).

We therefore decided to re-examine the issue of handedness in relation to BIS/BAS using not the Carver and White questionnaire (1994) as used in previous studies of BIS/BAS activation and handedness, but an improved questionnaire (see Corr & Cooper, 2016) that reflects the recent theoretical developments: the Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ) devised by Corr and Cooper (2016). Its psychometric properties are robust and allow a clear separation of FFFS/fear from BIS/anxiety. Using both exploratory and confirmatory factor analysis in separate studies, Corr and Cooper (2016) obtained independent factors for FFFS and BIS. Factor loadings for the scale items were high (most above 0.5), and correlations between the FFFS and BIS scores and relevant scores from existing questionnaires (STAI state scale—Carver & White, 1994; Spielberger et al., 1970 BIS scale, respectively) were also high. Internal reliability for the final questionnaire as used in the present study was good (Cronbach's alpha for FFFS and BIS being 0.78 and 0.93, respectively—see Table 3 of Corr & Cooper, 2016).

Based on previous findings (Beaton et al., 2015; Hardie & Wright, 2014; Wright et al., 2009), our prediction was that BIS scores on the RST-PQ, "uncontaminated" by FFFS/fear, would be higher for left-handers than for right-handers. We had no strong reasons for predicting an effect of handedness on either FFFS or BAS scores, although we left this an open question.

Method

Participants

A sample of 177 undergraduates or recent graduates (77 men, 100 women) recruited from City University London and other universities in the UK participated in the study. Mean age for males was 21.92 years ($SD = 3.08$); mean age for females was 21.44, $SD = 3.26$). The study was approved by the City University London Departmental Ethics Committee and complied with the conditions of the Declaration of Helsinki (1964) and its later amendments (Rickham, 1964). Participants comprised four ethnic groups as follows: Asian ($n = 51$); Black African/American ($n = 9$); White Caucasian ($n = 106$); other ($n = 10$). One female participant did not state her ethnic background.

Procedure

Participants were given two questionnaires, a handedness questionnaire (see below) and the RST-PQ in that order. After this they completed several other questionnaires that are not germane to the present report and will therefore not be discussed.

Participants were invited to participate in the study by being approached in the City University's libraries and through the University participant recruitment system. Participants were asked to attend a session to complete the questionnaires in a quiet room. In some cases, participants ($n = 55$) were unable to meet with the experimenter (S. M.) and were sent documents to complete and return via post or email. All participants gave written informed consent and were assured that their responses would be confidential and anonymous. Those who were eligible to do so received course credits for participation. All participants were also offered feedback on the results if they requested it. The questionnaires were completed in private by the respondents, sealed and returned in such a way that individual respondents could not later be identified. After completing the questionnaires and providing information on age, sex/gender and ethnic background, participants were asked to nominate another student/graduate of approximately the same age, sex/gender and (assumed) opposite handedness. He/she was then contacted via email and invited to participate in the study. In this way we managed to attract a comparatively large number of non-right-handers and thereby ensure a wide range of hand scores.

Handedness was assessed using the Briggs and Nebes (1975) modification of Annett's (1967, 1970) Hand Preference questionnaire (AHPQ). The BN version, shown to be a reliable measuring instrument by Loo and Schneider (1979), consists of Annett's original 12 items but asks participants to indicate on a 5-point scale (*always left, usually left, no preference, usually right, always right*) how often they use a given hand for a given action (e.g., *to throw a ball to hit a target; to hold scissors to cut paper*). In its original form, Annett's inventory is not scored in this way and there are good theoretical reasons (see Annett, 2002; Beaton, 2003) to prefer the method used by Annett to assign individuals to one of a number of hand preference classes rather than summing scores over all items of the questionnaire as employed by the BN modification. In the present study, therefore, both assessment methods were used (see Results section).

Responses on the BN version of the handedness inventory were scored by assigning values of −2, −1, 0, 1, 2 respectively to responses from *always left* to *always right*. The sum of scores across all 12 items gives the total BN handedness score, which ranges from −24 (strong left-hander) to +24 (strong right-hander). Taking negative scores and zero as indicating non-right-handedness and positive scores as right-handedness, there were 95 non-right-handers and 82 right-handers.

The RST-PQ (Corr & Cooper, 2016) is modelled on the conceptual scheme of Gray and McNaughton (2000). This was used to measure the following constructs: BAS Reward Interest (BAS-RI: 7 items—e.g., *I get carried away by new projects*); BAS Goal-Drive Persistence (BAS-GDP: 7 items—e.g., *I put in a big effort to accomplish important goals in my life*); BAS Reward Reactivity (BAS-RR: 10 items—e.g., *Sometimes even little things in life can give me great pleasure*); BAS Impulsivity (BAS-I: 8 items—e.g., *I think I should "stop and think" more instead of jumping into things too quickly*); BIS (23 items—e.g., *I am always weighing up the risk of bad things happening in my life*); FFFS (10 items—e.g., *I would be frozen to the spot by the sight of a snake or spider*). For each item of these sub-scales, a participant is asked to indicate how accurately each statement describes herself/himself on a four-point scale, ranging from 1 (*not at all*) to 4 (*highly accurate*). For each sub-scale, the ratings are summed across items to provide a total score.

Table 1. Means and standard deviations of variables of interest.

	FFFS	BIS	BAS_RI	BAS_GDP	BAS_RR	BAS_I	BN
Minimum	10	27	9	10	15	12	−24
Maximum	36	87	57	28	40	30	24
Mean	22.98	57.63	19.99	22.07	29.97	19.76	−.27
SD	5.90	12.09	4.97	3.86	4.58	4.09	17.83

Note: BIS = Behavioural Inhibition System; FFFS = Fight/Flight Freeze System; BAS = Behavioural Approach System; RI = Reward Interest; GDP = Goal-Drive Persistence; RR = Reward Reactivity; I = Impulsivity; BN = Briggs–Nebes.

Results

Mean scores and standard deviations for the sample as a whole are shown for each variable of interest in Table 1.

The means, SDs and alpha values for the RST-PQ were comparable with published data, as was the pattern of their inter-correlations shown in Table 2.

First-order correlations between variables

Not unexpectedly, the four BAS sub-scales correlated with each other in all cases but one (BAS-GDP with BAS-Imp; $r = .08$, $p > .05$). BIS scores correlated negatively, albeit weakly, with BAS-RI ($r = -.16$, $p = 0.03$) and positively with BAS-Imp ($r = .17$, $p = .03$). Corr and Cooper (2016) also found a modest correlation between the BIS and BAS-Imp. The reason for this is unclear. The correlation coefficients are typically very small and non-significant. Impulsivity is known to be associated with negative affectivity and depression, and it may serve as a form of fun-seeking that has negative reinforcing properties —serving to relieve the negativity associated with the BIS. BIS scores correlated significantly with FFFS ($r = .37$, $p < .001$), which is both in line with previous research and to be expected. Of particular interest, there was a significant negative correlation between handedness (BN total score) and BIS ($r = -.18$, $p = .02$), which, as shown below, survives detailed analysis.

Table 2. Correlations between variables of interest.

Variable	1	2	3	4	5	6	7
1. FFFS							
2. BIS	.37**						
3. BAS_RI	−.08	−.16*					
4. BAS_GDP	.18*	−.07	.32**				
5. BAS_RR	.17*	.09	.33**	.34**			
6. BAS_I	.13	.17*	.38**	.08	.43**		
7. BN	.07	−.18*	−.09	.05	−.01	.08	

Note: BIS = Behavioural Inhibition System; FFFS = Fight/Flight Freeze System; BAS = Behavioural Approach System; RI = Reward Interest; GDP = Goal-Drive Persistence; RR = Reward Reactivity; I = Impulsivity; BN = Briggs–Nebes.

*$p < .05$, **$p < .01$.

Table 3. Two multiple regressions of handedness on age, gender, method and Asian status and the six RST-PQ factors: hierarchical model and stepwise model.

	Hierarchical model			Stepwise model		
	β	t	Sig.	β	t	Sig.
Step 1						
Age	−.08	1.12	ns			
Gender	−.10	1.48	ns			
Method	−.29	4.01	< .001	−.28	3.72	< .001
Asian status	.22	3.11	< .01	.19	2.60	< .01
Model 1:	$F(4, 171) = 9.00$; Adj. $R^2 = .16$, $p < .01$					
Step 2 (RST-PQ factors)						
BIS	−.23	2.96	< .01	−.29	2.96	< .01
FFFF	.04	.45	ns			
BAS-RI	−.19	2.23	< .05	−.19	2.29	< .05
BAS-GDP	.01	.15	ns			
BAS-RR	.04	.42	ns			
BAS-Imp	.15	1.85	= .07	.15	1.85	= .07
Model 2:	$F(10, 165) = 5.02$; Adj. $R^2 = .19$, $p < .01$					

Note: Asian status = Asian participants vs. other (predominantly White Caucasian); BIS = Behavioural Inhibition System; FFFS = Fight/Flight Freeze System; BAS = Behavioural Approach System; RI = Reward Interest; GDP = Goal-Drive Persistence; RR = Reward Reactivity; Imp = Impulsivity; ns = non-significant.

Independent t-tests for effects of sex/gender, method of questionnaire completion/return and ethnic status

In terms of sex/gender, independent-sample *t*-tests revealed several effects on RST-PQ variables. Females were significantly higher on FFFS ($M_F = 24.76$, $SD = 5.75$; $M_M = 20.68$, $SD = 5.29$; $t = 4.85$, d.f. = 175, $p < .001$) and on BAS-RR ($M_F = 30.73$, $SD = 4.16$; $M_M = 28.97$, $SD = 4.92$; $t = 2.57$, d.f. = 175, $p = .01$). Females also scored higher on the BIS, the difference approaching significance ($M_F = 59.11$, $SD = 12.14$; $M_M = 55.70$, $SD = 11.82$; $t = 1.87$, d.f. = 175, $p = .06$).

We also determined whether any of the RST-PQ and handedness (total BN score) variables differed between the two modes of administration (Method: laboratory, L, and post/e mail, P). Independent-sample *t*-tests revealed an effect of handedness and an unexpected effect for FFFS. Those participants who returned the questionnaire by post or email were, on average, more left-handed than those who completed the questionnaires in the laboratory ($M_L = 3.71$, $SD = 17.83$; $M_P = -9.11$, $SD = 14.43$; $t = 4.68$, d.f. = 175, $p < .001$). This was not unexpected since participants who returned questionnaires by post or email were nominated as being of opposite handedness to participants completing them in the laboratory, the majority of whom were right-handed. Participants returning questionnaires by post or email were lower on FFFS than those who completed the questionnaires in the laboratory ($M_L = 23.90$, $SD = 5.94$; $M_P = 20.94$, $SD = 5.33$; $t = 3.16$, d.f. = 175, $p < .01$). This difference is intriguing. It is not altogether implausible (as suggested by one of the referees) that the fear items are susceptible to some form of state influence since the face-to-face participants had a higher score. It is not something that has been investigated before but it should be scrutinized in future research.

Given the socially defined usage of left and right hands in Asian culture, and considering that 51 of our participants were Asian, we next tested whether there were any differences between Asian (A) and non-Asians (NA) on the RST-PQ and handedness (total BN score) variables. (The ethnic background of one participant was unknown and for these comparisons the data from this participant were excluded). Again using a series of independent-sample *t*-tests, we found that Asian participants were, on average, right-handed ($M = 7.53$, $SD = 16.12$) compared to non-Asians ($M = -3.45$, $SD = 17.65$), $t = 3.84$, d.f. = 174, $p < .001$. A lower frequency and/or degree of left-handedness among Indian (Singh & Bryden, 1994; Singh, Manjary, & Dellatolas, 2001), Japanese (Hatta & Nakatsuka, 1976; Iwasaki, Kaiho, & Iseki, 1995; Maehara et al., 1988), Taiwanese (Teng, Lee, Yang, & Chang, 1976) and Hong Kong Chinese (Hoosain, 1990) respondents compared with Western respondents has been reported in the literature. While this may in part reflect genetic effects, most commentators see it as a reflection of cultural norms and social pressure (for discussion, see Iwasaki, 2000; Kushner, 2013; Mandal, 1999). In addition, Asian participants were, on average, slightly higher on FFFS ($M = 25.02$, $SD = 5.91$) compared to non-Asians ($M = 22.11$, $SD = 5.71$), $t = 3.04$, d.f. = 174, $p < .01$). This probably reflects the fact that there were relatively more females (33 of 51) among Asians than among non-Asians (66 of 125) since females on average had higher FFFS scores than males (see above).

Regression-based analyses of variance

As our main focus was on the potential difference between the effect of FFFS and BIS on handedness (total BN score), and for computational convenience, we ran a regression-based ANOVA which allowed inclusion of main and interaction terms involving the continuous variables of the RST-PQ. First we entered Method, Sex/Gender, FFFS and BIS and examined their main effects, which revealed significant effects for Method [$F(1, 172) = 18.32$, $p < .001$] and BIS [$F(1, 172) = 7.01$, $p < .01$] (by way of comparison, for FFFS, $F(1, 172) = 1.34$, $p = .25$). These results mirror the results reported above. Next, we examined two-way interactions entailing Method and Sex/Gender with FFFS/BIS. None of these interactions even approached significance.

Then we added the four BAS factors to these models. For the main effects model, the BIS remained significant, with an enhanced *F*-ratio of 10.36 ($p < .01$)—in addition, a main effect of BAS-RI was found [$F(1, 164) = 6.99$, $p < .01$]. Again, we entered two-way interactions, entailing Method and Sex/Gender with each of the six RST-PQ factors and, again, the BIS remained significant, although this time with a reduced *F*-ratio of 7.45 ($p < .05$)—the main effect of BAS-RI disappeared.

As there were effects of Asian status (Asian vs. non-Asian) on handedness and on FFFS, we explored possible interactions with this demographic variable; for comparison and completeness, we also examined possible interactions with the BIS. In addition to entering the main effects of Asian status, Method, Sex/Gender and these two RST-PQ factors (FFFS and BIS), we computed all two-way interactions involving Asian status. Main effects for Method and BIS on handedness remained significant ($p < .05$), but no interaction with Asian status even approached significance. Furthermore, adding BAS factors revealed no further (or close to) significant main effects or two-way interactions with Asian status.

Interim summary of findings

We have shown that the association between the BIS and handedness remained robust when interactions were computed with Method, Sex/Gender and Asian status. In the next omnibus hierarchical regression model, we summarized these effects.

Hierarchical regression analyses using continuous scores reflecting both direction and strength of handedness

Using the direct "enter" method (that simultaneously forces all terms into the model), we entered Method, Sex/Gender, Asian status, as well as age, in Step 1, and then in Step 2 we entered the six RST-PQ factors. This analysis provides simplicity of interpretation. As we should expect on the basis of the above ANOVAs, and as shown in Table 3, Method and Asian status were statistically significant in Step 1, and once more BIS was significant in Step 2 with a beta value of −0.23 ($p < .01$). We attempted to destabilize this model by using different methods of entry (i.e., Forward, Stepwise, and Backward), but the associations remained unaffected (significant results for Stepwise are shown in Table 3). There was also evidence of a negative relationship between handedness and BAS-RI and a positive (but not significant) relationship with BAS-I, although these associations were comparatively weak.

Hierarchical regression analyses using continuous handedness scores reflecting strength, but not direction, of handedness

We also examined the absolute strength or degree of hand preference, ignoring the direction, by disregarding the sign of the total BN score. Using zero-order correlations, there were no significant ($p = .05$) associations with the six RST-PQ factors, or with Method, Age, Sex/gender or Asian status. Using both Enter and Stepwise methods of entry in multiple regression, no significant coefficients emerged.

Analyses treating handedness as a dichotomous variable

We next split the sample into right-handers and non-right-handers (hereafter referred to as left-handers) based on positive vs. negative or zero BN score (omitting four participants with a BN score of zero made no material difference to any of the results we report). Within each handedness group, we looked at the association between strength of handedness and the six RST-PQ factors, and between handedness and Method, Age, Sex/Gender or Asian status. For the left-handed group, we observed no significant zero-order correlations; nor were any effects observed with the use of direct and stepwise methods in multiple regression. For the right-handed group, we observed a significant correlation of strength of handedness with FFFS ($r = .29$, $p < .01$). This result was also found with direct entry ($\beta = .30$, $p < .05$) and repeated with Stepwise ($\beta = .29$, $p < .01$) method of entry.

Further analyses using different classifications of handedness scores

We performed additional analyses on various classifications of handedness.

Binary logistic regression—handedness treated as dichotomous

First, we conducted a binary logistic regression for left- (BN score < or = 0) and right-handers (BN score > 0), repeating the structure of the linear multiple regression model reported above. For comparability, in Step 1 we entered Gender, Age, Method and Asian status, then, in Step 2 the six RST-PQ measures. As we might expect, there was a significant effect of Method (Wald = 15.11, $p < .001$); the only other significant terms were BIS (Wald = 8.12, $p < .001$) and BAS-RI (Wald = 5.14, $p < .05$)—both had negative slopes showing left-handers were higher on BIS (59.70, $SD = 13.10$ vs. 55.23, $SD = 10.44$) and BAS-RI (20.39, $SD = 5.62$ vs. 19.54, $SD = 4.10$). These results confirm those of linear multiple regression (see Table 3).

Analyses of effects of "consistency" of handedness

To examine the effect of consistency as proposed by the Toledo group of researchers (see Christman & Prichard, 2016; Christman et al., 2015; Prichard et al., 2013), we repeated the above binary logistic regression analysis to compare consistent left- (BN score −24 to −16; $n = 56$) with consistent right-handers (17–24; n = 53). (These cut-offs were chosen to be comparable to those used by the Toledo group for the reasons given by Beaton et al., 2015). Again, there was a significant effect of Method (Wald = 12.03, $p < .001$); the only other significant term was the BIS (Wald = 4.90, $p < .05$). The effect for BAS-RI approached significance (Wald = 2.72, $p < .10$)—both BIS and BAS-RI terms had negative slopes indicating consistent left-handers were higher on BIS (58.95, $SD = 1.60$) than consistent right-handers (55.79, $SD = 1.64$) and slightly higher on BAS-RI (20.95, $SD = 6.50$ vs. 19.40, $SD = 6.24$).

To examine the possible effect of consistency *within* each handedness group, we next used ANOVA to compare consistently left-handed (BN scores −24 to −16; n = 56) with inconsistently left-handed (BN scores −15–0; n = 39) participants and consistently right-handed (BN scores 17–24; n = 53) participants with inconsistently right-handed (BN scores 1–16; n = 29) participants on their FFFS and BIS scores.

There was no significant effect of consistency for either FFFS or BIS and no interaction between consistency and handedness group (right-handed vs. left-handed). For BIS there was a significant overall effect of hand group [F (1, 173) = = 6.82, $p < .01$] driven by the difference between consistent left-handers and consistent right-handers as reported above. There was no effect of consistency within each hand group.

Further analyses using Annett's classification of hand preference

As mentioned in the introduction, Annett (1970, 2002) advocates a method of classification of hand preference based on an association analysis of responses to her questionnaire which revealed which items tend to "go together" (Annett, 1970). She found almost all possible combinations of hand use (ranging from right hand for all 12 items; right for all but one—say, threading a needle; through, say, right hand for writing, hammering, striking a match, throwing a ball but left hand for all the other items; to using the left hand for all 12 items). Annett identified 23 contiguous hand preference classes or groups which for convenience she cut down to eight groups, which she subsequently (Annett, 2002) reduced to seven. Membership of a given hand preference class or group is determined by the *specific combination* of right- and left-hand use a respondent shows for the 12 items of the AHPQ. It should be emphasized that these groups were empirically derived from the association analysis, not decided *a priori*. As it is computationally somewhat difficult to apply, Annett's method of scoring her questionnaire has been largely ignored in the literature. Nonetheless, it has strong theoretical and empirical underpinnings (Annett, 1970, 2002; Beaton, 1995, 2003) and we therefore chose to examine our data from this perspective.

It is possible to derive Annett's classification from the BN method of scoring by combining scores of −2 and −1 and +1 and +2 to give three categories of response *for each item*: R, Either or L. By considering the pattern of responses to all 12 items, one ends up with the hand preference classes as proposed by

Annett. Although she favours use of seven classes, where numbers in the different classes are insufficient, Annett recommends (see Annett, 2002) combining classes to produce four groups. Because these groups are based on hand use for specific items and not on summed scores on a questionnaire, they cannot be straightforwardly equated with scores on the BN modification of the AHPQ (or with any other inventory, such as the EHI). In simple terms, however, the four groups can be considered to be: 1—strong or highly consistent right-handers (no item of the Annett questionnaire performed with the left-hand or either hand); 2—moderate right-handers (right-handed for writing with some actions performed by the left or either hand but not more than two of the "primary" actions, namely "throw, racket, match, hammer, toothbrush or scissors"); 3—moderate left-handers (left or either hand for writing and the right hand for some actions including primary actions); and 4—strong or consistent left-handers (right hand not used for any actions).

Using ANOVAs with sex/gender, age, method of administration and Asian status as factors, for the 4-groups classification of hand preference there was no effect of handedness on BIS ($F < 1$) or FFFS ($F < 1$). Null results were also found for the 7-groups classification (one group had no participants). None of the two-way interactions with hand preference approached statistical significance for BIS or FFFS for either the 7- or 4-group classification of handedness.

For completeness, we also examined the four BAS sub-scales, but found nothing approaching statistical significance for main or interaction effects.

Summary of main findings

We have found a robust association between handedness and scores on the BIS, left-handers scoring lower than right-handers. This result was obtained using total BN score reflecting both direction and strength of handedness and when handedness was treated as a dichotomous variable (right- vs. left-handed). No significant effects were found for BIS using an absolute measure of strength of handedness (i.e., disregarding direction). Using total BN score (direction and strength of handedness), there was no effect for FFFS. Nor was there an overall effect of absolute strength of handedness (disregarding direction) on the FFFS. However, looking separately at right- and left-handers revealed a positive correlation between strength of hand preference and FFFS scores in right-handers only (the greater the strength of preference for the right hand, the higher was the FFFS score). Using a definition of consistency of handedness analogous to that of the Toledo group, consistent left-handers had significantly higher BIS scores than consistent right-handers but there was no overall effect of consistency (consistent vs. inconsistent handedness) or within each handedness group considered separately. No significant main effects or interactions were found for any RST construct when hand preference was categorized according to the method advocated by Annett (1970, 2002).

Dimensionality of handedness items

The integrity of results such as those presented above rests upon the assumption of the unidimensionality of the handedness items. For this reason, we decided to explore this matter empirically by performing principal axis factoring. The results were clear. There was one factor, with an eigenvalue of 8.91 (next one was 0.65), which explained 74.28 per cent of the variance. All items loaded on this first factor with most loadings in the range of 0.8–0.9—the lowest loading was "jar" at 0.76. Given these results, we can be confident in the simple summation of scores on the 12 items of the questionnaire to obtain the handedness score and it would seem that for the present data set we cannot improve upon this straightforward approach to classification. It is presumably for this reason that the categorical classifications we used in our analyses failed to add further information to that provided by the continuous total score.

Discussion

We undertook this study in an attempt to clarify the source of the previously reported association between left-handedness and the BIS (Beaton et al., 2015; Hardie & Wright, 2014; Wright et al., 2009; Wright & Hardie, 2012). In particular, we wished to confirm that the relationship holds with improved measures of the constructs proposed by RST and when FFFS is looked at separately rather than (as in Beaton et al., 2015) conflated with BIS scores.

Our main finding is as follows. There is a robust association between handedness as measured by the Briggs and Nebes (1975) modification of the AHPQ and the BIS: left-handers (non-right-handers) have higher BIS scores than right-handers. We can now be sure that it is indeed the BIS, and not the flight-fight-freeze (FFFS) component of negative affectivity, that is associated with handedness. These two are conflated in anxiety measures such as the Taylor Manifest Anxiety (TMA) questionnaire, the Beck Anxiety Inventory (BAI) and the Spielberger STAI that have been used in several studies of handedness and anxiety (Beaton & Moseley, 1984, 1991; French & Richards, 1990; Hicks & Pellegrini, 1978; Lyle et al., 2013; Wienrich et al., 1982). This raises the possibility that some of the reports of an association between handedness and anxiety may be accounted for by the BIS, which itself is related to a range of behaviours. For this reason, we would suggest that the BIS is included in future studies of handedness and anxiety to examine and eliminate this possibility.

In recent years there has been a growing tendency to regard strength or degree of handedness, rather than direction, as the more important variable in laterality research (e.g., Arning et al., 2013; Newman, Malaia, & Seo, 2014). It is therefore important to note that in the present study a robust association between handedness and the BIS emerged when handedness was measured in terms of total BN score , which reflects both direction and strength of handedness, and when handedness was defined as a binary variable (right-handed vs. left-handed). No such effect was observed when handedness was treated as a four- or seven-group categorical variable (Annett's method of classification), albeit that this can be regarded as an ordered series from strongly right-handed to strongly left-handed. It seems, therefore, that the continuous directional measure (total BN score) captures something important (but elusive) in regard to hand preference since strength of handedness alone (i.e., ignoring direction of handedness as reflected in the sign of the BN score) did not predict BIS scores.

The Toledo group of researchers (Christman & Prichard, 2016; Christman et al., 2015; Prichard et al., 2013), in particular, distinguish between high scores on a handedness questionnaire (indicating a strong or consistent preference for a particular hand, usually the right), and scores indicating a relatively reduced preference for one hand, based on the median score on a hand preference inventory. We looked at our data from this perspective but, similar to Beaton et al. (2015), found no overall effect of consistency of handedness, nor within right- and left-handers considered separately, for any RST construct.

Beaton et al. (2015) found a relationship between handedness and BIS scores only when handedness was treated as dichotomous (right vs. left), whereas in the present study, as mentioned above, a relationship was also found if magnitude as well as direction of hand preference (i.e., total BN score) was taken into account. Using the Carver and White (1994) BIS/BAS scales and a different handedness questionnaire (Peters, 1998) from Beaton et al. (2015), Wright et al. (2009) treated handedness as a categorical variable (right vs. left) and reported higher BIS scores among left- than right-handers. However, in a subsequent analysis of the data from a larger number of participants, Hardie and Wright (2014) used the EHI developed by Oldfield (1971) and found that a score reflecting both direction and degree (strength) of handedness related to their BIS measure (as did strength of handedness regardless of direction). They also found, unlike the present study and that of Beaton et al. (2015), that if direction of handedness was ignored, then individuals categorized as strongly handed (referred to in their paper as consistent-handers for comparability with the Toledo group) had higher BIS scores, on average, than those categorized as inconsistently handed. Further sub-division of participants into three (consistent right, inconsistent, consistent left) or four (consistent right, inconsistent right, consistent left, inconsistent left) groups produced significant effects of consistency category in analysis of variance. In general, consistent left-handers had higher BIS scores than the other groups. However, using regression analysis to look at strength of handedness separately in right- and left-handers (for whom the negative sign of EHI score was removed), Hardie and Wright (2014) found no effect of this variable among right-handers but a significant effect among left-handers—BIS scores correlated positively with strength of (left) handedness.

The question may be asked, then, why in the present study did we not find effects of "consistency" or of absolute strength of handedness in relation to BIS whereas Hardie and Wright (2014) did so? The answer presumably relates to subtle differences in the classification of handedness. In their very thorough analysis, Hardie and Wright (2014) showed that the choice of cut-off score on the EHI used to classify individuals as consistently or inconsistently handed influenced the significance or otherwise of the consistency effects they reported.

In any event, although there is some lack of agreement between studies in precisely how different measures of handedness relate to the BIS, our finding of a significant relationship between handedness and BIS scores is in line with previous results and, importantly, shows that the relationship is not due to conflating BIS/anxiety with FFFS/fear.

With regard to the FFFS, we found, but for right-handers only, a significant correlation between strength of handedness and FFFS scores. The greater the strength of preference for the right hand, the higher was the FFFS score. Hardie and Wright (2014) reported that consistent-handers (left and right) had higher FFFS scores than inconsistent-handers. In their study, using tripartite and four-group classifications, consistent right-handers had the highest FFFS scores but the significance of differences between subgroups depended upon the particular cut-off score on the EHI they used to define the groups. Hardie and Wright did not examine strength of preference as a continuous variable in relation to FFFS as they did with the BIS; nonetheless, our own finding (positive correlation between BN score and FFFS scores for right-handers only) is consonant with theirs.

In general, then, it seems that the constructs proposed by RST relate to laterality in complementary ways. The BIS is inversely related to measures of handedness that reflect both direction and strength of handedness, while the FFFS is positively related to strength of handedness, in right-handers if not in left-handers.

That right- and left-handers might differ in terms of their neural organization of behavioural systems need not be surprising. Christman et al. (2015) have recently shown that whereas factor analysis of scores of consistent right-handers on (a slightly modified version of) the EHI yields a single factor solution, a two-factor solution emerged from the scores of inconsistent right-handers. This is an interesting finding since the EHI, despite the criticism that its instructions are frequently misunderstood (Fazio, Coenen, & Denney, 2012), is far and away the most widely used handedness inventory in the literature.

We also observed (rather weak) relations for the BAS; specifically, multiple regression analysis showed that BAS-RI (Reward Interest) was negatively associated with overall handedness (BN score), suggesting that a "shift" in the direction of left-handedness is associated with reward-related properties. We are not aware of any other reports of such an association though Hardie and Wright (2014) noted an association between BAS-Fun Seeking and BAS-Reward Responsiveness and consistency of handedness. These authors used Carver and White's BIS/BAS questionnaire which does not isolate BAS-Reward Interest. However, it may be pertinent to mention that there are a number of reports indicating that left-handedness is associated with higher earnings (Denny & Sullivan, 2007; Goodman, 2012; Ruebeck, Harrington, & Moffitt, 2007) and/or socio-economic status (Faurie et al., 2008; Faurie, Llaurens, Hegay, & Raymond, 2012) although the effects appear to be moderated by sex/gender and/or level of education.

Our findings that a measure (BN score) reflecting strength, and not just direction, of hand preference relates to BIS/BAS and to FFFS scores are not easy to interpret. Our results presumably reflect some aspect or other of hemispheric specialization (see below). However, there does not appear to be a straightforward linear relationship between strength of manual preference and degree of cerebral lateralization, even for language, the most clearly lateralized cognitive function. Somers, Aukes et al. (2015) investigated handedness as measured by the EHI in relation to language lateralization assessed by functional transcranial Doppler sonography (fTCD). Handedness and language lateralization were each classified into five groups (strong right, moderate right, bilateral, moderate left and strong left). Although atypical language lateralization (bilateral, moderate and strong right hemispheric) was most prevalent in strong left-handers (see also Josse & Tzourio-Mazoyer, 2004; Knecht et al., 2000; Mazoyer et al., 2014; Pujol, Deus, Losilla, & Capdevila, 1999; Szaflarski et al., 2002), these workers concluded that "degree of hand-preference does not mirror degree of language lateralization" (p. 11). However, they did not combine strong right-handers and strong left-handers into a single group, nor moderate right- and moderate left-handers. Strictly speaking, therefore, they cannot claim that there is no relationship between absolute strength of handedness (regardless of direction) and degree of language lateralization.

Groen et al. (2013) also carried out an fTCD study, this time with children. They reported that degree of handedness measured by a short (four-items) version of the EHI (see Bryden, 1977) and represented in terms of a conventional laterality quotient {(R-L)/(R + L)*100} correlated significantly with a laterality quotient reflecting degree of language lateralization. However, scores on the full version of the EHI were not reported to show such a correlation.

In contradistinction to the fTCD results of Somers, Aukes et al. (2015) are the findings of a functional magnetic resonance imaging (fMRI) study carried out on right-handers only by Newman et al. (2014). For several brain regions, these researchers reported that the extent of activation during a sentence comprehension task was related to degree or strength of handedness as measured by the EHI.

It would appear from the above findings that there is no consistent relationship between strength (degree) of handedness, at least as measured by the EHI, and various measures of language lateralization. As our own data demonstrate, and others have shown, measures of degree of handedness clearly account for some proportion of variance in the scores of some variables in some circumstances. The challenge is to identify when degree of handedness, as distinct from direction, captures some proportion of the total variance.

As considered by Beaton et al. (2015), thought should be given to the possibility that the results we report, as with all similar studies, are artefactual. Examination of the raw data showed that those participants ($n = 91$) with negative BN scores were no more likely to select the "Always left "response on the handedness questionnaire than were participants ($n = 82$) with positive BN scores to select "Always right." Similarly, the proportion of each handedness group who had an extreme BN score (−24 for non-right-handers, +24 for right-handers) was virtually identical at about 20 per cent. This suggests that there was no difference between the groups in the extent of any bias towards endorsing extreme responses (i.e., in response style) on the handedness questionnaire. On the BIS subscale of the RST-PQ, these two groups could not be distinguished in terms of the *pattern* of their responses (though their mean scores differed). There is therefore nothing in these data to suggest that the association we report between handedness and BIS score is artefactually related to response style in completing questionnaires. In any case, as argued by Beaton et al. (2015), any such artefact should have also applied to the BAS sub-scales and to the FFFS scale, yet the positive correlation (among right-handers) we found for FFFS was opposite in sign to the negative correlation we found for the BIS. It is difficult to see how the same artefact could produce two effects in opposite directions. Other arguments against our results being artefactual were set out by Beaton et al. (2015) and apply, *mutatis mutandis*, to the present findings.

Given that we believe our results are not artefactual, what are we to make of them? There is increasing support for the view that BIS/BAS mechanisms are associated with functional hemispheric differences. Indeed, this was foreshadowed by the idea that left and right cerebral hemispheres are associated with approach and avoidance behaviour, respectively (for reviews see Davidson, 1995, 2003). An extensive electrophysiological literature points to asymmetries in the prefrontal cortex (PFC) being associated with motivational direction, left PFC with approach behaviour and right PFC with avoidance behaviour. In relation to the RST, several authors (see Coan & Allen, 2003a, 2004; Gable & Poole, 2014; Spielberger, Heller, & Miller, 2013) have alluded to what they regard as a conceptual overlap between approach/avoidance motivation and the BAS/BIS constructs as originally conceptualized by Gray and MacNaughton (2000) and measured using the Carver and White (1994) BIS/BAS scales.

There is, in fact, direct evidence linking differential hemispheric activity to the BIS/BAS constructs. Sutton and Davidson (1997) reported that resting brain activity as reflected in electroencephalogram (EEG) recordings showed greater relative activation in the prefrontal region of the right than the left hemisphere in participants who had high BIS scores. Participants with higher prefrontal activation over the left hemisphere had relatively high BAS scores. Harmon-Jones and Allen (1998) failed to find any association between BIS scores and resting frontal asymmetry although they did find a significant correlation between an index of frontal asymmetry (reflecting higher levels of activity over the left hemisphere) and BAS scores. Similar results were reported by Coan and Allen (2003b), who suggested that while the constructs of approach and BAS "overlap substantially" there is considerable "heterogeneity among the constructs of withdrawal and BIS" (p. 112). An (unsuccessful) attempt to relate BIS/BAS indirectly (via the constructs of introversion/extraversion) to frontal EEG asymmetry was made by Hagemann et al. (1999).

More recently, Gable and Poole (2014) found that whereas BAS scores predicted greater activation in left than right frontal regions in participants viewing anger-inducing pictures, BIS scores failed to predict any EEG asymmetry. However, another study found that increased BIS scores were associated with greater right than left frontal EEG activation when participants judged faces to show negative emotions (fear, anger, disgust). Conversely, when participants made judgements on positive (happy) emotional faces, high BAS scores were associated with greater left than right-sided activation (Balconi & Mazza, 2010).

The above findings suggest a measure of consensus concerning a correspondence between the BAS and processing mechanisms of the left hemisphere but rather less agreement concerning the BIS and the right hemisphere. Nonetheless, it has been argued that BIS is associated with a motivational bias towards the left side of space, independently of variations in BAS, thereby suggesting a "right hemisphere specialisation for BIS" (Weick, Allen, Vasiljevic, & Yao, 2016). To the extent that non-right-handedness can be associated with right hemisphere activation or a leftward spatial bias, our own findings point in the same direction.

A limitation of our investigation is that the participants were all university students or recent graduates from a limited age range. Conversely, a particular strength of our study is that we were able to recruit a relatively large number of left-handers such that we had equal proportions of left- and right-handers in our sample of participants. Furthermore, unlike previous papers on laterality in relation to BIS/BAS, the instrument we used to measure the constructs proposed by RST reflects recent developments in the field and is arguably preferable to any of the other questionnaires that have been produced (see Corr, 2016).

In future studies, it would be interesting to examine the precise roles of handedness (assessed in terms of both preference and performance—see Badzakova-Trajkov, Häberling, & Corballis, 2011; Grimshaw, Yelle, Schoger, & Bright, 2008) and the BIS on different types of behaviour. It may be that some handedness effects are mediated by the BIS, while others are independent. In saying this, we do not wish to imply that it is through handedness per se that BIS has its effects. Rather they presumably operate through neuropsychological mechanisms reflected in hemispheric functional asymmetry of which handedness is one, albeit the most prominent, characteristic (Beaton, 2003). The constructs proposed by RST may help to tie together a large and disparate set of findings in the literature on handedness and hemispheric differences. We believe that for researchers interested in the neurobiological underpinnings of individual differences in motivation and personality, this would be a fruitful line to follow.

Disclosure statement

No potential conflict of interest was reported by the authors.

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