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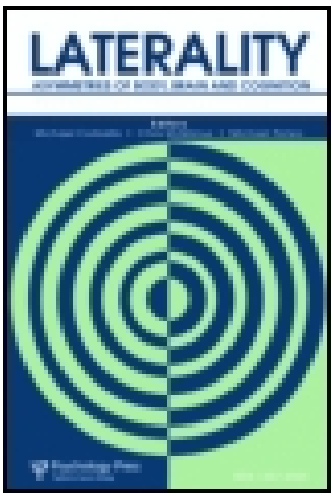

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Handedness and behavioural inhibition system/behavioural activation system (BIS/BAS) scores: A replication and extension of Wright, Hardie, and Wilson (2009)

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Handedness and behavioural inhibition system/ behavioural activation system (BIS/BAS) scores: A replication and extension of Wright, Hardie, and Wilson (2009)

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The Annett Hand Preference Questionnaire (AHPQ) as modified by Briggs and Nebes was administered along with Carver and White's behavioural inhibition system (BIS) and behavioural activation system (BAS) scale and a shortened form of the Big Five personality questionnaire to 92 university students. After eliminating the data from five respondents who reported having changed handedness and one outlier, there was a significant sex difference in mean BIS scores, with females (n = 43) scoring higher than males (n = 43). Replicating the results of Wright, Hardie and Wilson, non-right-handers (n = 36) had significantly higher mean BIS score than right-handers (n = 50). Controlling for sex of participant, neuroticism and BAS sub-scale scores in hierarchical regression analyses left this BIS effect substantially unaffected. There was no handedness or sex difference on any of the three BAS sub-scales. Further analyses revealed no association between strength, as distinct from direction, of handedness and BIS (or BAS) scores. The findings are discussed with reference to recent developments in reinforcement sensitivity theory on which BIS/BAS variables are based.

Keywords: Handedness; Anxiety; BIS/BAS systems; Neuroticism.

Handedness has been of interest to neuropsychologists for over a century, largely because of its association with asymmetry of hemispheric function (Beaton, 2003; Ocklenburg, Beste, Arning, Peterburs, & Güntürkün, 2014). In many, probably most, cognitive and behavioural studies left-handers are excluded with

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the intention of minimizing heterogeneity with respect to the cerebral representation of function or behaviour. Recently, however, a strong plea has been made to include left-handers in these studies as they "represent a substantial portion of the human population and therefore left-handedness falls within the normal range of human diversity" (Willems, van der Haegen, Fisher, & Francks, 2014). If this plea is heeded, then in studies involving left-handers it will be necessary to understand how, if at all, they differ from right-handers (see also Hancock & Bever, 2013).

Putative cognitive differences between left- and right-handers have long been of interest (see Beaton, 1985, 1995; Willems et al., 2014), but differences related to other aspects of behaviour, such as alcohol consumption (Bakan, 1973; London, 1987, 1990 but see Denny, 2011), smoking (Harburg, Feldstein, & Papsdorf, 1978), sleep duration (Hicks, Pellegrini, & Hawkins, 1979) and dream frequency (Schredl, Beaton, Henley-Einion, & Blagrove, 2013, 2014) have also been reported. Coren (1994) considered that left- and right-handers differ in temperament and personality. One aspect of personality/behaviour that has received considerable attention is anxiety.

On the basis of a questionnaire administered to a group of 14- to 17-year-old girls attending a classifying centre at what was then called an "approved" school (i.e. for adolescents with emotional and behavioural difficulties), Orme (1970) found that a greater proportion of 23 left-handers (defined by writing hand) showed high levels of emotional instability as 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) were significantly more anxious than 35 right-handers as assessed using the Briggs–Nebes (1975) modification of Annett's (1970) Hand Preference Questionnaire (AHPQ) and a modified version of the Taylor Manifest Anxiety Scale (TMAS). As pointed out by Wienrich, Wells, and McManus (1982), failure to state the numbers of participants of each sex is "unfortunate" since there are known sex differences in both handedness and anxiety. Wienrich et al. (1982), therefore, carried out a study of their own using 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 version of the AHPQ, and anxiety. However, in their study, Wienrich et al. (1982) obtained a quadratic relationship between handedness and anxiety such that extreme scores in both directions were associated with greater anxiety scores. This is interesting for two reasons. First, it suggests that the relationship is artefactual, arising from a tendency of some respondents to endorse extreme scores on both the handedness and the anxiety questionnaires. Second, Christman and his colleagues have argued that it is not so much direction, but rather degree, of handedness that is the important variable in assessing the relationship between laterality and cognitive and personality dimensions of behaviour (see Prichard, Propper, & Christman, 2013).

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The question of a relationship between handedness and anxiety was taken up by Beaton and Moseley (1984) who gave the Trait Scale of the Spielberger State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, & Lushene, 1970) to 247 university students of both sexes (see also Beaton & Moseley, 1991). The Spielberger State-Trait Anxiety questionnaire distinguishes between anxiety as a stable personality trait and anxiety as a transient state. 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). By this method, participants are categorized as belonging to one of a number of hand preference groups (or "classes") based on the particular combination of left- or right-hand preference reported for each of a number of everyday activities. The relative contribution of each activity to the classification of handedness varies and was identified by the association analysis conducted by Annett. 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, 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 (99 of whom were male) using both the Trait and State sub-scales of the STAI. These authors also failed to find any relationship between scores on either sub-scale of the STAI and handedness. Nor did they find any evidence that strong right-handers or strong left-handers tended to endorse more extreme scores on the STAI, a finding confirmed by Beaton and Moseley (1991) in a re-analysis of the data reported in their earlier paper.

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 (1) left-handed or (2) right-handed?", is related to basal levels of anxiety with only a suggestion in one of four samples of students that left-handers with high anxiety scores performed less well in terms of grade point average than right-handers high in anxiety.

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), Merkelbach, de Ruiter, and Olff (1989) compared the handedness of 77 anxiety disorder patients with handedness in a healthy control group and found no evidence of a relationship between left-handedness and clinically diagnosed anxiety.

In a recent study Lyle, Chapman, and Hatton (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, 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 subdivision was made between consistent (score less than –80 or greater than +80) and inconsistent handedness (scores between zero and –80 or between zero and +80). 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.

Whereas most researchers have conceptualized anxiety as a stable personality characteristic or clinical condition (e.g. Merkelbach et al., 1989), Wright and Hardie (2012) focused on state anxiety. Previously they had found (Wright, Hardie, & Wilson, 2009) that left-handers reported themselves to have higher behavioural inhibition system (BIS) scores than right-handers on a questionnaire developed by Carver and White (1994) to measure constructs proposed by Gray's (1982) theory of two independent neural systems—the BIS and the behavioural approach system (BAS). Subsequently these two systems, originally conceived of as underlying anxiety and avoidance on the one hand (BIS) and impulsivity or approach behaviour on the other (BAS), were modified and extended by the introduction of a third system representing a fight-flight-freeze system (FFFS) relating to an individual's responses to aversive stimuli motivated by fear (Corr & MacNaughton, 2008; Gray & MacNaughton, 2000). The BIS is now thought of as generating feelings that may include frustration or anxiety and to be involved in resolution of goal conflict by inhibiting FFFS- and BAS-mediated behaviour. In any event, behavioural inhibition, in the sense of a characteristically negative emotional and motor response to novel situations, and proneness to anxiety disorder are related (see Degnan & Fox, 2007).

Wright and Hardie (2012) reasoned that

> anxiety differences between left-and right-handed individuals may be related to circumstances where their BIS sensitivity comes into play, presumably when there is likely to be a conflict between approach (BAS) and avoidance (FFFS), rather than just being due to a difference in overall anxiety. (p. 632)

They argued that this is most likely within a specific, novel context such as a test situation. Their own research had shown that left-handers (particularly strong left-handers) are slower than right-handers to make their initial response in a number of experimental circumstances (Wright, Hardie, & Rodway, 2004; Wright, Watt, & Hardie, 2013). They therefore hypothesized that higher BIS levels of left-handers than right-handers would lead the former to report higher levels of anxiety in a test situation (i.e. higher state anxiety). The findings of their study (Wright & Hardie, 2012; see also Hardie & Wright, 2014) were consistent with this hypothesis; there were no handedness differences in relation to trait

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anxiety. Adding to the rationale given by Wright and Hardie, the BIS is more proximately related to the core neuropsychology of anxiety, as opposed to measures of "anxiety" which usually include mixed variance relating to fear, depression and general dysphoria (Corr, DeYoung, & McNaughton, 2013). How these different sources relate to laterality, and are moderated by sex and/or gender, is not known, and may account for previous inconsistent findings.

To summarize, it is still unclear whether left- and right-handers differ in terms of anxiety and, if so, under what circumstances. It is also unclear whether degree of hand preference, irrespective of direction, is important. While the lack of agreement in the literature suggests that situational and methodological factors having to do with how handedness and anxiety have been measured can explain much of the discrepancy in the literature, there is also a conceptual issue. Anxiety is a multifaceted construct (Corr, 2010a, 2010b) and individuals who tend to exhibit anxiety in certain situations may not experience it in others or be anxious all the time (i.e. demonstrate trait anxiety).

The finding of Wright et al. (2009) that left-handers have higher BIS scores than right-handers offers a new direction for research in the field of laterality in relation to individual differences, especially as behavioural response styles have been related to functional hemispheric differences (Davidson, 1995; Rutherford & Lindell, 2011) which in turn are related to handedness (Annett, 2002; Beaton, 1985, 2003; McManus, 2002). Reconsidering the question of anxiety differences between left- and right-handers in terms of the reinforcement sensitivity theory of personality potentially provides a more fruitful conceptual framework than has prevailed hitherto.

There has been much discussion recently regarding the desirability of replication in psychology (see Pashler & Wagenmakers, 2012). Accordingly, we decided to attempt to replicate the finding of a handedness difference using a specific measure of the BIS. Based on the studies of Wright et al. (2009) and Hardie and Wright (2014), our prediction was that left-handers would have higher BIS scores than right-handers. We did not expect any handedness effects on BAS scores.

METHOD

Participants

Students from a university psychology department subject pool were invited to participate in the study along with others recruited by means of requests made at lectures and through a department-wide e-mail. All participants gave written informed consent to their participation which was entirely voluntary and without payment. The study was approved by the Ethics Committee of the Department of Psychology, Swansea University and conformed to the principles laid down by the Declaration of Helsinki, 1964 and its later amendments. There were

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48 female and 44 male participants aged between 18 and 29 years (mean age 20.43 years, standard deviation 1.84) of whom 55 were right-handers and 37 were left-handers as assessed by a hand preference questionnaire (see below).

Materials and procedure

Handedness was assessed using the Briggs–Nebes (1975) modification of AHPQ. This consists of 12 items each asking the respondent to indicate on a 5-point scale how often they use a given hand to perform a specified action (e.g. to write a letter legibly; to hammer a nail into wood). The strength of preference for each item runs from *always left*; *usually left*; *no preference*; *usually right* and *always right* with scores of –2, –1, 0, 1, 2 assigned respectively. The total handedness score is obtained by summing scores across all 12 items.

Carver and White's (1994) BIS/BAS questionnaire consists of 24 items to assess the behavioural inhibition and BASs proposed by Reinforcement Sensitivity Theory (for a summary, see Corr, 2008). The BIS scale (7 items) measures avoidance behaviour and anxiety (e.g. "I worry about making mistakes") while the BAS scale measures approach behaviour and impulsivity using three sub-scales [BAS-FS (fun seeking—4 items; e.g. "I crave excitement and new sensations"); BAS-RR (reward responsiveness—5 items; e.g. "It would excite me to win a contest") and BAS-D (drive—4 items; e.g. "I go out of my way to get things I want")]. In addition, there are 4 filler items. Each item is scored on a 5-point Likert scale ranging from a score of 1 (*strongly disagree*) to a score of 5 (*strongly agree*).

We also administered a shortened form of the Big Five personality questionnaire. This was the 15-item questionnaire developed by McManus and Furnham (see Furnham, McManus, & Scott, 2003; McManus & Furnham, 2006) which measures the personality traits of Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. As neuroticism has been associated with anxiety (Corr et al., 2013), we wanted to be able to check that any effect we found for BIS scores could not be explained by an association with neuroticism.

The handedness questionnaire was administered first to all participants followed by the BIS/BAS questionnaire and the abbreviated Big Five Personality questionnaire in that order.

RESULTS

A question at the end of the handedness questionnaire asked whether the respondent had ever been forced (e.g. by teachers or by injury) to change writing hand from that which came naturally to them. Five participants (all female) reported this (three from left- to right-hand use, two from right- to left-hand use) and the BIS score of one (male, right-handed) participant was more than three standard deviations from the mean. Data from these six participants were

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TABLE 1
Mean scores (and standard deviation) of variables of interest

	BN	*BIS*	*BAS-D*	*BAS-FS*	*BAS-RR*	*Neuroticism*
Males	3.07	19.05	11.60	12.51	17.19	7.91
SD	17.20	3.21	1.76	1.90	2.02	2.24
Females	3.19	22.47	11.09	11.95	17.37	9.19
SD	18.22	3.04	1.89	2.25	2.25	2.44
Total	3.13	20.76	11.35	12.23	17.28	8.55
SD	17.61	3.55	1.83	2.09	2.12	2.42

BN, Briggs–Nebes handedness score.

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excluded and the following results are based on the remaining 86 participants (50 right-handed, 36 left-handed). Scores on the Briggs–Nebes modification of the AHPQ (BN scores) ranged from –24 (always use left hand for all 12 items) to +24 (always use right hand for all 12 items), with a mean of 3.13 and standard deviation of 17.61. The median score was 9.0.

Mean scores on the handedness questionnaire, neuroticism and BIS/BAS scales are shown for males and females in Table 1. The difference between male and female mean BIS scores was significant ($t = 5.07$; df = 84; $p < .001$). No other difference was statistically significant. (All probability values quoted in this paper are based on two-tail hypotheses.)

As anticipated, scores on the three BAS sub-scales correlated significantly with each other ($p < .001$ in each case). Unexpectedly (but not without precedent), BIS scores correlated ($r = 0.22$, $p < .05$) with BAS reward responsiveness (see also Heubeck, Wilkinson, & Cologon, 1998) while BIS scores and neuroticism were, as expected, highly significantly correlated ($r = 0.50$, $p < .001$).

The data were analyzed using a series of hierarchical multiple regressions. At step one the only variable entered was sex of participant. At step 2, the variable entered was handedness defined as total BN score. In order to eliminate the potential influence of BAS sub-scale scores on the effect of handedness these were entered at stage 3. Neuroticism scores were entered at stage 4 to gauge the effect of this variable on the variance explained by handedness after any effect of BAS sub-scale scores had been accounted for.

The results are shown in Table 2.

Sex was a significant source of unique variance (*standardized* $\beta = 0.48$, $t = 5.07$; $p < .01$). Neither ΔR^2 (the increase in R^2) from step 1 ($R^2 = 0.234$) to step 2 ($R^2 = 0.262$) nor that between step 2 and step 3 ($R^2 = 0.307$) was significant but that from step 3 to step 4 ($R^2 = 0.454$) was significant. Neuroticism was a significant source of unique variance (*standardized* $\beta = 0.406$, $t = 4.610$; $p < .01$).

We next analyzed the data by treating handedness as a categorical variable. Handedness was divided on the basis of BN score into three [right (8 to 24),

TABLE 2
Results of hierarchical regression analyses

	Adjusted R^2	ΔR^2	*p*
Step 1	0.225	0.234	<.001
Step 2	0.245	0.028	.078
Step 3	0.264	0.045	.167
Step 4	0.413	0.147	<.001

Independent variables were: step 1, sex of participant; step 2, handedness (BN score); step 3, BAS-D; BAS-FS; BAS-RR; step 4, neuroticism.

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mixed (7 to –7), strong left (–8 to –24)], four [strong right (13 to 24), weak or moderate right (1 to 12), weak or moderate left (0 to –11), strong left (–12 to –24)], or five [right (6 to 24), mixed (–4 to 5), weak left (–5 to –10), moderate left (–11 to –20), strong left (–21 to –24)] categories and, within each categorization, the cut-offs between adjacent categories were varied for different analyses. In none of these analyses did the effect of handedness approach significance. In the interests of brevity, the data will not be reported.

In the third set of analyses, handedness was treated as a dichotomous variable. BN scores less than or equal to zero were classified as non-right-handed while positive scores were classified as right-handed. There were 50 right-handers (mean BN score = 16.82, *SD* = 6.72) and 36 non-right-handers (mean BN score = –15.89, *SD* = 6.72).

The mean BIS score for right-handers was 20.08 (*SD* = 3.56) and for non-right-handers was 21.69 (*SD* = 3.38); the difference was statistically significant, $F(1, 84) = 4.50$; $p = .037$; $\eta_p^2 = 0.051$. The mean BIS scores broken down by sex and handedness were as follows: male right-handers = 18.52, *SD* = 3.02; female right-handers = 21.91, *SD* = 3.30; male non-right-handers = 19.94, *SD* = 3.44; female non-right-handers = 23.10, *SD* = 2.65. Two-way analysis of variance of these data revealed a significant sex difference, $F(1, 82) = 23.20$, $p < .001$; $\eta_p^2 = 0.22$, and a marginally significant effect of handedness, $F(1, 82) = 3.66$; $p = .059$; $\eta_p^2 = 0.04$, but no two-way interaction.

Again a series of hierarchical regression analyses were carried out. As before, sex was entered at step 1, handedness at step 2, BAS sub-scale scores at step 3 and neuroticism at step 4.

The results are shown in Table 3.

Sex was, of course, again a significant predictor of BIS (*standardized* $\beta = 0.48$, $t = 5.07$; $p < .01$) and the increase in R^2 from step 1 ($R^2 = 0.234$) to step 2 ($R^2 = 0.267$) was marginally significant ($p = .058$) indicating that handedness accounts for unique variance over and above that explained by sex alone (*standardized* $\beta = –0.17$, $t = –1.86$; $p = .067$). Inclusion of BAS sub-scale scores at step 3 did not lead to a significant improvement in the model. Neuroticism scores added at step 4 accounted for additional unique variance; *standardized* β

TABLE 3
Results of hierarchical regression analyses

	Adjusted R^2	ΔR^2	*p*
Step 1	0.225	0.234	<.001
Step 2	0.249	0.033	.058
Step 3	0.267	0.043	.179
Step 4	0.416	0.147	<.001

Independent variables were: step 1, sex of participant; step 2, handedness (right vs. non-right); step 3, BAS-D; BAS-FS; BAS-RR; step 4, neuroticism.

for handedness was reduced from –0.17 to –0.16 (t = –1.85; p = .068). Introduction of neuroticism in place of the BAS sub-scale scores at step 3 rather than step 4 led only to trivial differences; the effect of handedness remained marginally significant and *standardized* β again changed from –0.17 to –0.16 (t = –1.90; p = .06).

Of the five participants who reported a change of writing hand, only one did not have an overall handedness classification corresponding to their original writing hand. Including in the data analysis the four participants whose binary classification of handedness agreed with their original writing hand led to a slightly increased level of statistical significance for the effect of handedness. At step 2, *standardized* β = –0.18, t = –1.97, p = .052; at step 3, *standardized* β = –0.18, t = –1.92, p = .059; at step 4, *standardized* β = –0.16, t = –1.98, p = .051.

In view of the directional nature of our hypothesis the conclusion we draw from these results is that handedness (treated as a dichotomous variable) accounts for unique variance in BIS scores even after the effects of sex, neuroticism and BAS sub-scales are accounted for.

As a check on our results, we carried out a binary logistic regression analysis with sex, BIS scores, neuroticism and BAS scores as predictors and handedness (right versus non-right) as the dependent variable. BIS was a significant predictor of hand preference (p = .048).

Finally, we considered absolute strength or consistency of handedness. Strength of handedness regardless of direction was determined by removing the negative sign from BN scores of non-right-handers defined as above. The resulting positive scores thus represented an equivalent *degree* of (non-right) hand preference as for a right-handed participant with the same score. Strength of handedness, sex of participant, BAS sub-scale scores and neuroticism were entered as predictors in a series of hierarchical regression analyses as described above with BIS score as the dependent variable. There was no significant effect of strength of handedness treated in this way.

We also looked at strength of handedness based on the approach advocated by Prichard et al. (2013) who classify their participants as having consistent or inconsistent handedness on the basis of a reported population median score of 80

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on the EHI. Individuals with laterality quotients (LQs) between +80 and –80 are regarded as having inconsistent handedness while those with EHI scores greater than +80 or less than –80 are regarded as consistently handed. In our study we did not use the EHI but the Briggs–Nebes version of the AHPQ.

Briggs and Nebes (1975) provide a frequency distribution of the handedness scores of 1,598 students. The median score can be estimated as approximately 16. Using +16 and –16 cut-offs to distinguish between consistent and inconsistent (right or left)-handers, analogous to the definition adopted by Prichard et al. (2013) in relation to the EHI, we found no significant difference in BIS scores between these two groups. Nor was there any difference when the position of the cut-off was moved slightly in either direction (i.e. to scores between ±15 and ±18). Consistent with this, hierarchical regression analyses revealed no significant effect of consistency of handedness on BIS scores after taking account of the sex of participant, BAS sub-scale scores and neuroticism. Separate analyses of the data for left-handers and right-handers did not reveal an effect of consistency of hand use in either group. The same conclusions apply when, on the recommendation of one of the referees, analyses were based on our own sample median BN score of 9 (i.e. cut-off scores of ±9) or on 80% of the maximum possible BN score (19.2, i.e. ±20) by analogy with the ±80 cut-off on the EHI advocated by Prichard et al. (2013). It might be noted that in the case of the former, "consistency" of hand use is necessarily compromised (individuals classified as consistent are less so than with the previous cut-offs) and the number of inconsistent individuals is thereby reduced.

BAS scale

As expected, there was no significant handedness difference on any BAS sub-scale, nor any relationship between handedness, whether treated as continuous, categorical or dichotomous, and any of the three BAS sub-scales when handedness was entered as a predictor variable in a series of hierarchical regression analyses along with sex and neuroticism (with or without the inclusion of BIS scores). Similarly, there was no significant effect for strength of handedness whether treated as absolute BN scores or defined in terms of the median BN score (see above). Details are omitted in the interests of brevity.

DISCUSSION

The aim of this study was to confirm previous findings of a relationship between handedness and behavioural inhibition as conceptualized by Revised Reinforcement Sensitivity Theory (Corr, 2008). Our results replicate those of Wright et al. (2009) and Hardie and Wright (2014) that left-handers have higher BIS scores than right-handers while, as expected, there is no handedness difference for any BAS sub-scale. Like Wright et al. (2009), we found that non-right-handed

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females had the highest BIS scores. Our participant sample (university students) was similar in sex composition and demographic characteristics to that of Wright et al. (2009) and the relative proportions of left-handers and right-handers in their study ($N = 46$ and $N = 64$ respectively) was similar to ours ($N = 36$ and $N = 50$ respectively). Handedness as a dichotomous variable was defined in a similar way in the two studies (negative versus positive total scores on a handedness questionnaire) although the questionnaires were not identical. Wright et al. (2009) used the Peters (1998) questionnaire whereas we used the Briggs–Nebes modification of the AHPQ. The questionnaires differ in terms of their length (25 items in the Peters questionnaire; 12 in the AHPQ) but both adopt a 5-point Likert scale to assess strength of hand preference for each item.

Although our study is, therefore, not an exact replication, it has recently been argued (Stroebe & Strack, 2014) that focus on exact replications is "myopic" and "neglects basic epistemological principles". According to this view (Stroebe & Strack, 2014, p. 60):

> Exact replications are replications of an experiment that operationalize both the independent and the dependent variable in exactly the same way as the original study. (In contrast, conceptual replications try to operationalize the underlying theoretical variables using different manipulations and/or different measures.)

In this sense, ours is a conceptual replication and the results suggest that the relationship between handedness and the BIS is not related to the specific handedness measure used. Different questionnaires were used by Wright et al. (2009), Hardie and Wright (2014) and ourselves. Thus, the findings appear robust as to assessment instrument and provide a solid basis for further research. At the very least, our results, together with those of Wright et al. (2009) and Hardie and Wright (2014), imply that future studies of BIS/BAS should control for handedness.

We found no evidence of a relationship between *absolute* strength of hand preference and BIS scores. Our findings, therefore, do not support the arguments put forward by Prichard et al. (2013) that handedness effects are related more to consistency or degree than to direction of hand preference. In their view (p. 1):

> a major reason why previous research has failed to clearly determine individual differences in handedness effects on behavior is because the measure used to define handedness has heretofore been incorrect. Instead of *direction* of hand preference being the variable of interest, it should be *degree* (italics in original).

Our approach to this issue was to look for a relationship between BIS scores and unsigned BN handedness scores. If one is going to use questionnaires that purportedly give a numerical (as opposed to purely categorical) estimate of strength of handedness, then this seems to us an appropriate way of analyzing the

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data. This is not the approach taken by Christman and his colleagues in a number of their papers in which they compare participants in terms of consistency of hand use. Participants are classified as being consistent and inconsistent in their hand use on the basis of a reported median split of scores on the EHI. Thus "inconsistent handedness is defined as handedness scores below 80, which is equivalent to performing at least one of the 10 activities with the non dominant hand" (Prichard et al., 2013, p. 1). Since scores on the EHI range from –100 to +100 a median score of 80 is well into the category of right-handedness (reflecting the fact that the majority of the human population is right-handed by any definition). This means that relatively strong right-handers, who have long been known (Humphrey, 1951) to be very consistent in their preference for the right hand, are usually compared with a group of individuals who include both weak right-handers and weak left-handers who (as a group) tend to be less consistent in their use of the left hand for different activities, as acknowledged by Prichard et al. (2013). Comparing strong *right*-handers with individuals who are less consistent in their preference for *either* hand does not strike us as an intuitively convincing procedure though we cannot, of course, gainsay the empirical findings that have been reported using this definition of consistency of handedness. (It is not entirely clear from the Prichard et al. paper what happens to strong-left-handers. In some studies they are not recruited while in others (e.g. Christman, Henning, Geers, Propper, & Niebauer, 2008), they are specifically excluded from the analyses, which raise the issue as to whether consistency effects apply in the same way to right-handers and left-handers—see Hardie and Wright, 2014.) In any event, regardless of the definition we adopted, we did not find a significant effect of strength or consistency of hand use on BIS scores.

The relationship we observed did not depend on whether BIS or handedness was treated as the dependent variable but it was specific to a binary definition of handedness. This may reflect a genuinely dichotomous nature of handedness, as proposed by some authors (e.g. McManus, 1991), or it might simply mean that strength of handedness does not correlate with BIS scores to any large extent. Certainly we found no effect of strength of handedness when considered without regard to direction. Hardie and Wright (2014), using the type of classification scheme advocated by Prichard et al. (2013) and a number of different cut-off values to define consistent versus inconsistent handedness, found small but statistically significant effects of consistency or strength of handedness for their sample (N = 689) as a whole (consistently handed individuals had higher BIS scores than those of inconsistent handedness). However, when they looked separately at right-handers and left-handers an effect was apparent among the 202 left-handers but not among 481 right-handers. Our own failure to find an effect of strength of handedness may, therefore, be a consequence of the relatively low number of left-handers (36) in our sample.

In what circumstances right-handers and left-handers (or non-right-handers) show different levels of BIS activation, and why, are questions for future

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research. Clearly, handedness does not determine levels of BIS activation, any more than the latter is a cause of hand preference. Rather, the relationship between handedness and BIS scores presumably has to do with early neurodevelopmental processes which may include the influence of sex hormones on the foetal brain. Geschwind and Galaburda (1985) suggested that pre-natal levels of sex hormones influence cerebral lateralization and handedness. Despite criticism of their hypothesis (see Bryden, McManus, & Bulman-Fleming, 1994 and associated papers) it continues to provoke interest and finds some empirical support (Beaton, Rudling, Kissling, Taurines, & Thome, 2011; Hampson & Sankar, 2012a; see too Lust et al., 2011). Manning, Bundred, Newton, and Flannagan (2003) reported (see also Hampson & Sankar, 2012b but see Hönnekopp, 2013; Loehlin, Medland, & Martin, 2012; Voracek, 2014; Zhang et al., 2013) that the structure of the androgen receptor (AR) gene, which determines sensitivity to testosterone, was related to a putative marker of foetal testosterone, the ratio of the length of the index (second) finger to the ring (fourth) finger (Manning, 2011). Aspects of this 2D:4D digit ratio have been related to handedness (see Beaton et al., 2011; Manning & Peters, 2009). Polymorphisms of the AR gene (and 2D:4D ratio) have been related to measures of aggression (Hurd, Vaillancourt, & Dinsdale, 2011; see also Butovskaya et al., 2012). Conceivably, sensitivity to foetal testosterone (or to the ratio of prenatal testosterone to oestrogen, see Manning, 2011) both contributes to the development or manifestation of handedness and is related in some way to certain personality characteristics.

As an alternative to a neurodevelopmental explanation of our findings, some consideration should be given to the possibility that our results are artefactual. A number of papers in the literature have reported that high magical ideation (MI) is associated with weak right-handedness or mixed hand preference (Badzakova-Trajkov, Häberling, & Corballis, 2011; Barnett & Corballis, 2002; Chapman & Chapman, 1987; Grimshaw, Yelle, Schoger, & Bright, 2008; Nicholls, Orr, & Lindell, 2005). (A similar pattern has been found in several, but not all (e.g. Overby, 1993; Jaspers-Fayer & Peters, 2005), studies of schizotypy to which MI is related.) Since three studies (Badzakova-Trajkov et al., 2011; Grimshaw et al., 2008; Nicholls et al., 2005) failed to find any relationship between MI and a behavioural (performance) test of handedness, the suggestion has arisen that the relationship between mixed-handedness and MI is artefactual. At least two explanations have been put forward. These are, first, that in completing questionnaires such as Oldfield's (1971) EHI some participants might respond randomly or while paying little attention (Nicholls et al., 2005) and, second, that some few "individuals with high rates of magical ideation might like to remain open to the idea that they *could* use their nondominant hand for an activity some of the time, when in fact they would not actually do so" (Grimshaw et al., 2008, p. 23). In both instances the effect would be to shift LQs towards zero (ambilaterality or mixed-handedness). Responding randomly would raise MI

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scores above the mean (Nicholls et al., 2005) while the personality factor of openness might affect responses both to a handedness inventory and to a questionnaire measuring MI (Grimshaw et al., 2008).

Whatever the position with regard to MI, and it is quite conceivable that a relationship holds for one aspect of handedness (preference) but not for another, albeit related, aspect of handedness, namely relative hand skill, we do not think there is any reason to suppose that our finding of a difference in mean BIS score between left-handers and right-handers (defined by preference) can be explained as artefactual along lines similar to the above argument. Given the nature of the BIS/BAS scale, responding "randomly" would not have the effect of elevating BIS scores; nor would it tend to affect scores on the Briggs–Nebes modification of the AHPQ as would be the case with the EHI (used by Badzakova-Trajkov et al., 2011; Barnett & Corballis, 2002). The effect of some participants having an especially open attitude to the possibility of use of the non-dominant hand would slightly decrease the probability of having hand preference classified as other than extreme by the modified AHPQ but this should apply as much to right-handers as to left-handers. It is not clear that an especially "open" attitude would influence responding on the BIS/BAS scale or, if so, how. In fact, we had available to us each participant's Openness score on the abbreviated Big Five personality questionnaire. We were unable to find any relationship between this measure (not specifically concerned with handedness, of course) and either handedness or BIS scores for the sample as a whole. Nor did those participants with Openness scores in the highest quintile differ in mean BIS or BN score from those in other quintiles.

Consider an alternative possibility. If a participant tended to respond to questionnaire items in an extreme manner (endorsing extreme rather than moderate statements) then this would lead to their hand preference being classified as extreme on the BN modification of the AHPQ. Again, this would apply to both right-handers and left-handers. However, on the BIS sub-scale, in which respondents assign a number from 1 (*very true of me*) to 4 (*very untrue of me*) to each statement, any tendency to endorse extreme statements might apply to either one or both extremes (true versus untrue). It does not appear to us, therefore, that "extreme responders" can account for our finding that left-handers have a higher mean BIS score than right-handers. In fact, among those of our participants with a BN score greater than zero, and therefore classified as right-handed, a far greater proportion (13 of 50) had a maximum positive score of 24 than did the proportion (3 of 36) of those classified as left-handed who had a maximum negative score of –24. (Indeed, it is commonly asserted in the literature that right-handers are more clearly lateralized than lefthanders.) On the argument that the difference we (and by extension Wright and her colleagues) report between handedness groups is artefactually related to a tendency to endorse extreme statements, this would lead one to expect that, if anything (*vide supra*), right-handers would show greater BIS scores than left-handers.

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A final argument against our result being artefactual is that any response bias should have affected BAS scores in the same way as BIS scores, yet we found no handedness difference in mean BAS scores.

While our results provide a replication of the findings of Wright et al. (2009), further research is required before questions about the precise nature of the relationship between handedness, behavioural inhibition and anxiety will be answered satisfactorily. In particular, since publication of Carver and White's (1994) BIS/BAS scale, theoretical developments in relation to Reinforcement Sensitivity Theory (see Corr, 2008) have led to the construction of a new questionnaire (Corr & Cooper, 2015; see also Smederevac, Mitrović, Čolović, & Nikolašević, 2014) for measuring the constructs of Revised Reinforcement Sensitivity Theory. We are currently collecting data using this new questionnaire which we anticipate will help to clarify the somewhat elusive nature of any personality differences between left- and right-handers.

In common with the two previous studies in this area (Hardie & Wright, 2014; Wright et al., 2009), our findings are restricted to university students. In addition, we openly acknowledge a limitation in the analysis of the present data. It has been argued that fear and anxiety are separable constructs (Corr, 2011; Gray & MacNaughton, 2000; Perkins, Kemp, & Corr, 2007) and that the Carver and White BIS scale conflates fear and anxiety (see Corr, 2010a, 2010b, 2011). It has therefore been proposed that FFFS scores should be separated out from BIS scores (Corr, 2010a, 2010b). Given how we recorded and stored our raw data, we cannot now go back and do this. In any event, our aim in the present study was to use a general BIS measure to firmly establish BIS/anxiety and laterality associations; our future research will extend this work by differentiating FFFS/fear from BIS/anxiety.

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