Chiral Cognitive Science

Gregory V. Jones (G.V.Jones@warwick.ac.uk)
Department of Psychology; University of Warwick
Coventry CV4 7AL, UK

Maryanne Martin (maryanne.martin@psy.ox.ac.uk)
Department of Experimental Psychology; University of Oxford
South Parks Road, Oxford OX1 3UD, UK

Abstract

Development of powerful brain imaging techniques has revolutionised our knowledge of the patterns of cerebral activation which underlie the performance of cognitive tasks. Particularly striking is the extent to which cognitive performance has been shown to be accompanied by motor processing even in the absence of physical movement, consistent also with considerable behavioral evidence. By definition, left-handed and right-handed people exhibit systematic differences in motor processing. It is thus possible in principle that handedness-dependent differences in patterns of motor activation may exert observable effects upon cognitive performance. New evidence suggests that this is indeed the case. It has been shown that people's handedness can significantly influence the accuracy of what they remember. Cognitive Science thus needs a chiral component. The results of experiments support the hypothesis that handedness effects are linked directly to specific patterns of motor activation, rather than indirectly to general differences in hemispheric processing.

Motor Activation in Cognition

In recent years, neuroimaging and behavioral methods of investigation have provided two separate lines of evidence for motor activation during cognitive performance.

Brain Activation

The mapping of patterns of brain activation has produced evidence of the occurrence of motor processing during the performance of tasks which hinge upon mental activity rather than upon physical movement. For example, Decety and colleagues have shown in positron emission tomography (PET) studies that when a person imagines grasping an object (Decety et al., 1994) or observes a hand action that they have been asked to imitate (Decety et al., 1997) there is strong activation of cerebral regions involved in the planning and generation of movements.

Similarly, Cohen et al. (1996) used functional magnetic resonance imaging (fMRI) to examine cortical activity during the performance of mental rotation, employing the classic task of Shepard and Metzler (1971). Participants were shown pairs of two-dimensional pictures of three-dimensional block shapes, and had to decide whether the shapes were identical or mirror-images. In the experimental condition, the members of each pair of shapes were presented at different orientations. Participants were instructed "to visualize the right-hand stimulus rotating until it was aligned with the left-hand stimulus, and then were to decide whether the two shapes were identical or mirror reversed" (Cohen et al., 1996, p. 92). In a control condition, the members of each pair of shapes were presented at the same orientation, and participants thus did not have to perform mental rotation prior to making the same decision; as before, the response conveying the outcome of the decision (i.e., identical vs. mirror-image) consisted of pressing one of two buttons. Cohen et al. compared the fMRI data yielded by the two conditions for each participant. They found that, for at least half the participants, mental rotation was associated with increased activity in hand somatosensory cortex and in premotor cortex (though it should also be noted that increased activity in some other cortical areas was even more widespread among participants).

Inner Scribe

Brain activation findings raise the question of whether it is possible to detect the influence of motor processes within behavioral data that emanate from cognitive tasks for which performance is ostensibly determined by abstract processes unrelated to movement. A paradigmatic case is that of recall from memory. Here, there is indeed evidence that the retention of spatial information can be influenced by underlying motor processes, since it suffers interference from concurrent limb movement (e.g., Farmer, Berman, & Fletcher, 1986; Quinn, 1994; Smyth & Pelky, 1992).

To account for such findings, Logie has developed further the concept of the visuo-spatial store, hypothesised by Baddeley (1986) to be one of the three principal components of working memory. It is proposed (e.g., Logie, 1995; Logie & Pearson, 1997) that the visuo-spatial store itself has two parts, the inner scribe and the visual cache. The inner scribe is a dynamic, motor-linked system which allows the contents of the visual cache, a static visual store, to be redrawn. By this means, the inner scribe supports the rehearsal, manipulation, and transformation of visual and spatial information (cf. also Kosslyn et al., 1988). The concept of the inner scribe provides a bridge between the general indications from brain activity mapping of a motor component in cognitive performance and a specific issue to be focussed on here. The possibility to be investigated is that the outcome of some forms of memory retrieval may depend upon the handedness of the person concerned.

Handedness and Cognition

A striking characteristic of the human species is the predominant preference for movements of one limb, the right hand, rather than its symmetric counterpart, the left hand. Preference for the use of a right or left limb is widespread among individual members of nonhuman species. For these species, however, the preference appears in general to reflect chance factors, since left-limbed and right-limbed members of a species occur with approximately equal frequencies (though evidence of the exception provided by primatology is considered later). In contrast, approximately 90% of humans tend to favour use of the right hand. The ubiquity of the preference for the right hand across time and place suggests that it has a genetic origin (e.g., Corballis, 1997; McManus & Bryden, 1992), although social and cultural factors also play a role (e.g., Harris, 1990; Provins, 1997).

By definition, left-handed and right-handed people differ in some of their patterns of motor processing. They tend also to differ in the extent to which language functions are lateralised within the cerebral hemispheres (e.g., Loring et al., 1990). But the question to be examined here is that of whether they differ in their normal patterns of cognitive performance as well. It has been argued that it is difficult to establish any empirical link at all between handedness and cognition (e.g., Bishop, 1990), though an association between left-handedness and developmental reading difficulties has often been hypothesised. This association has also been hypothesised to extend to a number of manifestations of immune disease (e.g., Geschwind & Behan, 1982; Geschwind & Galaburda, 1987), although again a number of problems in assembling empirical support for the proposal have been noted (e.g., Bryden, McManus, & Bulman-Fleming, 1994).

What of the core cognitive domain of memory? Until recently, memory performance had generally been assumed to be independent of handedness. However, there is now reliable evidence that, at least in one area, what a person remembers is influenced by the person's handedness.

Handedness and a Mnemonic Illusion

The coin head illusion (Jones, 1990; Jones & Martin, 1992; Martin & Jones, 1995) was identified when participants attempted to recall the direction that the head of Queen Elizabeth II faces on British coins. All coins currently in circulation (and all those minted since the start of her reign in 1953) depict the Queen's head facing to the viewer's right. However, the majority of people recall incorrectly that the head faces to their left, with overall performance so bad that it constitutes systematic misremembering. That is, performance is significantly worse even than the baseline level of 50% correct recall which is expected to occur by chance. Rubin and Kontis (1983) had earlier proposed that coin recall is schema based, and thus the explanation of the illusion initially offered (Jones, 1990; Jones & Martin, 1992) was that the British coin head schema was influenced by experience of postage stamps, on which the Queen's head faces in the opposite direction (i.e., to the viewer's left). It now appears, however, that this explanation was incomplete because it did not allow for the influence of a person's handedness.

The normal procedure in human memory research is of course to test a population unselected as to handedness and thus in practice almost entirely right-handed. However, two recent studies (Jones & Martin, 1997; McKelvie & Aikins, 1993) have examined coin head recall separately for left-handed and right-handed participants. Both studies found that left-handed participants were not prey to the coin head illusion. The proportions of left-handed participants who incorrectly recalled that the head faced to their left were 41.3% (McKelvie & Aikins), 53.7% (Jones & Martin, Experiment 1), and 55.1% (Jones & Martin, Experiment 2), and correct recall did not fall significantly below the baseline of 50% in any instance. In contrast, for right-handed participants the corresponding proportions of incorrect, left-facing recall were 61.9%, 73.7%, and 65.9%, respectively. For these right-handed participants, correct recall did fall significantly below the baseline of 50% in each instance (marginally so in the case of the McKelvie and Aikins study), and also fell significantly below the corresponding left-handed percentage in each of the three cases.

If we aggregate the three sets of data, the proportions of left-facing, incorrect recall (weighted averages) are 52.1% for left-handed participants and 67.0% for right-handed participants. This difference in performance between left-handed and right-handed participants is highly significant, $\chi^2(1, N = 679) = 15.48$, $p < .001$. Also, whereas performance for left-handed participants did not differ significantly from 50%, $\chi^2(1, N = 328) = 0.60$, performance for right-handed participants was significantly worse than the 50% baseline, $\chi^2(1, N = 351) = 40.34$, $p < .001$.

In chemistry, a chiral compound (Greek χειρ, hand) is one which exists in two different forms (enantiomers) that are, like pairs of hands, mirror images of each other but are not superimposable. In the present context, we may thus refer to the variation in coin head recall with handedness as an instance of chiral cognitive performance: Only right-handed people reliably display systematic misremembering of head orientation. What is the origin of this phenomenon and what are its implications? To address these issues, we need both to investigate how widespread are the effects of handedness upon cognitive performance and also to evaluate possible explanations for such effects. We need, in short, a chiral cognitive science. Here, we report some initial steps in this direction.

Theoretically, at least two general mechanisms by which a person's handedness could influence the outcome of their thought processes may be distinguished. They will be referred to here as the hemispheric and the motor activation hypotheses.

Hemispheric Hypothesis

The hemispheric hypothesis notes that left-handed and right-handed people tend to have different patterns of cerebral dominance (e.g., McManus & Bryden, 1993). The performance of a cognitive task may rely upon processing which is predominantly supported by a single cerebral hemisphere, and the hypothesis asserts that it is the difference between left-handed and right-handed people in their utilisation of the hemisphere which is responsible for differences in overall task performance. This explanation has been advanced concerning handedness effects both in memory performance (McKelvie & Aikins, 1993) and also in chimeric perception (e.g., Gilbert & Bakan, 1973; Levy et al., 1983; Luh, Redl, & Levy, 1994).

In the chimeric perception paradigm introduced by Gilbert and Bakan (1973), participants are presented with pictures which combine the left side from one face with the right side from another face, and asked to match them to faces composed of either the left side plus its mirror image or the right side plus its mirror image. Gilbert and Bakan found that right-handed participants, but not left-handed participants, displayed a significant tendency to select as a match the face that had been constructed from the left side of the original stimulus.

The hemispheric hypothesis which has been advanced to account for the influence of handedness upon memory and chimeric perception has several distinct components. It is hypothesised that the visual world to the left of the observer tends to be processed by the right hemisphere, that facial information also tends to be processed by the right hemisphere, that this joint utilisation of the right hemisphere is advantageous, and finally that the advantage is more pronounced for right-handed people because they tend to have greater lateralisation of function than do left-handed people.

A major weakness of the hemispheric hypothesis concerns its first premise, namely that the visual world to the observer's left tends to be processed by the right hemisphere. The handedness effects arise under free presentation conditions. This unrestricted mobility in eye fixation means that both the left and right sides of stimuli are encountered in both the left and right visual fields of the observer. Thus the premise does not refer to the well-established relation between right hemisphere and left visual field. Instead, it is necessary to posit the existence of an additional tendency induced by the right hemisphere to attend more to the left sides of stimuli, irrespective of the stimuli's positions in the visual field.

Motor Activation Hypothesis

The motor activation hypothesis, in contrast, notes that the performance of cognitive tasks may be accompanied, as indicated earlier, by activation of areas of the brain associated with motor processes. Left-handed people and right-handed people differ by definition in some of their major patterns of movement and associated neural processing, and the proposal is that it is this difference in patterns of motor activation between the two groups which is responsible for differences in memory and perception between them. Of course, this motor activation during the performance of memory or perception tasks does not necessarily result in actual physical movement. Motor activation in the absence of physical movement is characteristic of motor imagery (e.g., Jeannerod, 1994, 1997), though our introspective awareness of motor imagery appears to be considerably less extensive than in the case of visual imagery.

Are handedness effects explained better in terms of hemispheric differences or in terms of motor imagery? Recent work provides considerable corroboration for the latter possibility. For example, in a neuropsychological study of a group of patients who suffered from asymmetrical Parkinson's disease which affected only one side of the body, Dominey et al. (1995) showed that not only real but also imagined movement of the hand on that side was slowed. Similarly, in a PET study Martin et al. (1996) reported activation of the cerebral left premotor area as a result not only of imagining hand movements but also of generating the name of a tool, and in another PET study Parsons et al. (1995) reported activation of frontal motor cortex as a result not only of real and imagined movement but also of visually discriminating pairs of mirror shapes, such as pairs of hands. Corroboration of the hemispheric hypothesis appears more difficult. For example, Kosslyn et al. (1993) studied a split-brain patient's identification of previously seen pictures from among distractors consisting of their mirror-reversals, and found no consistent difference between the patient's two hemispheres in their recognition performance.

Although suggestive, the previous work cited bears only indirectly on the issue of handedness. It can be argued therefore that it does not allow a conclusive choice to be made between the hemispheric and motor activation hypotheses. The issue of contralaterality, however, appears more promising in this respect.

Contralaterality

A basic feature of the hemispheric hypothesis is its prediction that, because cerebral lateralisation of function is less pronounced in left-handed than in right-handed people, any asymmetry in cognitive performance for left-handed people should be of reduced magnitude but the same direction compared to that for right-handed people. In contrast to this prediction of ipsilaterality by the hemispheric hypothesis, the motor activation hypothesis predicts that contralaterality may be observed (i.e., a change in handedness produces a reversal in the sign of an associated effect). For example, rather than possessing a less strong version of a right-handed person's tendency to produce a left-facing response, a left-handed person may possess a tendency of comparable strength to produce a right-facing response. Motor activation patterns underlying such responses may echo a tendency in physical drawing to avoid obscuring earlier detail. There is evidence (Shanon, 1979) that right-handed people tend to draw heads facing to the left, and vice versa, and it may be that this is because facial details are entered first and, to avoid obscuring the face when drawing the back of the head, a right hand is then moved away to the right, and a left hand away to the left.

Recently completed work (e.g., Martin & Jones, 1998) provides considerable evidence of the occurrence of contralaterality. In one experiment, participants were instructed to recall two British road-signs, one depicting a left-facing person digging (road works) and the other depicting a right-facing person walking (pedestrian crossing). The percentage accuracy of verbal recall of figure direction for each stimulus as a function of participant handedness is

Table 1: Recall of figure direction (% correct)

	Participant handedness	
Figure direction	Left-handed	Right-handed
Left-facing	44.2	64.0
Right-facing	59.6	48.2

shown in Table 1. Statistical analysis confirmed that the accuracy of right-handed participants was significantly higher than that of left-handed participants (and significantly above the 50% baseline level) when recalling the orientation of the left-facing figure, whereas the accuracy of left-handed participants was significantly higher than that of right-handed participants (and significantly above the 50% baseline level) when recalling the right-facing figure.

If the effects of handedness upon cognitive performance are indeed being exerted by means of motor activation, then a further implication is that similar effects may be expected to occur in overt motor behavior as well. In free-drawing experiments, this prediction also has been confirmed. The results of other experiments have demonstrated that the observation of contralaterality is not confined to semantic memory, if multiple memory systems are distinguished (see Gardiner & Java, 1993; Tulving, 1995). Nor is it confined to recall, as opposed to alternative methods of retrieval (see Jones, 1987).

It should in addition be confirmed that the present results are robust with respect to the way in which a participant's handedness is established. The results shown in Table 1 relate to a dichotomous measure of handedness (namely, preferred hand for drawing). As an alternative, the questionnaire of Annett (1985) was used to obtain a pseudocontinuous measure of handedness. This instrument elicits one of three responses (right, either, and left) concerning hand preference for each of 12 activities; allocating scores of 1, 2, and 3, respectively, to the three responses yields overall handedness scores ranging from 12 to 36. Using Annett score to predict percentage correct recall, logistic regression analysis confirmed that for both left-facing and right-facing figures there were significant relationships, and that these were of opposite polarity. Dichotomous and pseudocontinuous measures of handedness have yielded consistent conclusions in a series of experiments providing evidence of contralaterality.

Finally, it is interesting to note that the present observation of contralaterality in cognitive science finds an apparent parallel in chemical science. A cardinal feature of a chiral molecule is its effect upon the orientation of polarized light, two enantiomers rotating the plane of polarization by an equal amount in opposite directions. Nevertheless, the apparent similarity between this effect and that of handedness upon memory for orientation presumably does not attest to any commonality in mechanism beyond, perhaps, the abstract geometrical link between mirror reflection and angular displacement exemplified by left-handed and right-handed helices.

Scope of Chiral Cognitive Science

In addition to the areas focussed on here, the role of handedness may be explored not only among other forms of human cognitive performance but also, potentially, among nonhuman primates.

Human Cognition Thus far, handedness has been shown to influence people's performance of only a small number of cognitive tasks. It is possible, however, that the smallness is deceptive in that it may primarily reflect the limited range of tasks for which handedness has been examined, rather than the actual scope of chiral influence. The limited range is likely to reflect the pragmatic circumstance that, because of their relative scarcity, it is relatively difficult to arrange the participation in experiments of left-handed people in numbers comparable to those of right-handed people. If, as a result, the usual procedure is followed of planning the appropriate statistical power of an experimental design in terms of an overall number of participants who are unselected as to handedness, then the imbalance in numbers of left-handed and right-handed participants will tend to make the detection of any effect of handedness relatively unlikely.

In addition to the basic elements of cognitive processing focussed on here, more complex cognitive performance may also be examined. For example, it has been reported (Benbow, 1986; O'Boyle & Benbow, 1990) that the incidence of left-handedness is unusually high among students with exceptionally high levels of scholastic aptitude. There is thus scope for future exploration of a chiral dimension in a wide range of cognitive activity.

Cognition in Primates Finally, although the research considered here has focussed upon handedness in humans, it has been suggested (e.g., MacNeilage, Studdert-Kennedy, & Lindblom, 1987) that handedness is an attribute of primates in general. In particular, MacNeilage et al. have proposed that primates tend to possess a posture which involves reaching with the left hand and manipulating with the right hand. Similarly, it has been suggested by Day and MacNeilage (1996) that human motor asymmetry may also be described more fully with reference to overall posture, in terms of a combination of hand and foot preferences. Recent work has provided empirical support for the general hypothesis of handedness among primates, although not always in accordance with the predicted pattern. Thus Diamond and McGrew (1994) found that cotton-top tamarins exhibited a uniform preference for using the right hand in a range of activities, whereas Laska (1996) found that spider monkeys exhibited an equally uniform preference for the left hand.

If nonhuman primates share with humans the attribute of handedness, the possibility also arises that their cognitive performance is influenced by handedness in a manner which is analogous to that for humans. Practical difficulties in testing nonhuman primates suggest, however, that exploration of the potential chiral dimension in primate cognition may prove less rapid than in the human case.

Conclusion

Cognitive science has tended to neglect the possibility that cognitive performance may be significantly influenced by handedness. There is evidence, however, of a chiral dimension to some aspects of human memory and perception. For example, it appears that cerebral motor activation occurring in the absence of movement is responsible for the observed role of handedness in determining the accuracy of recall of orientation. A chiral cognitive science would embrace further exploration of the extent and origin of such phenomena.

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