Is handedness just response bias?

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Abstract Although most people prefer to use the right hand for unimanual tasks, it is unknown whether handedness arises from response bias. Whether it does is a question inspired by signal detection theory. We drew on the framework of signal detection theory to assess bias and sensitivity in hand choice by asking right-handers to choose between two tasks—one performed with the left hand, and one performed with the right. For some participants, the left-hand task stayed constant while the right-hand task was varied. For other participants, the right-hand task stayed constant while the left-hand task was varied. We reasoned that if hand preference only reflected bias, participants would choose the generally preferred hand to the same degree, regardless of whether its task was constant or varied. Our participants followed this strategy only to some extent, suggesting that bias and sensitivity both contribute to hand preference.

Keywords Choice behavior · Motorplanning/programming · Motor control · Decision making

About 90 % of people prefer to use the right hand for unimanual tasks, such as throwing and writing (Corballis, 1997). This estimate is based on surveys (Oldfield, 1971), but behavioral studies have confirmed that people use the right hand predominantly (e.g., Bryden & Roy, 2006; Helbig & Gabbard, 2004; Mamolo, Roy, Rohr & Bryden, 2006). The source of right-handedness has been attributed to an evolutionary response to social pressures for cooperation (Vallortigara & Rogers, 2005), coevolution of brain areas for language and gesture (Corballis, 2003), and modeling of

others (Hepper, Wells & Lynch, 2005). Sainburg and Eckhardt (2005) suggested that the right hand is specialized for position change, while the left hand is specialized for position maintenance.

Does handedness reflect simple preferences (McManus, Murray, Doyle & Baron-Cohen, 1992) or actual performance differences (Annett, 1995)? While some studies have linked a right-hand preference to right-hand performance advantages (see Annett, 1995), no study, to the best of our knowledge, has shown that the extent of observed hand preference is fully ascribable to an equally strong performance difference. This raises the question, Is handedness just response bias? Even if handedness is not *just* response bias, to what extent is it bias-based?

Response bias is, of course, well known to readers of this journal, especially in connection with signal detection theory (Green & Swets, 1966). Ironically, however, response bias has hardly ever been evaluated in the study of motor control (but see Deplancke, Madelain, Chauvin, Cardoso-Leite, Gorea & Coello, 2010; Gordon & Rosenbaum, 1984; Kim & Basso, 2008).

How could one apply the methods of signal detection theory to the quantification of response bias and sensitivity in hand selection? A first thought is to ask whether the preference for one hand equals the objective superiority of that hand over the other. The problem with this approach is that it is unclear how to relate degree of preference to the degree of performance difference: If the right hand is twice as good as the left hand at performing a task, should the right hand be preferred twice as much? Uncertainty about this issue makes it difficult to estimate the extent to which observed choices are sensitivity or bias based.

Recognizing this problem, we took an approach that departed in detail from signal detection theory as classically pursued, but was motivated by the conceptual framework that signal detection affords. We asked right-handed people

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to choose between a left-side task that was done with the left hand and a right-side task that was done with the right hand, picking whichever task seemed easier. For some participants, the left-hand task was constant, while the right-hand task was varied; for other participants, the right-hand task was constant, while the left-hand task was varied. We reasoned that if hand preference reflects response bias, participants would choose the generally preferred hand to equal degrees, regardless of whether or not it was associated with the constant or variable task. By analogy to a doting parent who always prefers his or her child when asked who does better on some task, his or her own child or someone else's, that parent might say, "My child," no matter what the objective qualifications of the contenders.

We focused on the probability, $p(\text{right hand})$, of using the right hand, and we defined sensitivity regarding the right hand as $p(\text{right hand} \mid \text{variable right task}) - p(\text{right hand} \mid \text{constant right task})$. We also defined bias with regard to the right hand as $[p(\text{right hand}) - 0.5] \times 2$. Our idea concerning sensitivity was that the larger the positive difference in the expression just given, the stronger would be the sensitivity favoring the right hand (i.e., the more the right hand would be chosen on the basis of its judged superiority over the left hand); similarly, the larger the *negative* difference, the stronger would be the sensitivity *disfavoring* the right hand as compared to the left. Our idea concerning bias was that, a priori, $p(\text{right hand})$ would be 0.5; the larger the positive difference between $p(\text{right hand})$ and 0.5, the stronger the bias favoring the right hand, or the larger the *negative* difference, the stronger the bias *disfavoring* the right hand. For the bias measure, we multiplied the difference by 2 in order to map the differences to the range -1 to 1 , the range as for the sensitivity measure.

Method

We used tasks that varied with respect to the physical features that we thought would selectively tax the abilities of the left and right hands. All of the tasks involved reciprocal tapping between two targets in time with a metronome. The tapping movements were made back and forth between two left-side targets with the left hand or between two right-side targets with the right hand (see Fig. 1).

We tested eight groups of participants. Four of the groups had constant *left* targets, along with right targets that varied from trial to trial. Four other groups had constant *right* targets, along with left targets that varied from trial to trial. Within the four left-constant groups, two groups had the constant targets located *near* where the participant stood (Targets 1 and 3), while two other groups had the constant targets *far* from where the participant stood (Targets 2 and 4). For each of these groups, the other, variable, target pairs

Fig. 1 Schematic overhead view of the experimental setup

appeared in the following combinations: 5 and 6, 5 and 7, 5 and 8, 6 and 7, 6 and 8, and 7 and 8. Similarly, within the four right-constant groups, two groups had the constant targets near where the participant stood (Targets 5 and 7), while two other groups had the constant targets far from where the participant stood (Targets 6 and 8). For each of these groups, the other, variable, target pairs appeared in the following combinations: 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4. Finally, within each set of four groups, two groups always used an unweighted manipulandum with both hands, while the other two groups always used a weighted manipulandum with both hands.

We formed these groups for the following reasons. First, having the constant targets on the left or the right let us estimate sensitivity and bias, as outlined above. Second, having the constant targets near or far away let us draw on previous research showing that the cost of reaching near versus far from a standing position is greater for the left hand than for the right hand in right-handed individuals (Rosenbaum, Brach & Semenov, 2011). On the basis of this finding, we predicted that if participants were sensitive to this performance difference, they would use the right hand more when the left-constant task required a great deal of body leaning (*far left-constant* targets) than when the left-constant task did not require a great deal of body leaning (*near left-constant* targets).

Our third reason for forming the groups as we did concerned the unweighted or weighted manipulanda. Previous research has shown that the increased coordination required to generate greater force, which would be needed to move a heavier manipulandum, is better for the dominant (right) hand than for the nondominant (left) hand (Sainburg,

2002). On the basis of this finding, we predicted that if participants were sensitive to this performance-based difference, they would use the right hand more when the manipulandum was loaded than when it was unloaded.

The three factors just discussed—Side of the Constant Targets, Distance of the Constant Targets From the Standing Position, and Manipulanda Weight—were manipulated between subjects. We also had two within-subject factors: One was which pairs of targets were presented per trial on each participant's varied-target side (as already noted), and the other was the prescribed rate of reciprocal tapping (*driving period*). We used three metronome rates: 150 beats per minute (2.5 Hz, or one click every 0.40 s), 125 beats per minute (2.08 Hz, or one click every 0.48 s), and 88 beats per minute (1.47 Hz, or one click every 0.68 s). Previous research has shown that when people aim for targets under time pressure, they are more efficient with the right than with the left hand (Vaughan, Barany & Rios, 2012). On the basis of this result, we predicted that if participants were sensitive to this performance difference, they would use the right hand more when the required movement rates were high than when the required movement rates were low.

In each trial, the constant target pair, to the left or right, was presented with one of the six possible target pairs on the other, variable, side. With the three driving periods, this led to 18 total combinations of constant target pair and alternative target pair. The order in which any given participant experienced these 18 conditions was random.

The apparatus (Fig. 1) occupied the surface of a 0.76-m high $\times$ 1.51-m wide $\times$ 0.76-m deep table. On the table were two radial lines, with possible target locations being located at 45° and 135° relative to the horizontal edge of the table where the participant stood. Each radial line had four targets made of blue paper squares (0.11 m $\times$ 0.11 m). The centers of the possible targets in each radial arm were 0.21 m apart. The centers of the targets nearest the participant in each radial arm were approximately 0.21 m away from the participant's midline and were 0.21 m away from each other along the horizontal axis. Each of the eight targets was tagged with a number that was visible to the participant.

The manipulanda were two new bathroom plungers. These were convenient manipulanda to use, because they could stand on their own. Plungers have been used in previous studies in our laboratory; see Rosenbaum, Chapman, Weigelt, Weiss and van der Wel (2012) for a review of work that happened to use these homely but convenient devices. Each plunger used here had a wooden shaft 0.51 m tall and 0.023 m in diameter, as well as a rubber base 0.15 m in diameter. The mass of each plunger was 0.135 kg. Weighting a plunger was achieved by putting a 1.13-kg metal ring atop its base.

The participant stood at the apparatus while the experimenter read the directions aloud, whereupon the experimenter

asked the participant to say, in his or her own words, what he or she would be doing. Once the experimenter was satisfied that the participant understood the task, he gave the participant six practice trials. The driving periods and target pairs used in the actual experiment did not repeat those used in the practice trials.

Once the actual experiment began, the experimenter initiated each trial by reading aloud the numbers of the targets for the constant and alternative tasks. The participant repeated these numbers before lifting his or her left or right hand from his or her side to carry out the chosen action.

The three metronome periods were tested in separate blocks of six trials each. The metronome played from the beginning of the block until the end of the last trial of the block. The order of the driving periods was random for each participant. The experiment lasted 30 min.

Each back-and-forth movement was completed four times, for a total of eight intertarget movements. The experimenter told the participant in advance that he or she would not be responsible for knowing when to stop tapping. The experimenter indicated that he would always tell the participant when to terminate the back-and-forth movements, which he did. At the end of each trial, the experimenter told the participant where to put the plunger for the next trial. The participant's performance was visually monitored but not electronically recorded. Previous research in our lab had shown that temporal precision in a reciprocal-tapping task done in time with a metronome, in which the times were recorded with switches closed by a hand-held manipulandum like those used here, were very precise; virtually all asynchronies between object placements and metronome beats were within 20 ms (van der Wel, Sternad & Rosenbaum, 2009).

The participants were Penn State undergraduates, 170.35 cm tall on average ($SD = 10.22$ cm), who collectively reported using their right hand to perform an average of 10.35 ($SD = 1.39$) out of 11 items on the Edinburgh Handedness Inventory (Oldfield, 1971). All of the participants read and signed a consent form approved by the Penn State University Institutional Review Board and took part for course credit.

Twenty participants were supposed to be tested in each of the eight groups, but due to a clerical error, five of the groups had 20 participants, two groups had 21 participants (the left-constant/far-learning/unweighted group and the left-constant/near-leaning/weighted group), and one group had 19 participants (the right constant/far-leaning/unweighted group). Of the 161 participants, 61 were male and 100 were female.

Results

Figure 2 shows that the probability, $p(\text{right hand})$, of choosing the right-hand task was higher when that task was variable than when it was constant. This result was obtained

Fig. 2 Probability (± 1 SE) of choosing the right-hand task, $p(\text{right hand})$, when the constant task was on the left (L) or right (R), when the targets for the constant task were near or far, and when the manipulanda were unweighted or weighted.

in three of the four main conditions: the near unweighted condition, the far unweighted condition, and the far weighted condition.

To evaluate these differences and assess the effects of side of constant task, constant task distance, object weight, and metronome rate on $p(\text{right hand})$, we ran a four-way, mixed-model ANOVA with Side of Constant Task (left or right), Leaning (near or far), and Object Weight (light or heavy) as between-subjects factors, and Metronome Rate as a within-subjects factor. There was a main effect of side of constant task, $F(1, 153) = 26.78$, $p < 0.001$. Participants chose the right hand more when the constant task was on the left ($M = 0.751$, $SE = 0.018$) than when the constant task was on the right ($M = 0.619$, $SE = 0.018$). There was a trend for a main effect of constant task distance, $F(1, 153) = 2.61$, $p = 0.10$, suggesting that participants tended to use the right hand more when the constant task was near ($M = 0.706$, $SE = 0.018$) than when the constant task was far ($M = 0.664$, $SE = 0.018$). There was also a two-way interaction between constant task side and constant side distance, $F(1, 153) = 18.15$, $p < 0.001$, such that $p(\text{right hand})$ was largest when the constant task was on the left and far away ($M = 0.784$, $SE = 0.025$), and smallest when the constant task was on the right and far away ($M = 0.545$, $SE = 0.026$). Post-hoc t tests showed that $p(\text{right hand})$ was significantly larger for the left-constant task than for the right-constant task in the far unweighted condition, $t(38) = 5.32$, $p < 0.001$, and in the far weighted condition, $t(38) = 4.87$, $p < 0.001$, but not in the near unweighted condition, $t(38) = 1.47$, $p = 0.149$, or the near weighted condition, $t(38) = 0.649$, $p = 0.649$. There was a trend for a main effect of object weight, $F(1, 153) = 2.86$, $p = 0.09$,

Fig. 3 Sensitivity favoring the right hand as a function of bias favoring the right hand, for the four conditions corresponding to the four panels in Fig. 2. The range of possible sensitivity values occupies the gray area.

but there were no other weight-related effects nor any main effects or interactions involving metronome rate.¹

The results concerning sensitivity and bias are shown in Fig. 3. Each data point corresponds to one of the four panels in Fig. 2. All four data points had positive bias values, suggesting that at least some bias favoring the right hand was brought to bear in all four conditions. The relative magnitudes of bias and sensitivity depended on whether the constant task was near or far. The near constant conditions showed the most bias and the least sensitivity, and the far constant conditions, by contrast, showed the least bias and the most sensitivity.

Discussion

To the best of our knowledge, previous research on handedness has not addressed the question of whether hand choice is due to response bias. We addressed this question by asking some of our participants to choose between a left-constant reciprocal tapping task and various right reciprocal tapping tasks. We asked other participants to choose between a right-constant reciprocal tapping task and various left reciprocal tapping tasks. We varied the physical properties of the tasks according to our expectations, from previous research, about which ones would selectively influence the performance capabilities of the hands.

¹ When the analysis of variance was restricted to the first 19 participants tested in each condition, to check that the unequal numbers of participants per group had not affected the results, none of the results changed in any meaningful way. All p values stayed the same in terms of statistical significance.

We found that participants chose the right-hand task more when it was variable than when it was constant (Fig. 2), that hand selection depended to some extent on bias, but also on sensitivity to relations between the performance abilities of the two hands (Fig. 3), and that the relative contributions of bias and sensitivity depended on the conditions in which the choices were made (Fig. 3). Regarding the last point, we found that our participants relied much on bias and little on sensitivity when the constant task was near, but they relied roughly equally on bias and sensitivity when the constant task was far.

The fact that the distance of the constant task had the marked effect that it did accords with previous research showing that the difference between the cost of reaching far versus near is greater for the left than for the right hand (Rosenbaum et al., 2011). The fact that loading the manipulanda had the effect it did (albeit marginally) accords with previous research showing that the dominant (right) hand better controls force-related coordination than does the nondominant (left) hand (Sainburg, 2002). Finally, the fact that the metronome rate had no effect shows only that this variable was not picked up by the present procedures. The greater efficiency of the right hand than of the left in aiming for targets under time pressure is small (Vaughan et al., 2012), so perhaps the failure here to pick up a rate effect is unsurprising.²

How does the present study bear on previous accounts of handedness and the understanding of bias versus sensitivity? Regarding handedness, our study indicated that neither a purely bias-based account nor a purely sensitivity-based account is likely to provide a complete picture of handedness in all circumstances. Bias appears to be a good candidate for explaining hand choices when the factors affecting it include attention (Gabbard & Rabb, 2000; Verfaellie & Heilman, 1990) and reinforcement contingencies (Stoloff, Taylor, Xiu, Ridderikhoff & Ivry, 2011). The method introduced here may help quantify the extents to which bias and sensitivity affect hand choice, both when bias seems to play a role and when its role is less clear. For example, one might ask whether and how bias and sensitivity underlie the right-hand preference for more complex tasks (Hill & Khanem, 2004; Leconte & Fagard, 2004). Likewise, one could apply the method to study what has been called *hemispheric bias*

for the hand ipsilateral to the target and *proximity bias* for the nearer hand (Helbig & Gabbard, 2004).

A final comment concerns the understanding of bias versus sensitivity in the study of motor control. The present study showed that both components play roles and that the relative role of bias was less when the constant task was far than when it was near. Sensitivity, in other words, became more important when participants had to lean forward a lot for the constant task, and as a result, the alternative task also required much forward leaning in some conditions. This finding makes sense, considering that bias alone can be an acceptable basis for choice when the task alternatives are both relatively easy. When neither task is easy, or only one is, it becomes more important to be sensitive to actual performance differences. By analogy to a doting parent who is biased to say that his or her own child is better than some other child at some task, when the task becomes very difficult and the other child is clearly better suited for it, bias may need to give way to sensitivity.

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² One might argue that the effects of leaning and load observed here could be attributed to greater strength in the dominant (right) hand than in the nondominant (left) hand. The dominant (right) hand is indeed about 10 % stronger than the nondominant (left) hand (Peterson, Petrick, Connor & Conklin, 1989). We cannot rule out this possibility. However, if a right-hand strength advantage accounted for the sensitivity that we observed, we would have expected more sensitivity favoring the right hand with heavier objects, not less sensitivity, as we found in the near conditions. We would have also expected to see differences in sensitivity between the unweighted and weighted far constant conditions, but we did not.

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