On the Left Hand of Time

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The present experiment examined the effects of sex and handedness on the perception of brief intervals up to 20 s in duration. In order to obtain participants with sufficiently high scores on a scale of handedness, we screened 1,276 people; the process yielded 16 men and 16 women eligible for testing. In an empty production procedure, each person estimated 4 intervals of 1, 3, 7, and 20 s, respectively, using both their preferred and nonpreferred hands to provide recorded responses. The order of presentation was randomized across participants but yoked across the sexes in each of the respective handedness subgroups. Results indicated significant effects for handedness in conjunction with the hand used to make the respective response. The pattern of these interactive effects differed between male and female participants, however. These results are discussed in terms of a hemispheric account of interval timing control and potential sex difference in hemispheric specialization.

Time is the punishment for consciousness. Therefore, the understanding of the nature of time should lie at the very heart of all science. This is especially true for a science of psychology because nontemporal behavior simply does not exist (Block, 1990). Yet the experimental study of the perception of time, despite its extended history (e.g., Guyau, 1890; James, 1890), continues to be largely peripheral to the mainstream of the psychological sciences. Although there has been a gratifying increase in interest in the study of time in many facets of the neurosciences (Buhusi & Meck, 2005; Wittmann & van Wassenhove, 2009), psychology in general continues to treat the perception of time as a largely peripheral concern (but see Grondin, 2008). There are a number of reasons why this situation persists. Unlike other forms of sensory psychophysics, the perception of time deals with an evidently intangible dimension. Thus, the very foundation of what is conceived as being perceived is itself unclear. This issue is a subset of a larger concern over the fundamental nature of time itself (Fraser, 1987).

For the empirical researcher, an almost equally problematic concern is the extensive level of individual variability that accompanies people's estimates of even the simplest discrete interval of time (Doob, 1971; Rammsayer, 1997). For those wanting to understand general principles of human behavior, this large variation has proven to be a stiff barrier to overcome.

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This is especially true with respect to efforts to integrate time perception with the more established facets of behavior such as memory and attention (Block, 1990; Block, Hancock, & Zakay, 2010). A step toward the fruitful resolution of this impasse is to seek an understanding of, and explanation for, these sources of individual variability. It is encouraging to see that such efforts have begun to burgeon in the past decade (see Hancock, 2010; Pos, 2006; Rammsayer, 2002; Zimbardo & Boyd, 1999, 2008).

Useful steps in this direction are represented by a number of recently reported meta-analyses (Block, Hancock, & Zakay, 2000; Block, Zakay, & Hancock, 1998, 1999), which have distilled numerous overall patterns from the quantitative results in the extent literature. In general, these syntheses have shown that age, sex, and maturational state all exert consistent effects on how a person perceives short intervals of time up to approximately 1 min in duration. Such meta-analytic findings establish the descriptive state of present understanding and provide outcome patterns against which to compare current causal theories. However, although they identify empirical lacunae, meta-analyses do not, in themselves, generate theories. Rather, viable hypotheses and subsequent theoretical advances often derive from unusual or contradictory empirical observations.

The genesis of the present effort was founded in just such a circumstance. In recent work, Hancock and Rausch (2010) examined the perception of brief intervals of time by 50 men and 50 women ranging in age from 20 to 70 years. The primary goal of this investigation was to explore the influence of sex and age on duration perception. However, in post-performance questionnaires, a record was taken of the handedness of the people involved. It should be noted that there was no a priori screening of participants with respect to handedness in this original experimental procedure. However, it proved to be the case that there were 92 right-handers and 8 left-handers in the eventual sample. This percentage representation is reasonable for a quasirandom convenience sample because it is close to the estimated frequency of right- and left-handedness in the general population (Coren, 1992). Comparison of the data derived from these respective handedness groups showed extensive differences in response patterns. Thus, the ratio of the duration estimates for left- to right-handers at 1 s was 1:0.73, at 3 s this ratio was 1:0.69, at 7 s the ratio was 1:0.68, and finally at 20 s the ratio of left- to right-handers was 1:0.82. Such a strong differentiation gave encouragement that handedness per se might exert a significant effect on the perception of brief intervals.

This observation concerning handedness and time perception was not original in that Efron (1963a, 1963b) had previously postulated such a possible influence. Also, handedness itself is known to play an intriguing role in a variety of human response capacities (Coren & Halpern, 1991; Halpern & Coren, 1988, 1991). If handedness also plays a significant role in timing and time perception, this may implicate differences between the hemispheres of the brain as an important explanatory characteristic of the timing of many forms of individual behavior (see Bruyer, 1986; Carmon & Nachson, 1971; Cohen & Haran, 1974; Efron, 1990; Polzella, DaPolito, & Hinsman, 1977; Riss, 1984; Witelson, 1976, 1985). Indeed, a hemispheric argument could be made to account for the previously established sex difference in the perception of brief intervals up to approximately 1 min (Block et al., 2000; Hancock & Rausch, 2010; Rammsayer & Lustnauer, 1989). Therefore, the purpose of the present experiment was to investigate whether there exists a consistent effect for handedness in time perception and whether any such effects are contingent on the sex of the person producing them.

EXPERIMENT

METHOD

Participants

To begin the process of participant selection, the Edinburgh Handedness Inventory was used as a screening device to initially determine degree of each participant's handedness (Oldfield, 1971). This test evaluates responses on a 10-item questionnaire (Williams, 1991) in which strong or exclusive use of one hand scores two points (positive for right-hand responses, negative for left-hand responses), and weaker use of either hand receives one point. The scale thus varies from +20 to –20. For the purposes of the present study, people scoring from +18 to +20 on the test were considered strong right-handers, and people scoring from –18 to –20 were considered strong left-handers. To derive a sufficiently large size sample, a total of 1,276 people completed this screening test. Of these, 935 were female and 341 were male, and only 19 women and 17 men scored at a sufficiently high level to qualify to participate in the subsequent experimentation. Of these 36 eligible people, 32 participants, 16 men and 16 women, agreed to proceed to testing on the time estimation task. These 32 volunteers were all students at a major southern university in the United States. All professed to be in good health at the time of testing. In age they ranged from 18 to 24 years, with a mean age of 20.13 years. Each of two groups, 16 men and 16 women, consisted of eight right-handers and eight left-handers. With respect to the degree of handedness, all four groups (female and male right-handers and female and male left-handers) had the same mean absolute handedness score of 18.625, which rendered a uniform laterality quotient of +86.25 for the right-handers and –86.25 for the left-handers, where laterality is calculated from the appropriate equation (see Williams, 1991). In the present experiment, one female researcher collected all the experimental data. For this task the potential interaction between the sex of the participant and the sex of the experimenter (Rumenik, Capasso, & Hendrick, 1977) was considered negligible in light of previous null findings for a test of this specific interaction (see Hancock & Rausch, 2010).

Procedure

Participants first signed the informed consent form and were assured that all procedures followed the appropriate American Psychological Association strictures on human subjects testing. To record the time estimates, the experimenter asked each participant to be seated at a table on which was a response apparatus that transmitted the participant's estimates to a recording system. The response apparatus had two buttons, one of which started the timing mechanism and one that provided the stop signal. Participants were asked to remove their watches and any other timekeepers in their possession. The experimenter returned these items to the participants at the end of the procedure. Ten practice trials, without feedback, were given that asked participants to estimate a 10-s period. Upon completion of this practice element, participants were considered ready and eligible to proceed to the experimental phase.

The time estimation method used in the present experiment was the production procedure of an empty interval (Bindra & Waksberg, 1956; Clausen, 1950; Guay & Salmoni, 1988). Empty intervals are considered to be those in which no concurrent activity is taking place, so explicit processing of information or stimulation is not required of the participant (Hicks, Miller, & Kinsbourne, 1976). After completing the initial practice, participants were asked to estimate four specific time intervals of 1 s, 3 s, 7 s, and 20 s in duration, respectively. These four target intervals represent a natural logarithmic progression that brackets temporal thresholds that have been proposed to be of theoretical importance, namely the boundary of brief intervals at 10 s (Allan, 1979), the range of the immediate present at 3 s (Poppel, 1988), and the duration of conscious intention at 6 s (Iberall, 1992, 1995). Each person produced 40 trials at each selected interval. These 40 total trials were divided in half, with 20 trials conducted with the participant's preferred hand and the other 20 trials conduced using the participant's nonpreferred hand.

The order of presentation of the different time intervals was randomized, except that orders were matched across sex such that one man and one woman were yoked with respect to a particular presentation order, as were one left- and one right-handed participant. Participants were told to change to the next interval, whose duration was specified by the experimenter, only on completion of each block of 40 trials. Participants were also asked to pause briefly during the change from one interval to the next. After each trial, the experimenter recorded the time estimation to the nearest millisecond. Participants were not given any form of feedback about their performance. The opportunity to take a break was offered to each participant after completion of each of the blocks of trials, but this opportunity was taken only rarely. The overall experiment took approximately 45 min to complete for each participant.

RESULTS

Data from the experiment were analyzed using a mixed procedure in which there were two between-participant factors (i.e., sex and handedness) and three within-participant factors (i.e., the response hand used, target duration, and trial). The first primary dependent performance measure used in the present analysis was the recorded times themselves. Subsequently, a number of derived performance measures were also calculated. These included the duration judgment ratio (DJR, the actual recorded estimate divided by the target interval); the constant error (CE), which represented the deviation of each score from the respective target interval; the absolute constant error (ACE), which is the absolute value of the previously defined CE scores; the variable error (VE), which is the standard deviation of responses; and the coefficient of variation (COV). The latter two measures did not include a trial factor because they are derived from summations across trials. Overall, these measures provide a portrait of participant response in terms of central tendency and dispersion with respect to the target duration.

Recorded Times

Analysis of the recorded times revealed a number of significant effects. First, and unsurprisingly, there was a clear, main effect for duration. This result confirmed the primary manipulation that participants were able to distinguish the differing intervals requested. It would be surprising only if this duration length manipulation had not shown significant effects. Of somewhat greater interest and informational value was the significant main effect for trial, $F(19, 532) = 2.103$, $p < .005$. As in a number of prior experimental procedures concerning the estimation of brief temporal intervals, the participants in the present experiment exhibited the classic lengthening effect (see Vroon, 1972). That is, as the trials proceeded there was a significant trend for an increase in the length of the estimate made. As is also typical of many previous findings, this effect resembles an inverted learning curve wherein the primary change occurs within the first few trials, a change that is sequentially attenuated as the trial number increases. This general effect, parsed by sex and handedness, is illustrated in Figure 1.

Superseding these main effects were a number of higher-level interactions. Specifically, there was a significant trial × sex × handedness effect, $F(19, 532) = 2.74$, $p < .05$. As a general pattern, both left- and right-handed women showed the same lengthening pattern as was evident in the initial main effect, although these respective groups showed the effect at different absolute time values. This lengthening was also evident in the responses of right-handed men. However, the divergent group in the present case was the left-handed men. Although they show an initial lengthening in the first few trials, they subsequently reduced their estimates, especially in the latter half of the 20 total trials. This comparative pattern is illustrated in Figure 1. This effect is evidently different across the four durations explored, as confirmed by a significant trial × sex × hand × duration interaction,

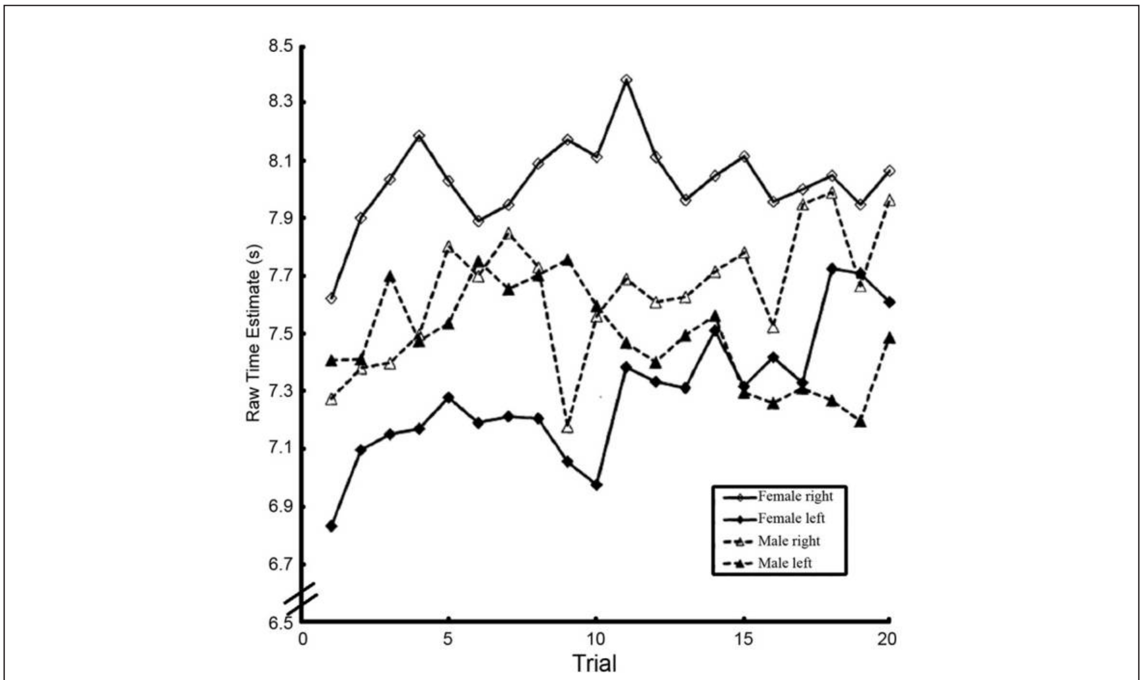

FIGURE 1. Recorded time estimates for the left- and right-handed men and women show differential lengthening patterns across trials

$F(57, 1596) = 3.525$, $p < .01$. In general, this latter effect is simply a logical extension of the initial lengthening effect itself because the three-way interaction becomes sequentially more evident as the length of the requested duration increases from 1 to 20 s. Thus, the three-way effect appears more and more evident as the target duration increases.

Of even greater interest was the significant interaction between sex, handedness, and the hand used to produce the respective responses, $F(1, 28) = 9.508$, $p = .005$. This interaction is illustrated in Figure 2. Here, when left-handed women switch to their nonpreferred right hand they increase the length of the estimated interval. With this pattern they behave similarly to right-handed men, who also increase their estimate when they switch to their nonpreferred left hand. In contrast, right-handed women switching to their nonpreferred left hand reduce the length of their estimate. In this pattern they follow left-handed men, who when they switch to their right hand also reduce the length of their estimate. As with the previous three-way interaction, this interactive pattern was also significantly influenced by the length of the interval estimated, $F(3, 84) = 10.594$, $p < .01$. In general, this four-way interaction of sex × hand used × handedness × duration replicated the earlier cited effect for target duration. That is, the three-way interactive effect became sequentially clearer as the target duration of the estimate itself increased.

Duration Judgment Ratio

As with much prior experimentation (see Hancock & Rausch, 2010), one way in which the aforementioned absolute effects of duration can be addressed is by expressing outcome results in the form of a DJR. This measure divides the outcome responses by the target duration and thus theoretically should express any noted effects per unit of estimated time. It is very important to note that this ratio scaling process assumes that intrinsic effects are embedded in each unit of time (i.e., per second of the estimate) and that there are therefore no important thresholds between es-

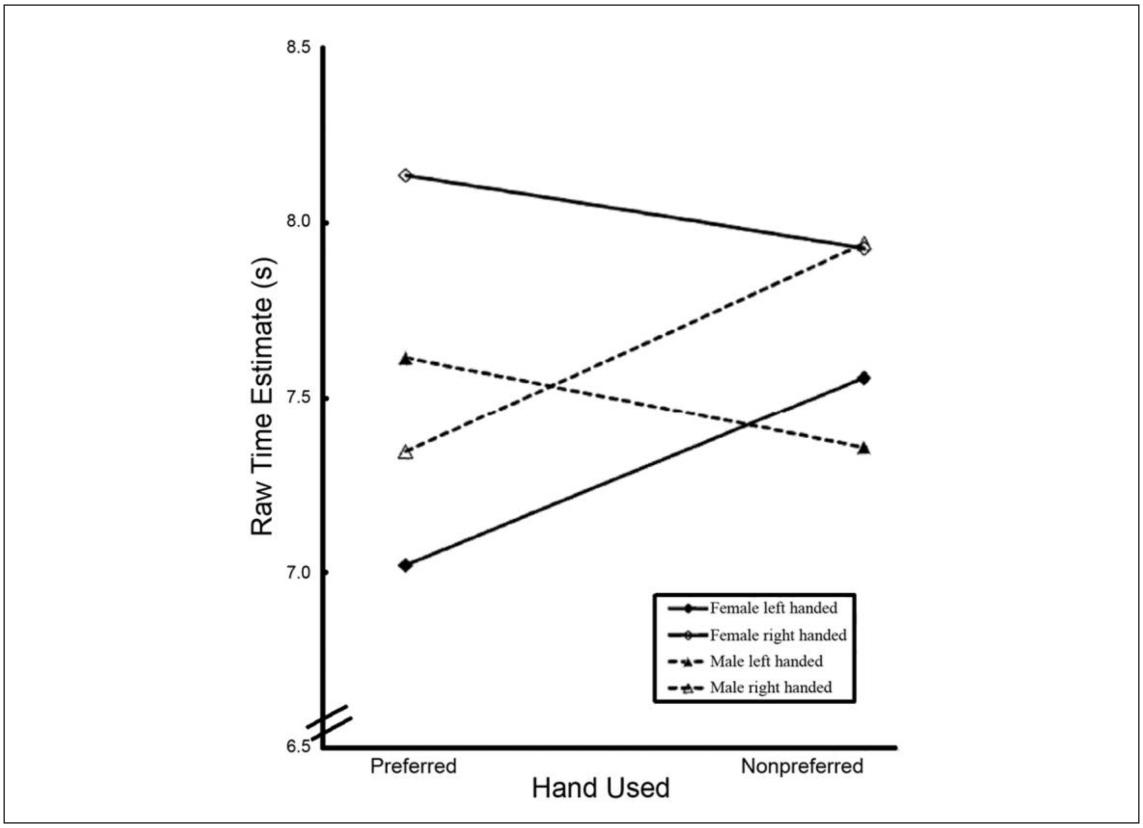

FIGURE 2. Interaction of time estimates with preferred hand (left side) and nonpreferred hand (right side) for male and female left-handers and right-handers

timates that range from 1 to 20 s. This proposition is itself subject to much debate (see Allan, 1979). However, as a consequence of the division process, analysis of the DJR should, again at least theoretically, provide little in the way of difference across the differing durations because the actual absolute estimate is divided by the respective target intervals to give an error rate per second measure. Thus, if any timing process were simply proportional to each unit of time (i.e., per second of the estimate), then no main effect for duration would be present.

However, this is not the case with the present results, where we do see a significant main effect for duration in DJR, $F(3, 84) = 9.59$, $p < .001$. The respective DJRs for the four intervals were 1 s, 1.051; 3 s, 0.849; 7 s, 0.926; and 20 s, 1.019. For the three highest durations, we see a sequential increase in DJR. However, the exceptional result is the DJR value for the 1-s interval. It may be that this unexpectedly high DJR results primarily from the fact that a large percentage of this interval is occupied by the obligatory motor response time (i.e., the minimum reaction time and the minimum movement time) to produce the 1-s estimate itself by pressing one button and then sequentially pressing another. This argues, as others have previously done (e.g., Block et al., 2010), that intervals below 3 s are actually disproportionately affected or masked by these motor response elements. In addition to a main effect for duration in DJR, there was also a main effect for the hand used. Here, the DJR value for the preferred hand (0.948) was significantly different from the DJR value for the nonpreferred hand (0.974), $F(1, 28) = 5.166$, $p < .05$. For DJR there was also one significant higher-level interaction. This involved a duration × hand × sex × hand used effect, $F(3, 84) = 6.472$, $p < .003$. This pattern replicated that found in the recorded times themselves.

Constant Error

A primary reflection of central tendency is the CE value, which is defined as the difference between the estimated duration and the target duration. Analysis of CE scores showed that there was a significant four-way interaction between the duration of the estimate, the hand used, the preferred hand, and the sex of the participant, $F(1, 28) = 10.594$, $p < .001$. Again, this followed the pattern as reported in the recorded times themselves. There was also a comparable three-way interaction in CE between the hand used, the preferred hand, and the sex of the participant, $F(3, 84) = 9.508$, $p < .006$. This latter pattern shows that left-handed women using their preferred left hand underestimate (i.e., have the greatest negative CE) the most of any combination of handedness, hand used, and sex. However, right-handed women using their preferred right hand overestimate to the greatest degree (i.e., this group has the largest positive CE). This pattern follows the results for this interaction in the overall recorded times, as shown in Figure 2. Given the relationship of the CE scores to the original recorded times, this replication is expected. The subsequent interaction with duration, as indicated by the aforementioned four-way interaction, again derives from the absolute differences occasioned by the length of the durations themselves.

Absolute Constant Error

A further reflection of performance error can be derived from these CEs by simply taking their absolute values. That is, the error from the target value is summed whether the participant underestimates or overestimates. For these ACEs there were two significant effects. The first was a simple main effect for duration, $F(3, 84) = 36.292$, $p < .001$. Unsurprisingly, the level of absolute constant error grew with the length of target duration. These results very much followed the reported pattern for CE. The second significant effect was a four-way interaction between duration, the hand used, the hand preference, and the trial, $F(57, 1596) = 2.315$, $p < .05$. This general pattern again follows that previously established in other measures of central tendency.

Variable Error

Whereas the aforementioned reflections of performance largely emphasize reflections of the mean, the first distributional moment, VE is a reflection of the second moment and is calculated as the standard deviation of any particular grouping of independent variables. With respect to the VE results, there was a strong and expected significant main effect for the interval duration, $F(3, 84) = 98.628$, $p < .001$. This result simply confirms that as the size of the requested duration grew from 1 to 20 s, the variability of the associated estimates also grew with it. The four VE values were 0.132 s for the 1-s target interval, 0.299

s for the 3-s target interval, 0.594 s for the 7-s target interval, and 1.837 s for the 20-s target interval, respectively. There were no other main effects or interactive effects for VE, which suggests that the significant influences involved in the present findings are predominantly those of central tendency.

Coefficient of Variation

Because it has been established that the variability of response grows with the target duration, it is important to ascertain whether such variability grows in direction proportion to the size of the target interval. This can be assessed through analysis of the COV, which is derived from the standard deviation of response divided by the associated mean. Analysis was conducted on these COV scores, which produced an expected but nevertheless interestingly significant effect for duration, $F(3, 84) = 19.96$, $p < .001$. Not unexpectedly, the COV decreased sequentially with the length of the target interval. However, subsequent analyses of these scores showed that the value derived from the 1-s interval (0.126) did not differ from that derived from the 3-s interval (0.117). However, each of these latter values differed significantly from both the value for the 7-s interval (0.089) and the 20-s interval (0.087). These two latter scores did not differ significantly from one another. This result might indicate some discontinuity in the processes used to estimate the intervals below 3 s as compared to those above 7 s. This proposition is considered in more detail in the *Discussion*. One other significant effect derived from analysis of the COV scores, and this involved the interaction between duration and hand, $F(3, 84) = 3.149$, $p < .05$. Subsequent tests of simple effects showed that whereas the pattern for the left-handed participants followed the pattern shown in the main effect for duration, the pattern for right-handed participants varied in one particular respect. In this case, the COV value for the 1-s estimate for right-handed participant proved significantly greater than that for all three other duration intervals, and some potential reasons for such an interaction are discussed in the next section.

DISCUSSION

With respect to the initial goal of this work to identify some of the sources of individual variation in the estimation of brief temporal intervals, the present experiment provides some degree of illumination. The patterns of results with respect to sex and handedness are especially informative. Right-handed women consistently produce the longest estimates, both on average and across each condition from the first to the last trial (see Figure 1). If we consider first the pattern for the use of the preferred hand only, we find that right-handed female respondents consistently produce longer estimates than their left-handed peers. In stark contrast, this pattern is directly reversed in male participants: Using their preferred hand, the right-handed men produce lower estimates than their left-handed peers. Although the variation across individuals still permeates these general effects, the outcome is suggestive in terms of possible explanations based on sex-related hemispheric differentiation (Contreras, Mayagoitia, & Mexicano, 1985). Such outcomes provide further support for the contention of positive sex differences in time estimation (see Block et al., 2000; Hancock & Rausch, 2010), but in the present case of highly screened participants, the effect is moderated by their high degree of handedness. As with previous findings, the sex difference here is consistent but not especially powerful and accounts for only a limited amount of the variance due to overall individual differences.

To explicate further these individual differences, we clearly have to explore beyond the sex of the participant alone. In the present work, this exploration was extended to the handedness of that participant. Based on the serendipitous observation derived from the results of Hancock and Rausch (2010) it was hypothesized that handedness would indeed play a significant role in duration estimation (see Efron, 1963a, 1963b; Hecaen, Agostini, & Monzon-Montes, 1981). The first observation to be emphasized here is that there were no main effects observed solely for the handedness of the participant alone. Thus, handedness per se played only an interactive role, and this was usually associated with the sex of the participant. Also, such effects were seen in conjunction with the hand used to produce responses, whether this was the preferred or nonpreferred one. The primary example of this pattern is illustrated in Figure 2. This shows the respective mean recorded times for male and female right- and left-handers using their preferred and nonpreferred hands, respectively. Intriguingly, we found that left-handed women behave in a manner that is very similar to that of right-handed men when they are asked to switch to their nonpreferred hand. Conversely, in their pattern of response, right-handed women follow the pattern for left-handed men. In addition to this overall pattern, the absolute difference of the level of change between preferred and nonpreferred hand in these respective groups is also very similar (see Figure 2).

This pattern of results in the mean response times shown in Figure 2 also exhibits other interesting features. When these radically handed participants generate their estimates using their preferred hand, we see a strongly differentiated response for the female group. In contrast, when using their preferred hand, there is little difference between the left- and right-handed men. However, when these respective groups switch to their nonpreferred hand, a very different outcome pattern emerges. Specifically, we see a coalescence in response that appears to be based primarily on the hand and not on the sex of the participant. Thus, right-handers, both male and female, when using their nonpreferred left hand produce almost exactly the same level of mean overall estimate. The exact same convergence is true for the left-handed participants, both male and female, who, when using their nonpreferred right hand, also produce estimates of a very similar duration but at an absolute level below that of the right-handers (Figure 2).

These patterns of convergence suggest that there are differential emphases on central and motor outflow components of processing emphasized when the person is constrained to respond using the hand that they very rarely use in everyday life. We must again remember that these respective groups are very high on the handedness scale. However, it is these patterns of results that can inform our theorizing about the potential hemispheric control of timing capacities. Before proceeding to such considerations, it should again be noted that the patterns reported here are derived from a highly selected sample from the overall range of handedness in the general population (i.e., approximately 2.5% of the people first screened). This observation gives rise to concern about how much an understanding of handedness effects actually helps us to explain the overall variability in time estimation in the other 97%+ of the population at large.

Also, before we proceed to a consideration of possible explanatory mechanisms underlying the present outcome pattern, it is important to examine the assumption that was stated about the use of the DJR measure. As noted earlier, use of the DJR itself actually represents an implicit theoretical assumption. This assumption concerns the homogeneity of time in human perception. Thus, when we divide estimates by the actual target duration, the calculation embodies a specific assumption that all durations are composed of homogenous time units. More explicitly, it assumes that the mechanisms that underlie the estimation of 20 s are essentially the same mechanisms that underlie the estimate of 1 s but just multiplied 20 times. Typically, this mechanism has been conceived of as some form of clock (see Treisman, 1984) but one that can vary in its intrinsic frequency. Some aspects of the present results can address this assumption. For example, the coefficient of variation showed a significant discontinuity between the 3-s and 7-s intervals. This discontinuity might imply that there is indeed some threshold above 3 s but below 7 s that parses the activity of two separate timing processes (see Iberall, 1992). Differentiation of such processes would implicate at least two potentially distinct mechanisms in the generation of estimates at these different durations. A number of relevant commentaries (e.g., Allan, 1979; Poppel, 1988) have suggested this notion of separate mechanisms for the estimation of intervals of differing duration (see Grondin, 2001). The notion of temporal horizons also raises the issue of time estimates via learned motor productions such as button presses, as used in the present experiment. The production technique, like the reproduction technique also used in time perception research (Bindra & Waksberg, 1956), often uses motor outputs to provide the starting or stopping response. In this they are unlike verbal estimation, which requires the person to attach a temporal–semantic label to a presented interval. The problem here derives from the percentage of the estimated duration, which is obligatorily taken up by the motor element. When estimating an interval of 20 s, the two motor responses of perhaps 500 ms in total represent only a very small fraction of the total time. However, when those same obligatory starting and stopping movements are included in an estimate of 1 s, they take up 50% of the estimated interval. At this juncture it is difficult to ascertain whether one is testing temporal perception of temporal motor accuracy. It is for this reason, despite the present findings, that care must be exercised in the selection of the assessment method when looking to examine time perception at short durations (see Block et al., 2010).

Any explanatory account of the present pattern of findings has to be founded on certain established effects. The primary established effect in the present work is the consistent difference between the sexes (see Hancock, 2011). Traditionally, in the area of sex differences in cognition, such capacity variations have often been explained by reference to differential hemispheric specialization (see Baker, 1987; Kimura, 1999; Maccoby & Jacklin, 1974; Witelson, 1976). The degree to which hemispheric effects in general exert an impact on human behavior has also been the subject of ongoing contention (see Efron, 1990). However, there is evidence that timing capacities are differentially enabled in the respective hemispheres (Vroon, Timmers, & Templaars, 1977). Furthermore, the link between individual characteristics and cortical networks underlying time perception remains a fruitful avenue of evaluation, and this area is the subject of growing clarification (Harrington, Haaland, & Knight, 1998; Rammsayer, 1997; Rao, Mayer, & Harrington, 2001; Witelson, 1989). Many accounts can be derived of differences in temporal processing caused by differences in hemispheric function (Brown & Nicholls, 1997; Bruyer, 1986; Contreras et al., 1985; Sobotke & Budohoska, 1988; Szymanski, Czachowska-Sieszycka, & Sobotka, 1982). Indeed, it is possible to generate an account of the aforementioned sex differences founded almost completely on hemispheric asymmetry alone (Genetta-Wadley & Swirsky-Sacchetti, 1990). However, such various interpretations still need clarification (Mo & Chavez, 1986; Molfese, 1980; Molfese, Buhrke, & Wang, 1985; Vroon et al., 1977) especially in light of the important neurophysiological evidence that is rapidly emerging (Coull, Vidal, Nazarian, & Macar, 2004; Eagleman et al., 2005; Gibbon & Malapani, 2002), and most especially because the number of free variables in the potential explanation can account for almost any outcome pattern in the data.

However, here we can seek to use this understanding to explain the observed differences, especially in the multiple-way interactions between sex, handedness, and the hand used to produce responses (see Harshman, Hampson, & Berenbaum, 1983). Initially, given the screening of participants for a high degree of handedness, we might assume that these people represent a high level of a priori hemispheric specialization. Furthermore, we might suggest that resident sex differences are expressed to some degree in the response scores between right and left-handed men and women when using their preferred hand. This being so, it suggests that the right-handed men are most closely allied with left-handed women and vice versa. The interactive pattern shown in Figure 2 can now be explained by a notion of spreading activation. If the timing function is initiated in the left hemisphere and then spreads to the contralateral hemisphere for response to occur, we get the pattern illustrated in Figure 2. Such hemispheric differentiation and cross-hemisphere activation imply the convergence of estimates by right-handers when forced to use their left hand, and this convergence is replicated when left-handers are forced to use their right hand. The absolute difference in the left- and right-handed groups when using their nonpreferred hand is a function of the need to cross the respective hemispheres to initiate response.

The overall pattern suggests that the women are more highly lateralized in their timing responses than the comparatively selected men, although they both express the same score on the handedness inventory (Bryden, 1989; McGlone, 1980; Webster, Scott, Nunn, McNeer, & Varnell, 1984). Although this might imply a need to provide additional temporal measures in batteries of handedness assessment itself, this observation provides the starting point for any hemispheric-based account of the current pattern of findings (Potter & Graves, 1988; Ray, Morell, Frediani, & Tucker, 1976). The time taken for the estimate to be generated in the left hemisphere for the right-handed women and subsequently transmitted through the left response hand actually is lower than that of their normal use of the preferred hand, although this difference is itself very small. However, the absolute time estimates themselves are each above the required target times and are therefore overestimates. Because they express less lateralization in their original estimates with their preferred hand, the right-handed men are thus slowed when they cross to the nonpreferred left hand. Now, when they use their nonpreferred hand, the original sex difference disappears. The mirror of this pattern is seen for left-handed men and left-handed women. The difference between these two overall patterns appears to be one of degree and is apparently related to the individual processing capacities of the hemispheres themselves regardless of sex, handedness, or even hand used for response (Kimura & Archibald, 1974; but see Witelson, 1985). The next step in a fuller, hemisphere-based differentiated explanation of these effects depends on more detailed neurophysiological exploration of the specific time course of events (see Sobotke & Budohoska, 1988; Treisman, 1984). This could be achieved through neuroimaging techniques that are sufficiently temporally discriminative to elucidate the specific time course of response, contingent on both central processing and motor outflow elements of response.

The final duty of discussion of the present results is to consider the logical antithesis to the original motivation for the search for the source of individual differences in time estimation itself. The whole search arises because of the reification of the physical metric of time. That is, the clock time derived by the deterministic changes in the spatial position of the reference timekeeper is here considered the reality (the physics of the psychophysics), and the deviation exhibited by each participant from this referent value is called the perceptual error (the *psycho* of the *psychophysics*). This issue permeates the whole of psychophysics, in which the physics element is considered the reality and the psychological response is either the matching veridical percept or the error-reflected, mistaken perception of this reality. Questioning this assumption begins to involve us in important philosophical disputes about the degree to which reality is an external construct and our perception of it only a limited subset. Such issues have sat at the foundation of philosophical and scientific inquiry since the time of Plato and before. Here, it is sufficient to ask whether time itself is a unitary dimension or whether it might have multiple aspects. The upshot for the present investigation is that the basic assumptions, which underlie a search for sources of individual variation in time perception, may themselves be flawed in their very essence. It is not the purpose here to endeavor to solve such issues but rather to raise them as the effort progresses in order to ascertain the ongoing value of such efforts to identify individual variation. Larger concerns about such pertinent issues have been expressed in psychology itself for many decades (Cronbach, 1957).

Summary

The present work has sought to distinguish some of the individual characteristics that affect the perception of brief intervals of time. When samples were matched for their degree of handedness and when differences in the hand used for response were evaluated, it became clear that handedness plays a role in time estimation. However, this effect occurs in conjunction with the sex of the individual. The individual-specific differences that affect the perception of both brief and more prolonged intervals of time have yet to be determined (but see Hancock, 2010). However, the data reported in the present work elucidate one small piece of this ongoing puzzle.

NOTES

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