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A New Law for Time Perception

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Effects of sex and handedness on the perception of temporal durations from 1 to 20 s were studied. A total of 80 male and 40 female participants were divided equally into left-handed and right-handed subgroups. Using an empty interval production procedure, each person estimated durations of 1, 3, 7, and 20 s, respectively, 50 times each. The order of presentation was randomized across participants but yoked across the sexes in each of the respective handedness subgroups. Results showed significant sex differences but no effects for handedness. One important facet of this sex effect was expressed in a consistent intercept difference in the identified relationship that linked the log-linear size of the absolute error of estimation against the logarithmic magnitude of the target duration at which such error was recorded. This new finding provides a new descriptive, empirical relationship for time perception of brief temporal intervals. The potential methodological, evolutionary, and cognitive reasons for this lawful relationship are discussed.

KEYWORDS: time perception, sex differences, handedness

In an influential text, now published almost half a century ago, eminent time perception researcher Paul Fraisse (1957/1963) suspended his judgment on the question as to whether there were consistent sex differences in time perception. He claimed that the then-current state of understanding was insufficient to determine whether such effects were real or illusory (see Hancock, 2011a, for a review of that and more recent evidence). More than two decades after his initial expression of opinion, Fraisse clearly had not revised his view because in his later and perhaps most influential work, he passed over this whole area of research in silence (Fraisse, 1984). Of course, we must first postulate an a priori reason why any such sex differences might exist in the first place. Many maturational, physiological, and cognitive accounts have been offered for the well-documented differences that have been observed for sex in spatial processing ability (e.g., Geary & DeSoto, 2001; Glickson & Hadad, 2012). We therefore anticipate that a similar contrast should be evident in male versus female temporal capacities. Noting Fraisse's suspension of determination on the matter, Block, Hancock, and Zakay (2000) conducted a formal meta-analysis to clarify such sex-related temporal effects. This analysis demonstrated that there are indeed important and consistent differences. Hancock (2011a) elaborated on the various methodological issues, limitations, and

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flaws of the spectrum of previous investigations and showed that the previous inconsistencies in conclusions actually derived from common misunderstandings about the procedural differences in the methods to elicit duration perception. So, while remaining a matter of some contention, sex differences in the perception of time are both consistent and important (see Koglbauer, 2015; Strang, Rust, & Garrison, 1973).

Indeed, the ability to estimate duration can prove to be vital in many everyday tasks (Hancock & Manser, 1997). For example, in driving sex differences are expressed in differential traffic collision rates (Evans, 1991). Although not all such sex differences in collision frequency and pattern can be attributed to either spatial or temporal processing variations, it is important to understand which can in order to address and eliminate the death and injury that accrue. Yet such differences potentially affect response capacity in almost all everyday realms, and it is important to understand both the practical and theoretical ramifications of the overall pattern of difference observed (Hancock, 2011a).

Numerous contextual influences have been postulated to mediate or moderate sex differences in time perception. These include various environmental characteristics, such as the ambient lighting conditions (Aschoff & Daan, 1997; Delay & Richardson, 1981; Geer, Platt, & Singer, 1964; Hancock, Arthur, Chrysler, & Lee, 1994; Meredith & Wilsoncroft, 1989) and the type and level of stress the person experiences (Greenburg & Kurz, 1968). Also, the time of day at which the test itself is administered seems to modulate the degree of difference observed (Hancock, Vercruyssen, & Rodenburg, 1992). Interactive influences also derive from the specific characteristics of the individual being tested. These include ego strength (Getsinger, 1974), obesity level (Nail, Levy, Russin, & Crandall, 1981; Rodin, 1975), age (Block, Zakay, & Hancock, 1998; Newman, 1982) as well as others such as personality adjustment and cognitive style (Davidson & House, 1978). Finally, the size, presence, and direction of sex effects are especially contingent on the method selected. Such choices include the sensory modality through which the estimate is requested (Roeckelein, 1972), the absolute duration of the estimate itself (Hancock & Manser, 1997), and most crucially the time estimation procedure (e.g., production vs. verbal estimation) chosen to elicit duration estimates (Hornstein & Rotter, 1969). In general, however, consistent main effects have now been identified, and this overall pattern is now understood to a reasonable degree (Hancock, 2011a). Therefore, it is of interest to know that even though a wide range of interactive effects have been examined, there have been few if any studies where the effects of both sex and handedness on duration perception have been evaluated (but see Hancock, 2010b). This is an especially curious omission because hemispheric differentiation has often been identified in the search for an explanation of sex differences in all of cognition (see Halpern, 2010, 2011; Williams, 2012; Witelson, 1976). Although the effects of handedness on some dimensions of temporal ability have been examined (Efron, 1963a, 1963b; Westfall, Jasper, & Zelmanova, 2010), the interactive effects between sex and handedness have not been systematically explored (although for one exception, see Gunstad et al., 2007).

The possibility of this important interactive effect was indicated as a result of a serendipitous observation that emerged during a reported experimental investigation. In this latter work, Hancock and Rausch (2010) examined the perception of brief intervals of time of 50 men and 50 women ranging in age from 20 to 70 years. The primary goal of their work was to explore the influence of age and sex on duration perception. However, in postperformance questionnaires, a record was taken of the handedness of each participant. It should be noted that there was no a priori screening of participants in respect of handedness in the original experimental procedure, and thus handedness was identified by self-declaration. Given this caveat, it proved to be the case that there were 92 right-handers and 8 left-handers in the eventual sample. This percentage representation is a reasonable one for a quasirandom, convenience sample because it is close to the estimated frequency of all right- versus left-handers in the general population (see Coren, 1992). As shown in Table 1, comparison of the data derived from these respective handedness groups showed an extensive difference in their respective response patterns. Such a strong differentiation suggested that handedness per se might exert a significant effect on the perception of brief intervals.

Handedness alone has been previously implicated in differences in time perception capability (Efron, 1963a). However, this latter work focused on the issue of simultaneity and temporal order rather than duration estimation per se (Efron, 1963a). Similarly, Westfall and colleagues (2010) have examined the effects of strength of handedness but on the perceptions of extended intervals within a prospective frame of reference (see Hancock, 2010a). Thus, the purpose of our present experiment was to evaluate whether handedness itself affects the ability to estimate intervals up to 20 s in duration and to establish whether any such differential handedness effects might interact with the sex of the person who is making that estimate. A subsidiary hypothesis concerned the increase in the rate of error of the estimate. We anticipated that this would grow with the length of duration estimated. This would follow on the precepts of scalar expectancy theory (SET), but we also hypothesized that such a function would also interact with the sex and the handedness of the individuals involved (and see Church, Meck, & Gibbon, 1994; Wearden & Lejeune, 2008).

TABLE 1. Mean (*SD*) Duration Estimates

Target time	Left-handers	Right-handers	Cohen's *d*
1 s	1.57 (0.743)	1.14 (0.426)	0.94
3 s	4.06 (2.148)	2.81 (0.907)	1.20
7 s	10.09 (5.159)	6.83 (2.096)	1.33
20 s	24.51 (8.938)	20.12 (6.537)	0.65

Note. *Left-handers,* n *= 8 (5 men, 3 women); right-handers,* n *= 92 (45 men, 47 women). Data from Hancock & Rausch (2010).*

TABLE 2. Mean (*SD*) Age of Each Sample Group by Sex and Handedness

	Men	Women
Right-handed	26.0 (4.98)	25.8 (8.91)
Mean handedness score	16.86	15.34
Left-handed	25.4 (7.35)	26.8 (8.53)
Mean handedness score	–12.64	–9.78

EXPERIMENT

METHOD

Participants

A total of 80 adult participants were recruited from the faculty, staff, and students of a large Midwestern university in the United States. All were in professed good health at the time of testing. Each group, 40 men and 40 women, consisted of equal numbers of right- (20) and left-handers (20). Age details for each group are given in Table 2 together with the average handedness score for each group and their calculated laterality quotient (Oldfield, 1971; see also Williams, 1991). All experimental data were collected by a single male experimenter (Rumenik, Capasso, & Hendrick, 1977), in accordance with the tenets of the American Psychological Association treatment on human subjects. Informed consent was obtained before any experimenter's participation.

Handedness Scoring Procedure

Handedness can be measured in a variety of ways (see Chapman & Chapman, 1987; Fazio, Dunham, Griswold, & Denne, 2013). To evaluate the respective level of handedness of each volunteer, we administered the Edinburgh Inventory for the assessment of handedness (Oldfield, 1971). The questionnaire consisted of a list of 10 activities in which participants were asked to indicate their preference in the use of hand for each of these selected activities (see Williams, 1991). Participants were asked to indicate which hand they preferred to use to perform such simple tasks as writing, using a spoon, using a toothbrush, and opening a box lid. Their score was determined by hand preference (left vs. right) and the strength of that preference (a + symbol for use and a ++ symbol for exclusive use). The total score for each screened individual was the sum of 1 point for each "right" answer and –1 for each "left" answer. An additional point was given for each activity if participants indicated a ++ response. Thus, for the 10 total activities the maximum possible score was 20 points, with scores ranging from +20 (for completely right-handed) to –20 (for completely left-handed). The respective age demographics and mean handedness scores for the four distinct groups are given in Table 2.

Experimental Procedure

To record time estimates, the experimenter asked each participant to be seated at a table, on which there was a response apparatus that transmitted the participant's estimates to an adjacent recording system. The response apparatus had two buttons, one of which started the timing mechanism and a second that stopped it. Upon completion of the informed consent materials, participants were asked to remove their watches or any other form of timekeeper in their possession, and then the experimenter left the testing room. Ten practice trials, without feedback, were given that asked participants to estimate a 10-s interval. This interval was chosen to represent an intermediary level with respect to the actual test duration range. The absence of performance feedback here in practice matched the method used in the full procedure.

The time perception method used was production of an empty interval of time (cf. Bindra & Waksberg, 1956; Guay & Salmoni, 1988). This particular method was chosen to reflect the most pertinent nonverbal-based approach. This selection is actually an important decision because the type of method used has been demonstrated to interact with the sex of the participant (see Block et al., 2000; Hancock, 2011a; Hornstein & Rotter, 1969). Each participant pressed one response button to start the interval and another button to terminate their estimate when they thought their response was equivalent to the stated target interval. Participants were asked not to use any counting strategy and also asked to pause briefly before initiating the next trial. After completing the initial practice trials, participants were then asked to estimate four specific time intervals of 1, 3, 7, and 20 s. These four target intervals were chosen to represent as nearly as possible a natural logarithmic progression that brackets temporal thresholds that have been proposed to be of major theoretical importance. These are the boundary of brief intervals at 10 s (Allan, 1979), the range of the immediate present at 3 s (Pöppel, 1988), and the duration of conscious intention at 6 s (Iberall, 1992, 1995). The precise sequence was calculated from a natural (base_e) logarithmic progression. The numbers were rounded to the nearest integer to facilitate participants' estimates in whole number values.

Participants completed 50 consecutive trials at one of the intervals before proceeding to the equivalent number of trials at the next designated interval until all four intervals were complete, for a total of 200 trials per participant. The order of presentation of the different time intervals was randomized across participants. However, any sequence in which the respective durations were presented was then matched across sex and handedness. Thus, there were a total of 20 random orders of duration administration in the full experiment. Participants were requested to change to the next interval only when the previous block of 50 trials had been completed, and they were also asked to take a slightly longer pause during the transition from one specified interval to the next. After each trial the participant's production was recorded to the nearest millisecond. Participants were given no feedback about their performance during any of the trials, which, as noted, also included all practice trials. The opportunity to take a break was offered after the completion of each of the four blocks of trials. This opportunity was rarely taken. The overall experiment took approximately 1 hr for each participant to complete.

RESULTS

The present data were evaluated using a mixed-model ANOVA in which there were two between-subject factors and two within-subject factors. The between-subject factors were participant sex (male vs. female) and handedness (right vs. left), and the within-participant factors were the length of the estimated interval (1, 3, 7, and 20 s) and a block factor (10 blocks of five trials each). The outcome dependent measures that were analyzed were the duration judgment ratio (DJR), which is the ratio of the outcome estimate against each respective target interval (see Block, Hancock, & Zakay, 2010); the constant error (CE) of the estimates; the absolute error (AE); the variable error (VE); and the coefficient of variation (CV), which is derived measure from a combination of both mean and variability in response. Use of these differing measures of central tendency and variability explores the full range of response distribution (but see Newell & Hancock, 1984). This specific profile of measures is used frequently in research areas such as motor control (see Hancock & Newell, 1985) but has been used previously only sporadically in time perception investigations. The ways that these differential reflections of central tendency and variability each provide insight into an overall picture of performance have also previously been communicated (see Schmidt & Lee, 1988). For example, with respect to absolute error, which proved to be an important measure in the present experiment, Newell (1976) argued that in understanding group effects, the absolute error score (which after all is the criterion measure that each participant is seeking to minimize) is central

TABLE 3. Pairwise Effect Sizes at Each Duration for Sex and Handedness (N = 80)

Duration (s)	Male vs. female	Right vs. left	Male right vs. left	Female right vs. left	Right-handed male vs. female	Left-handed male vs. female
1	–0.40	0.27	–0.20	0.60	–0.89	0.02
3	–0.26	0.05	–0.41	0.41	–0.69	0.14
7	–0.31	0.24	–0.06	0.46	–0.55	–0.02
20	–0.29	0.07	–0.19	0.27	–0.52	–0.05

to a full portraiture of response (and see K. M. Newell, personal communication, 2012). As will become evident, use of each of these differing forms of error measure renders important insights.

Pairwise Effect Sizes

An analysis was conducted on the pairwise effect sizes to determine the power to detect significant effects (see Cohen, 1988). These respective effect sizes are reported in Table 3. As can be seen, for an n = 40, which represents the subgroups for both sex and handedness here, we have medium to large effects (e.g., f = 0.30 to 0.35, resulting in a power of 0.77 to 0.88; Cohen, 1988, Table 8.3.12, pp. 311–312) for the male versus female comparisons. The effects are less robust for the handedness comparisons, with lower associated power. The implications for these observations are examined in the *Discussion*.

Duration Judgment Ratio

To analyze mean effects, we first expressed the summated raw scores as a DJR. This measure is calculated through the use of the means of the estimated intervals divided by the length of the specific target duration. A DJR lower than 1 represents underestimations, and a DJR greater than 1 indicates an overestimation. This measure is in common use in time perception research (Block et al., 2010). The outcome for this DJR is shown in Figure 1. Right-handed female participants appear to produce longer interval

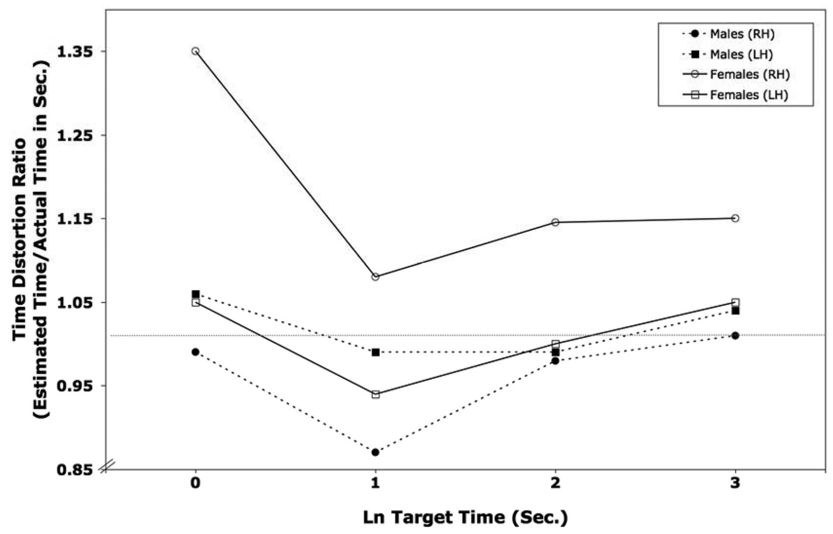

FIGURE 1. Duration judgment ratio (DJR), defined as the value of the mean estimate divided by the target interval. The higher DJRs for all groups at the 1-s interval may well represent the beginnings of a floor effect in motor response capacity for this time period. The actual intervals of 1, 3, 7, and 20 s do not map precisely to the base axis, although for illustrative purposes any differences are minimal. LH = left handed; RH = right handed

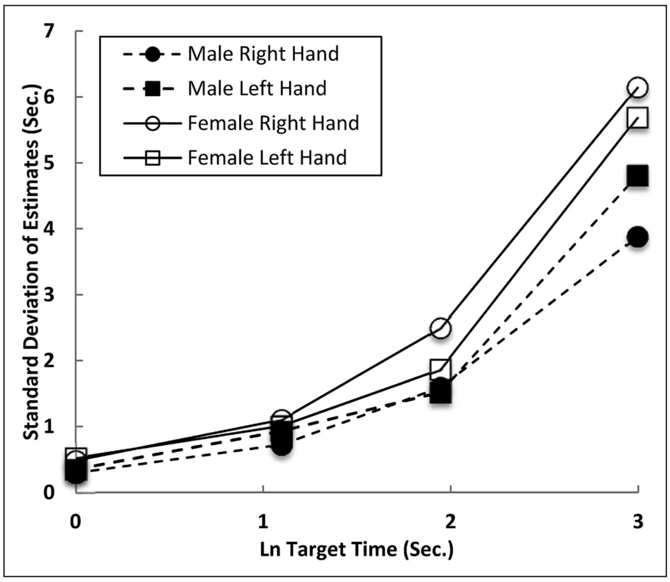

FIGURE 2. Standard deviation for each of the combinatorial conditions shown in Figure 1. As can be seen, the pattern of variability across sex and hand is consistent. Women are more variable than men. For men, left-handers are more variable than right-handers, but this pattern is reversed for women. This ordering replicates the pattern for mean responses shown in Figure 1

estimates than their left-handed peers. However, the opposite pattern appears for male participants. That is, left-handed men produced higher mean DJRs than right-handed men. However, these patterns are merely suggestive because there were no significant interactive or main effects associated with this measure. One primary reason for this null effect derives from the large interindividual and intraindividual differences in variability in time estimation. Such large individual differences permeate time perception research and are the rule rather than the exception (Doob, 1971). To illustrate this observation, the actual values for the standard deviations of each interval for each respective group are shown in Figure 2.

Constant Error

Given the pattern illustrated in Figure 1, an alternative way to examine central tendency other than DJR is through the evaluation of CE. CE is derived by taking the difference between the target interval and the actual estimate on any one particular trial. Thus CE can be either positive, in which case the participant has overestimated the interval, or negative, in which case the participant has underestimated the target interval. An overall CE value of 0 indicates perfect accuracy on average. Results of the ANOVA for CE here did indicate a number of significant effects. There was an anticipated main effect for the length of the interval itself, $F(3, 228) = 7.45$, $p < .001$. This effect was reflected in the fact that CE increased in proportion to the length of the interval estimated. This is an unsurprising outcome that represents a function of the range of target times chosen for investigation (although see Gibbon, Church, & Meck, 1984). However, the second main effect was for the block factor, $F(9, 684) = 6.21$, $p <.001$. This latter effect for blocks of trials is consistent with, and representative of, previously observed lengthening effects. Here, the length of the estimated interval, as reflected in CE value, grows with the progressing number of trials undertaken. This effect has been previously reported on a number of occasions (see Brown, 1997; Schiffman, & Greist-Bousquet, 1992; Vroon, 1972) and occurs in the absence of feedback on performance. No researchers have offered an unequivocal explanatory account of this phenomenon. The fact that this effect stabilizes after a number of trials (i.e., approximately two to three blocks of 10 trials each) suggests it is a transient phenomenon that may be associated with learning even in the absence of explicit feedback (and see Seashore & Bavelas, 1941).

In addition to these main effects for CE, there were 2 two-way interactions. The first interaction was between the length of the target interval and the block factor, $F(27, 2052) = 3.524$, $p < .001$. In essence, this is an elaborated or meta-form of the lengthening effect. The interaction indicates that lengthening became progressively more pronounced as the duration of the target interval increased from 1 to 3 to 7 to 20 s. Even more interestingly, there was a significant interaction between block and sex, $F(9, 684) = 2.90$, $p < .01$. The latter interaction illustrates that there was a difference in the lengthening effect produced by men and women. Apparently, men and women do not experience such lengthening equally. Why this might be so remains uncertain. The latter interaction is itself embedded in the final, significant effect, which was the higher order, three-way interaction between interval, block, and sex, $F(27, 2052) = 2.579$, $p < .001$. The latter pattern showed a difference between men and women in the lengthening effect, which was again magnified as the duration of the target estimate increased. In essence, this shows that sex was a modifying influence on the previously observed block × target interaction. The difference is seen in the absolute magnitude of the lengthening effect or, as we have called it, the meta-lengthening effect. Such lengthening across sequential blocks of trials is pronounced for male participants. However, the comparable lengthening effect for women, in contrast, is attenuated and muted. The constant error values for women increases only marginally across the successive blocks of trials. A somewhat similar outcome pattern was reported by Hancock and Rausch (2010) and is illustrated in Figure 3 of the latter article. Such a result suggests that there is a potential sex difference in the frequency of an intrinsic pacemaker (Treisman, 1963). This model-based account of such a difference is further elaborated in the *Discussion*.

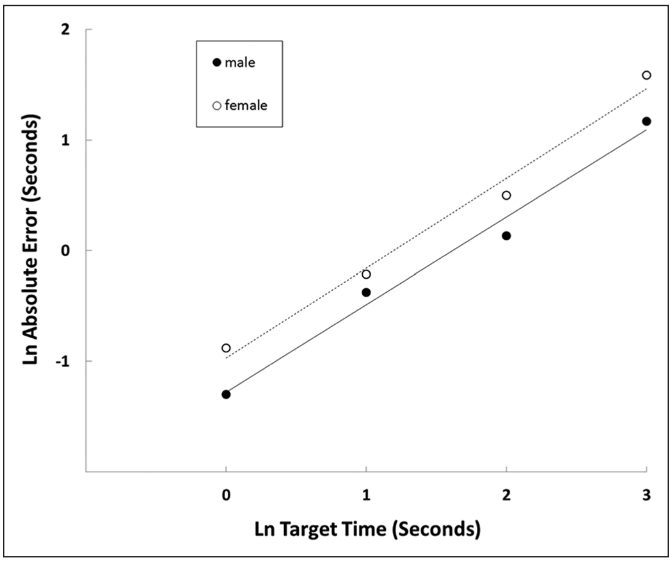

FIGURE 3. Absolute error in duration estimates for each target time versus the sex of the respondent. Both axes expressed as logarithmic functions. Linear trends shown

Absolute Error

AE is defined as “the average absolute deviation of a set of scores from a target value” (Schmidt & Lee, 1988, pp. 59–60; see also Newell, 1976; Newell & Hancock, 1984; Schutz & Roy, 1973). In our experiment, the results for these AE scores were straightforward. There was the expected, significant main effect for interval, $F(3, 228) = 110.9$, $p < .001$, in which the size of AE grew proportionately with the length of the target interval. There was also a main effect for sex, $F(1, 76) = 4.15$, $p < .05$, in which women made a greater degree of AE than their male counterparts (i.e., men = 1.49 s, women = 2.04 s). The final significant effect for AE was an interaction between sex and interval, $F(3, 228) = 2.79$, $p < .05$. Thus, AE differences between the sexes grew proportionately as the length of the target interval increased.

There is an interesting way to illustrate this last interactive effect. Such an illustration is contingent on the original choice of the range of target intervals. Largely for the theoretical reasons that have been noted, the lengths of the present target durations were selected on the basis that they bracketed potentially important thresholds of time (and see Hancock & Rausch, 2010). However, across such temporal thresholds of theoretical interest, the times were also chosen as a natural logarithmic progression. This progression provided the opportunity to express these durations as a simple, increasing logarithmic sequence. When the present AE values are also expressed on a comparable logarithmic scale, the following pattern derives (see Figure 3). This illustration represents the main effect for both the sex of the participant and the length of the estimate. The linear relationships observed express the potential to formulate a new “law” for time perception. This would take the form $\log(AE) = a + b\log(TT)$. Here, AE is the absolute error of the estimate, and a represents a constant that is the intercept value. The constant b represents the value of the slope function, with TT being the target time chosen. In this framework, the intercept a appears to represent some minimal level of response error, perhaps related to the necessary minimal response time associated with the motoric component of any produced time estimate. The more theoretically interesting slope variable b could represent the accumulative error related to the frequency of some central clocking mechanism. The use of logarithmic transforms on both axes tends to be a very powerful influence here. Thus, the attractive linear relationship must be treated with caution. Any pretension to lawful consistency is necessarily contingent on repeated empirical confirmations of this relationship.

Variable Error

As well as the preceding reflections of mean performance level, it is important to present information about the second moment of the response distribution, namely variability (see Figure 2). One such measure is VE, which is the standard deviation of recorded responses. With respect to VE there were two main effects. The first was again the significant but largely unsurprising main effect for interval, $F(3, 228) = 31.3, p < .001$. Here, the size of VE grew with the length of the target interval. The second main effect was that for sex, $F(1, 76) = 4.87, p < .05$. Women proved to have significantly more variability in their estimates than did men (i.e., men = 0.16 s vs. women = 0.19 s; see Figure 2). As with measures of central tendency, there were no interactive or main effects involving the handedness of the participant.

Coefficient of Variation

The degree to which the level of variability covaries with the change in the mean of a series of estimate can be measured by taking the CV. Formally, CV is derived by dividing the standard deviation of the scores by the mean value of those scores. The results for the present experiment, with respect to CV exhibited two significant effects. There was a main effect for interval, $F(3, 228) = 43.5, p < .001$, in which CV decreased significantly with length of the interval. There was also an interactive effect between sex and interval, $F(3, 228) = 4.43, p < .01$; see Table 4. The CV for both women and men consistently decreased across the four respective target times, although the rate at which they decreased was not equivalent, hence the interaction observed. Unlike the strong prediction from SET (Gibbon, 1977) of equivalent CVs across differing durations, the CV scores varied significantly by both duration and sex. This tendency is further addressed in the *Discussion,* but it is noteworthy in this context that there were no significant effects involving the handedness of the participant for such a measure.

TABLE 4. Coefficient of Variation for Male and Female Participants for Each Target Time

Target time	Men	Women
1 s	0.32	0.43
3 s	0.30	0.35
7 s	0.22	0.30
20 s	0.21	0.27

DISCUSSION

In the present experiment, the two factors investigated were the sex of the participant and his or her handedness. Although there were a number of consistent and significant effects for sex, no significant effects were observed for handedness (and see Potter & Graves, 1988). As shown in Table 3, power was not considered to be a major concern because even though the values for handedness were smaller than for sex effects, the former did exhibit sufficient power such that any effects ought to have been detected by the present procedure. Obviously, the first pattern of interest for discussion concerns the consistent sex differences. Over the last century and more, there has been a persistent debate about the size and nature of all sex differences in cognition (see Halpern, 2011; Jordan-Young, 2010; Putz, Ulbrick, Churan, Fink, & Wittman, 2012). With particular reference to time perception, numerous investigations have reported significant differences between the sexes across the same span (e.g., Carlson & Feinberg, 1970; Hancock et al., 1994; Hornstein & Rotter, 1969; MacDougall, 1904; Yerkes & Urban, 1906) that are consistent with the currently reported pattern. However, there have also been some experiments in which no significant differences were found (e.g., Geer et al., 1964; Loehlin, 1959; Swift & McGeoch, 1925). Reviews of these apparently contrasting findings have themselves, on occasion, proved equivocal (e.g., Gilliland, Hofeld, & Eckstrand, 1946). Much of the confusion concerning the veracity of this effect has arisen through the use of differing methods to assess time perception (see Hancock, 2011a; Hornstein & Rotter, 1969). Also, there have been intrinsic investigative limitations in a number of studies, especially related to the stability of reported mean values. This has occurred most frequently when only one single trial has been recorded. Such unstable values have been used as evidence to support a negative conclusion (for a discussion, see Block, Hancock, & Zakay, 2000). This latter issue proves relevant to the findings in the present experiment.

We found some significant sex × trial (block) effects. This pattern reveals that sex differences become progressively more evident as a result of the differential lengthening effects, which exert their impact across both an increasing number of trials and increasing length of estimate. From our previously meta-analytic findings (Block et al., 2000), we identified trials as a significant moderating variable. However, the present results make clear that this moderating effect derives from the actual shape of the curve expressed in the observed lengthening effect (see Hancock & Rausch, 2010, Figure 3). Typically, in curves that show lengthening effects, large changes in response value are evident in the first few trials of any sequence of estimates. Thus, investigations that use only one or two trials are mired in the most volatile region of change. The greater the number of trials, the greater the stability of the derived estimate and the greater the likelihood that reliable sex differences are observed. Almost certainly, one or two trials are insufficient to establish this stable level. When only this particular influence is accounted for, the collective literature shows strong evidence of a consistent sex difference (Espinosa-Fernandez, Miro, Cano, & Buela-Casal, 2003; Hancock, 2011a). However, it is important to recognize that a number of other external influences can still mask such sex effects (e.g., Botella, Bosch, Romero, & Parra, 2001). Overall, our present findings support the effect of sex on the production of brief intervals of time, an effect that is reflected in changes in both mean and variability of recorded estimates.

Interestingly, the interaction between sex and the duration of estimate indicated law-like relationship in respect of AE. The implication of this description, which is shown in Figure 3, is that the obligatory motor response time, which is intrinsic to the present production method, is highly similar across sexes, because the actual values are expressed here on a logarithmic scale. However, the slope functions for men and women are parallel in log/log space, which indicates that they diverge consistently in the nontransformed case. The implication from this observation is that the actual sex effect is most likely to reside in the frequency difference of some internal pacemaker or set of pacemakers, which vary in their average rate across collective samples of men and women. Such differences have commonly been located in the frequency of a postulated internal clock (Hancock & Rausch, 2010). Such frequency variations may well be related to resting internal body temperature (Hancock, 1984, 1993; Hoagland, 1933; Treisman, 1963). This would mean that such sex differences are not a necessarily predominantly a function of memory, because certain animal work has shown that memory and pacemaker may indeed be clastic physical entities in the active nervous system (see Meck, 1983; Wearden, 2005). If the relationship shown in Figure 3 can be replicated in further empirical confirmation, it may not only support the establishment of a lawful description but also would add weight to the postulate of an average pacemaker frequency difference between the sexes.

It is important to compare the present observations with those that found one of the major models of time perception. In the SET conception, Gibbon (1977, p. 281) emphasized that "the core of the scalar-timing hypothesis is that variance of the time estimates increases with the square of the mean, and accordingly, (his) account focuses on the first two moments of distributional phenomena" (see also Gibbon et al., 1984). SET has proved very influential and useful in the timing and time perception domain for understanding the behavior of humans and other animals (see Malapani & Fairhurst, 2002). It has also been the subject of numerous reviews as to its validity and utility (see Wearden, & Lejeune, 2008). Initially, it might appear that the present descriptive relationship in AE relates directly to the second descriptive possibility that Gibbon discussed in his introduction to SET (i.e., Gibbon, 1977, Figure 3, p. 283). However, the current description is founded in the logarithmic expression of both independent and dependent variables. The use of these logarithmic transforms and the formal relationship between AE and VE means that the two respective descriptions (i.e., that of Gibbon, 1977, Figure 3, relationship #5, p. 283, and the present one expressed in the current Figure 3) are by no means contradictive but may actually be highly complementary. However, to reiterate an earlier observation expressed by Newell (1976, personal communication, 2012), AE is the dependent variable that each participant is seeking to minimize, not VE or the associated CV level. Whether this manifest goal increases or reduces the value of SET as a construct is open to debate. The matter of an inverse power law description has not escaped our attention, although the range of times investigated must urge caution (Perline, 2005).

Perhaps a more important question arises as to whether the observed function represents an important fundamental finding or is, in contrast, merely a banal side effect of a necessarily increasing variability. The latter propositions are certainly worthy of exploration. Thus, on one hand, one might suggest that the relationship shown is actually an intrinsic statistical property such that variability (expressed in this case in the derived form of an AE score) grows proportionately with the mean value of the estimate. At first blush, this can seem to be a finding that is almost unworthy of report. However, if we pursue this logic further we can see that in certain existing laws of psychology, their consistency holds only because of this same underlying property. Consider Fitts's law (Fitts, 1954). Here, the target width (W) is an effective surrogate for response variability. Through application of Fitts's equation, $\mathrm{MT} = a + b_{\log 2}(2A/W)$, we find that when movement time (MT) is held constant, the law describes a relationship between the systematic growth in the amplitude (magnitude) of the movement and the concomitant variability of that movement (effective target width). Because time is held constant in this example, the relationship refers to the spatial dimensions of motion only. The importance and ubiquity of Fitts's law is that it involves consistency in both spatial and temporal dimensions (see Hancock & Newell, 1985). We suggest that the present observation represents the analogous case but for time perception in the absence of any spatial element. This is arguably the first formal report of such equivalence.

It is important to note that this is actually part of a wider debate in psychology and indeed in the wider realms of science. For example, Chater and Brown (1999) argued that many of the laws of psychology that govern perception and action are reflections of scale invariant. As such they reflect the way in which organisms in general are *tuned* to the fundamental properties of the environment of which scale invariance is one primary element. Here, we argue that, in a similar manner to the observations of Fitts, Stevens, Weber, and Pieron, these same properties extend to the perception of time alone without the spatial elements intrinsic to the formulations in the aforementioned laws. Because pure time perception is an important characteristic in dealing with many of the necessities to coordinate action within the environment (e.g., Hancock & Manser, 1998), this extension concerning lawful observations reflecting scale invariance is a logical and valuable one (Tung, 2007).

With respect to the second major independent variable, the present experiment provides scant evidence for differences in temporal perception due to handedness, even in interactive expressions. Although this is a disappointing outcome, there may well be a number of reasons for these present outcomes. One concern with respect to the explored interactions is that the current sample of men showed much higher levels of handedness than their female counterparts. This was especially true for comparison across the left-handed group (Table 2). This latter pattern reinforces the consistent observation that strongly left-handed women are rare in the general population. However, when selection is made in order to balance the level of handedness across the sexes, there are some indications of interactive effects (Hancock, 2010b). Another issue that could contribute to the reported null effects for handedness concerns the hand that participants used for response. In the present experiment the participant was free to use either hand to generate the response requested. Although this was most often their dominant hand, there was no obligatory need to use their stated dominant hand. Thus, participants could choose to use the nondominant hand if they preferred. Although observation suggests this is actually unlikely to have had a major influence on results, it does represent a possible reason for the null effects reported. Indeed, as noted, in addressing such sources of variation Hancock (2011b) has shown that there are consistent effects for the handedness of the individual that interact with whether the preferred or nonpreferred hand is used for response.

In light of all these collective observations, it is important to consider explanations for the patterns of recorded response (see Zelanti & Droit-Volet, 2011). The question is bound up with two difficult areas in psychological research. The first concerns sex differences in cognition in general (and see Halpern, 2010, 2011), and the second, associated area concerns the issue of hemispheric effects on response capacity (see Efron, 1990; Ornstein, 1998). Although they remain unclear, the latter hemispheric contentions have often been invoked to explain the former observed sex differences (and see McGlone, 1980, and associated response articles). If timing is more associated with left hemisphere function (Brown & Nicholls, 1997; Bruyer, 1986; Polzella, DaPolito, & Hinsman, 1977;

Vroon, Timmers, & Tempelaars, 1977, but see also Harrington, Haaland, & Knight, 1998) and laterality were greater, on average, in men than in women, then we would have an account of sex differences in the production of brief temporal intervals. In general, greater male laterality should be evident, such that it should be harder to find strongly left-handed women compared with strongly left-handed men (see Faurie, Schiefenhovel, LeBomin, Billiard, & Raymond, 2005). That is, women who score more highly on the respective handedness scales ought to be rarer in the population. In general, this pattern appears to be confirmed in samples assessed to date. Furthermore, this pattern may hold even beyond the human species alone (Wells & Millsopp, 2009). This could mean that extremely handed women are the most exceptional group. This appears to be a possibility in respect of the present suggestive but nondeterminative results shown in Figure 1.

If the corpus callosum is larger in left-handers (see Witelson, 1985) and if, because of the greater degree of lateralization, female left-handers prove to be rare in the population, then the notion of differential strength of connections between the discrete timing centers and the motor response centers (see Kimura & Archibald, 1974) could be one central element in an account of the differences observed here and those in other associated work (Hancock, 2010b). Indeed, differences in connectivity and the subsequent organization of appropriate response output are probably concomitants of individual brain organization. It is reflections of these differential levels of organization as expressed via sex and potentially also via handedness (Hancock, 2011b) that could provide crucial insight into the manifest and often highly frustrating individual differences in the temporal production of even brief intervals of time (Doob, 1971).

Summary and Conclusion

In his classic text at the very foundation of experimental psychology, James (1890) expressed a clear interest in, and emphasis on, the importance of the perception of time. James located the perception of time as the conscious experience of the present moment. In contrast, he viewed memory as the experience of the past, and planning was the experience of potential futures. The order of the chapters in his classic text reflects this logical perspective. However, although James's prognostications about our scientific pursuit of capacities such as memory and attention have come to fruition in the psychological literature, where they might well be considered the centerpieces of modern experimental and cognitive psychology, the centrality James identified for time perception has not been fulfilled. Indeed, time perception even today remains an academic backwater, especially in comparison to the aforementioned topics (Adams, 1964; Hancock & Block, 2012). This is not because we do not understand the centrality of time, for as Block (1990) has noted, time is crucial to all of behavior because atemporal behavior is a pure oxymoron. Rather, it is in part the general intractability of the whole topic of time (see Hancock, 2005) but especially in psychology the large individual differences that bedevil almost all time perception experiments, including the present one (Cronbach, 1957). If the identified lawful relationship proposed here stands up under further experimental scrutiny, then we may be able to invigorate the psychological study of time by beginning to conquer the individual difference barrier. Allied with comparable progress in the neurosciences of time (Buhusi & Meck, 2005) and with evaluations of the perception of much longer durational intervals (Hancock, 2010a), we may begin to fulfill James's aspiration for articulating the perception of time as perhaps the central element in understanding all human behavior.

NOTES

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