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Response Timing Accuracy as a Function of Movement Velocity and Distance

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ABSTRACT. In two experiments, patterns of response error during a timing accuracy task were investigated. In Experiment I, these patterns were examined across a full range of movement velocities, which provided a test of the hypothesis that as movement velocity increases, constant error (CE) shifts from a negative to a positive response bias, with the zero CE point occurring at approximately 50% of maximum movement velocity (Hancock & Newell, 1985). Additionally, by examining variable error (VE), timing error variability patterns over a full range of movement velocities were established. Subjects (N = 6) performed a series of forearm flexion movements requiring 19 different movement velocities. Results corroborated previous observations that variability of timing error primarily decreased as movement velocity increased from 6 to 42% of maximum velocity. Additionally, CE data across the velocity spectrum did not support the proposed timing error function. In Experiment 2, the effect(s) of responding at 3 movement distances with 6 movement velocities on response timing error were investigated. VE was significantly lower for the 3 high-velocity movements than for the 3 low-velocity movements. Additionally, when MT was mathematically factored out, VE was less at the long movement distance than at the short distance. As in Experiment I, CE was unaffected by distance or velocity effects and the predicted CE timing error function was not evident.

Key words: speed-accuracy tradeoff, timing accuracy

In contrast to this generalized application of Fitts’ law, some evidence has shown that when the response demands emphasize timing accuracy, as opposed to spatial accuracy, response timing error decreases with increased response speed (Ellis, Schmidt, & Wade, 1968; Newell, 1974, 1976; Schmidt, 1969; Schmidt & Russell, 1972; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). Early reports of this temporal speed-accuracy relationship were inconclusive, however, because the independent variables, movement duration and velocity, were often experimentally confounded.

This methodological problem was rectified by the work of Newell and his colleagues (Newell, 1980; Newell, Carlton, & Halbert, 1980; Newell, Carlton, & Kim, 1994; Newell, Hoshizaki, Carlton, & Halbert, 1979), who found support for the temporal speed-accuracy relation. What remains unclear from these studies is whether a decrease in response timing error holds true across an entire range of movement velocities or is applicable only to a limited spectrum of the velocity range. One of our purposes in the present experiment was to provide a test of this question by examining temporal error over the entire spectrum of movement velocities, thereby providing maximum resolution of temporal error effects.

Our second purpose in conducting the experiment was to investigate predicted shifts in temporal CE as movement velocity increased. The motivation behind this study was prompted by Newell et al. (1982), who proposed that timing error can be transformed into spatial error, or vice versa, thereby providing a formal link between space and time. This concept was more fully developed 3 years later by

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Hancock and Newell (1985), who proposed that "when temporal and spatial error are measured in the same movement plane, the error functions are homeomorphic" (p. 178). One form of expressing this homeomorphism is to calculate spatial error from timing error produced during a task that emphasizes timing accuracy. The calculation involves noting the spatial error, with respect to a criterion spatial target, at the time when the criterion target time is achieved.

Using the space–time linkage as a theoretical foundation, Hancock and Newell (1985) predicted that temporal CE would vary as a function of increasing movement velocity. It should be noted that their prediction does not necessitate the transformation of temporal error into spatial error, because both temporal and spatial functions have the same shape (i.e., they are homeomorphic). Specifically, the CE function was predicted to have negative and positive CE values associated with slow and fast average movement velocities, respectively. Additionally, the zero-CE crossover point from a negative to positive response bias (i.e., the point of maximum timing accuracy) would occur at 50% of maximum movement velocity for any given movement distance. Therefore, in Experiment 1, we also examined whether the temporal CE function follows the predicted form described by Hancock and Newell (1985).

**EXPERIMENT 1**

**Method**

**Subjects**

Six right-hand-dominant men and women (Mean age = 30.08 years; range, 24–42 years) were recruited from the university population. Hand dominance was ascertained from a questionnaire administered prior to testing. Subjects were paid $40 for their participation.

**Apparatus and Task**

A lightweight aluminum lever (51 cm long) was mounted on a low-friction, metal-bearing mechanism fastened to a table surface. The subject's forearm was positioned on the upper surface of the lever, with the elbow placed in a plastic elbow mold attached over the center of rotation. Subjects grasped a freely rotating wooden handle placed distally on the lever arm.

At the movement start position, the subject's shoulders were square to the apparatus and the right arm was fully extended to hold the lever against a metal stop. When movement was initiated, a digital timing clock was activated. An infrared target device securely placed on the table surface at a predetermined criterion distance from the start position designated the target point. Movement of the lever through the target device interrupted an infrared beam that deactivated the timing clock. Movement time was defined as the time taken to traverse the distance between the movement start position and the target device.

**Determination of Target Distance**

For the first testing session, we adjusted the seat height so that the table top was level with the subject's xiphoid process and adjusted the apparatus handle to fit the subject's forearm length. Before testing was initiated, the point of maximum forearm flexion of each subject was determined by requiring a slow flexion of the forearm from the movement start. Using reference points marked on the apparatus table surface (graduated 5° interval markers), the experimenter recorded the angle beyond which the subject could not continue the movement without rotating or moving the shoulders. This typically occurred at an angle of 171.2° from the start position. This procedure was repeated three times, and the average value of maximum forearm flexion was calculated.

Maximum flexion distance was defined as the distance from the movement start position to the point of maximum forearm flexion. An experimental target distance was arbitrarily set at 45% of maximum flexion distance. The infrared target device was placed at this target distance point for the duration of each testing session.

**Determination of Average Maximum Movement Velocity**

Average maximum movement velocity was determined by having each subject move the lever arm through the target distance as fast as possible. Subjects were instructed to minimize movement time and were required to "move through" the experimental target distance. Fifteen trials were recorded at maximum movement velocity; we used the last 12 trials to calculate the average maximum movement velocity. A pilot study indicated the reliability of using 12 trials as an estimate of average maximum movement velocity to be $r_{av} = .97$. In addition, because the average maximum velocity values between subjects were similar enough, we used absolute values to calculate target times.

**Determination of 19 Target Times**

Subjects completed 19 movement conditions. Each condition represented a percentage of the average maximum movement velocity across the target distance. The 19 movement conditions were: 6, 12, 18, 24, 30, 36, 42, 48, 50, 52, 56, 62, 68, 74, 80, 86, 92, 98, and 100% of average maximum movement velocity. These movements were selected because they provided good resolution of measurement across the entire velocity spectrum without creating an undue number of movement conditions. Absolute target times for each condition, which depended on individual average maximum velocity values, were calculated by the experimenter and presented to the subject immediately before the start of each movement condition.

Subjects were instructed to move the lever through the target distance as close as possible to the target time. Dash and wait strategies were treated as mistrials and were repeated at the end of each block of trials. Only four mistrials occurred for all of Experiment 1 (one mistrial each for
Subjects 1, 3, 5, and 6). The difference between the target time and actual movement time was considered as timing error measured in milliseconds (ms). A positive and negative error, respectively, represented slower and faster movements than the criterion. Subjects completed 24 trials per condition.

Procedure

During Sessions 1, 2, and 3, subjects received 6, 6, and 7 experimental conditions, respectively. Presentation of the experimental conditions was randomized across subjects. Subjects completed 24 trials for each condition. The first 4 trials were practice trials, and the last 20 trials were used for data analysis.

A trial was initiated by a “ready” command followed by a “go” signal. The intertrial interval ranged from 15 to 25 s, during which the experimenter reset the timing apparatus, recorded the subject’s movement time on a 386 laptop computer, and provided knowledge of results to the nearest millisecond. Response information was not available to the subject during the movement. The intercondition interval was 3 min, during which subjects removed their arm from the lever and rested.

Results and Discussion

Temporal constant error (CE) and variable error (VE) data for the 19 velocity conditions are presented graphically as a function of percent of average maximum velocity in Figure 1. Data were analyzed by using a 19 (velocity) x 5 (block of trials) analysis of variance (ANOVA), with repeated measures on both factors (Kirk, 1968). The a priori probability level was set at .05. Following recommended statistical procedures (Hertzog & Rovine, 1985; Schutz & Gessaroli, 1993), when the Huynh-Feldt adjusted degrees of freedom value of epsilon (ε) was found to be less than .75, we used a Greenhouse-Geisser ε to assess the significance of the F value. In all other cases, the Huynh-Feldt epsilon factor was used.

Analysis of VE data revealed no significant effects for block, F(4, 20) = 0.22 p > .05, or the Velocity x Block interaction, F(72, 360) = .73, p > .05, but did indicate a significant velocity effect, F(18, 90) = 56.32 p < .05; Greenhouse-Geisser ε =.112. The VE curve illustrated in Figure 1 revealed a rapid decrease in mean VE from 6 to 42% of maximum velocity. Beyond the 42% value, VE continued to decrease but at a less rapid rate. By using a curve fit analysis program (Graphpad), it was found that the data for VE can be described by the following fourth-order polynomial:

\[ Y = 368 - 21.99x + .52x^2 - .005x^3 + .00002x^4. \]

Goodness of fit was ascertained by using the least squares method, which produced a significant R² value for the polynomial equation of .922, p < .05 (df = 109).

The VE data confirmed the results of previous studies (Newell et al., 1980; Newell et al., 1979; Simmons & Williams, in press), which indicated significantly greater VE during slow movement velocities than during fast velocity movements. Additionally, the VE function was nonlinear, with a major decrease in VE occurring between 6 and 42% of maximum movement velocity.

The curvilinear function of the VE curve could be attributable to two factors. First, the shape of the curve and the relatively small amount of VE error between 42 and 100% of maximum velocity (range = 29.10 to 9.02 ms) suggested the influence of a floor effect. If present, however, the floor
effect did not completely prevent decreases in VE as velocity increased, even at the fast end of the velocity continuum.

Secondly, the VE error function may have been caused, in part, by the putative effect of slower velocity movements; that is, they provide greater movement time in which response error can be produced (Schmidt, Zelaznik, & Frank, 1978). To factor out the effect of MT, we divided VE by MT and multiplied the result by 100. The result of this calculation is presented in Figure 2. A one-factor repeated-measures ANOVA on the VE/MT% revealed a significant condition effect, $F(18, 90) = 6.24, p < .05$, Huynh-Feldt $\varepsilon = 1.00$. Consistent with earlier findings (Newell et al., 1980; Newell et al., 1979), this result indicates that VE still decreased with increasing movement velocity regardless of movement time.

The results for the CE analysis revealed a significant effect for block, $F(4, 20) = 19.92, p < .05$, Huynh-Feldt $\varepsilon = 1.00$, which was attributable to the relatively large CE mean value for the first trial block (mean = 42.01 ms) as compared with that of the last trial block (mean = 6.79 ms). Neither the velocity factor, $F(18, 90) = 2.32, p > .05$, nor the Velocity $\times$ Block interaction $F(72, 360) = 2.10, p > .05$, was significant. Examination of Figure 1 together with the statistical analysis of CE showed a CE function curve that indicated approximately zero error across the velocity spectrum. This result is not consistent with a CE function in which negative and positive response bias is associated with slow and fast movement velocities, respectively, and with zero error occurring at 50% of maximum velocity (Hancock & Newell, 1985).

The shape of the CE function in the present study may have been the product of algebraic summation resulting from the pooling of subjects' data. However, a visual inspection of individual subjects' CE functions revealed that none of the individual curves conformed to the predicted CE function of zero CE at 50% of maximum movement velocity.

**EXPERIMENT 2**

The results found in Experiment 1, especially for VE, led us to ask whether a similar decrease in VE would be observed during longer movements when movement velocity increased from low to high. If the observed VE function holds for short and long movement distances, this would indicate that the reduction of VE is related to changes in movement velocity rather than movement distance. Additionally, Experiment 1 did not support Hancock and Newell's (1985) CE error curve for the single movement distance studied. This led to the possibility that the error function would occur at different distances.

Consequently, for Experiment 2, three movement distances were selected together with six different velocity values. These represented three movement velocities each from the high and low end of the movement velocity range. Because the larger movement required a maximum range of displacement greater than that provided by the curvilinear apparatus, a different task was selected for Experiment 2. This task, in which a rotary positioning device was used, had the added advantage of allowing a VE timing effect (if confirmed) to be generalized to curvilinear responses.
Subjects
Six right-hand-dominant men and women (Mean age = 33.50 years; range, 26–42 years) were recruited for the experiment. Subjects had not participated in Experiment 1 and were unpaid for their effort.

Apparatus
The apparatus consisted of a stainless steel lever arm (23.0 cm long × 1.2 cm in diameter) attached to a near-frictionless metal bearing mounted on a wooden baseboard (16.0 × 31.0 cm). The lever arm freely rotated through 360° in the horizontal plane. A freely rotating wooden ball-shaped handle (5.0 cm diameter) was attached to the distal end of the lever 6.5 cm from the center of rotation. The height of the rotary lever was adjusted to be 5 cm below the xiphoid process of the subject. Subjects stood throughout the experiment and served as the movement start position. With movement initiation, the pin dropped 3 cm, which allowed the subject to complete several clockwise movements unimpeded by the pin.

Angular displacement of the lever arm was recorded by using a 10-turn potentiometer positioned under the center of rotation. Rotation of the hand crank resulted in a linear voltage threshold value was preset to correspond to an angular position that defined the movement endpoint. When this value was reached, the electronic counter was deactivated. Movement time was recorded to the nearest millisecond and was defined as the elapsed time from initiation of movement until the lever arm passed through the designated target position.

Determination of Maximum Average Velocity and Target Times
Three experimental distance conditions of 90, 360, and 720° were selected. Because maximal movement velocity changes with distance (Newell, Hancock, & Robertson, 1984), the maximal average movement velocity for each of the three distances was determined by having each subject rotate the lever arm through the three experimental distances at maximal velocity. Fifteen trials were provided; we averaged the last 12 to obtain an estimate of the maximal average velocity for a particular experimental distance. Pilot testing indicated that an average of the last 12 trials provided reliability estimates of maximal movement velocity ranging between .95 to .97.

For each of the three distances, six velocity conditions of 6, 12, 18, 86, 92, and 100% of maximum velocity were used. Target times for the 18 conditions were determined by converting the percentage value of maximal average velocity for each distance into target times. Presentation of the 18 conditions was randomized within each subject and consisted of 24 trials per condition.

Procedure
Subjects participated in two 1-hr testing sessions on 2 separate days, with an intertest period that never exceeded 1 week. At the start of the testing session, subjects were provided a demonstration of the required response, which was followed by completion of 15 to 20 practice trials of an experimental condition that was not included in the experimental protocol.

Immediately prior to beginning each condition, subjects were informed of the target time for that specific velocity–distance condition. With a continuous movement, subjects rotated the lever arm so that it passed through the target distance as close as possible to the target time. Dash and wait movement strategies were treated as mistrials and repeated at the end of each block of trials. A total of five mistrials occurred in Experiment 2 (two for Subject 1 and one each for Subjects 3, 4, and 6). Subjects completed 24 trials at each condition, the last 20 of which were used for data analysis.

The time taken to complete the response (to the nearest millisecond) was verbally provided immediately after completion of each trial. The intertrial interval was 15 s, during which the subject returned the rotary arm to the start position. The between-condition interval was 5 min, during which the subject was allowed to move or sit. During this interval, the experimenter reset the voltage threshold at a level appropriate for the next experimental distance condition.

Results and Discussion
VE and CE data were analyzed, using a 3 (distance) × 6 (velocity) × 5 (block) design with repeated measures on all factors. Figure 3 presents the average VE data as a function of movement distance and illustrates a significant interaction between velocity and distance, $F(10, 50) = 9.98, p < .05$, Greenhouse-Geisser $\varepsilon = .210$, together with significant main effects for velocity, $F(5, 25) = 137.41, p < .05$, Greenhouse-Geisser $\varepsilon = .269$, and for distance, $F(2, 10) = 28.17, p < .05$, Greenhouse-Geisser $\varepsilon = .630$. The interaction was further analyzed, using Tukey's HSD post hoc technique. This analysis revealed that mean values for the 86, 92, and 100% velocity conditions were significantly lower than the mean values for the 6, 12, and 18% velocity conditions. Additionally, although the three high-velocity means were statistically equivalent, mean VE decreased significantly as the velocity increased from 6 to 18% of maximum. This result confirms the findings for VE reported in Experiment 1.

For the distance main effect, post hoc analysis revealed that the mean VE associated with the long distance movement (720° movement mean = 225.73 ms) was significantly larger than the mean for the short distance movement...
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FIGURE 3. Mean temporal VE as a function of percent maximum movement velocity and movement distance. Note that the standard error bars for the high-velocity movements were too small to appear on the graph.

FIGURE 4. Mean temporal CE as a function of percent maximum movement velocity and movement distance.

(90° movement mean = 59.28 ms). There was no significant difference between the medium distance mean (360° movement mean = 136.16 ms) and the long or short distance movement mean values.

Therefore, whereas VE decreased with increased velocity, at slow movement speeds VE was also affected by distance, with VE increasing as movement distance increased. This result suggests the presence of a velocity threshold value above which movement distance no longer differentially affects VE. One could confirm this prediction by using a spectrum of velocity values of multiple movement distance conditions to generate a greater resolution of response assessment than was provided by the three distances used in the present study.

The aforementioned VE result must be interpreted with caution, however, because increased movement distance coupled with slower velocities resulted in greater overall movement times. As noted in Experiment 1, increased MT has been associated with greater response variability; therefore, an analysis of VE/MT% was completed by using a 3 (distance) × 6 (velocity) repeated-measures ANOVA. The analysis revealed significant effects for both velocity, F(5, 25) = 10.43, p < .05, Greenhouse-Geisser ε = .425, and distance, F(2, 10) = 29.55, p < .05, Huynh-Feldt ε = .905. The Distance × Velocity interaction was not significant, F(10, 50) = .55, p > .05.

Tukey’s HSD post hoc tests for velocity and distance revealed that all three high-velocity conditions had significantly lower VE/MT% means (3.97, 5.58, and 8.59 ms for 720, 360, and 90° movements, respectively) than for the respective three low-velocity conditions (8.07, 8.69, and 12.62 ms). None of the means within the high- or low-velocity conditions were significantly different from each other. This finding demonstrated that the VE that was not attributable to movement time decreased significantly with increased movement speed.

Post hoc analysis also revealed significantly larger VE/MT% for the short distance movement (90° movement mean = 10.62%) when compared with either the medium or long movement distance (360 and 720° movement means = 7.13 and 6.02%, respectively). It was concluded that at all velocity conditions, greater VE was associated with relatively short movements. Although this result corroborates VE timing effects reported in an earlier study (Schmidt, 1988), our results differed in that we also observed a distance effect.

Figure 4 illustrates the average CE data for the six velocity conditions as a function of distance. Analysis of CE data revealed no significant main effects or second- or third-order interactions. The results indicate that directional timing accuracy, as measured by CE, does not manifest any consistent response pattern with distance, velocity, or practice.

GENERAL DISCUSSION

Our original intention in Experiment 1 was to test Hancock and Newell’s (1985) predicted CE error function. To this end, we wanted to examine timing errors across the entire velocity spectrum with sufficient resolution to be able to detect any possible discontinuities that might have arisen. This was especially true for the high-velocity conditions (> 90% of maximum velocity), where most previous studies have examined only a few velocity conditions in that range. In addition, the results from Experiment 1 generated new questions, one of which was addressed by Experiment 2.

The results of the two experiments confirmed the presence of an inverse relationship between temporal VE and movement velocity (Newell, Carlton, & Carlton, 1982; Newell, Carlton, Kim, & Chung, 1993). Experiment 1 illus-
trated this VE function across velocity values ranging from 6 to 100% of maximum movement velocity, and again when MT was factored out. In addition, Experiment 2 established that temporal VE is differentially affected by distance at slow movement velocity values (6–18% of maximum velocity). That is, short movements at slow velocities resulted in significantly smaller VEs than either medium or long movements (Carlton, Robertson, Carlton, & Newell, 1985; Simmons & Williams, in press). It was also apparent that the distance effect was reduced as velocity increased. What remains unclear from the experiment is whether the distance effect continues to disappear with movement distances longer than 720° (two rotations).

The factor(s) that contribute to the VE timing function remain unclear. Using apparatus identical to that described in Experiment 2, Simmons and Williams (in press) investigated the EMG activity associated with the VE velocity function during a rotary arm movement. Although muscle activation patterns shifted from predominantly cocontraction to reciprocal activity as movement velocity increased, there was no indication that EMG patterns changed as a function of the two movement distances studied. This may have been caused, in part, by synergistic complementary activation of the muscle groups studied by nonmonitored muscles of the arm or by the fact that the shortest movement was 240° in extent. In the context of the present experiment, a movement of this magnitude would be closer to a medium distance than to a short distance condition. If there is an absolute value above which temporal VE no longer changes, it becomes critical that future work in this area first define what this absolute value might be.

Carlton et al. (1985) also studied EMG records produced during a timing task requiring horizontal flexion of the arm. They reported that the duration of the agonist and antagonist burst, together with the time to the antagonist burst, all decreased as movement distance increased. This finding suggests a distinct organizational mechanism, possibly at a central timing level (Wing & Kristofferson, 1973), that results in greater response variability during short movements. Although the neuromuscular patterning was not reported for this study, horizontal arm flexion to an experimenter-defined target is known to be associated with a triphasic (reciprocal) EMG pattern (Wadman, Denier van der Gon, Geuze, & Mol, 1979). This leaves open the possibility that the temporal–spatial organization of neuromuscular activity (as reflected by EMGs) changes as a function of movement velocity, which, in turn, results in varying degrees of temporal error.

The direct relation between VE of timing and movement velocity could also be explained by the speed-sensitive (SS) and speed-insensitive (SI) interpretation of motor control (Gottlieb, Latash, Corcos, Liubinskas, & Argawal, 1992). Use of a SS strategy implies manipulation of movement time to a designated target. A SI strategy would be appropriate when movement time or velocity is not controlled. In both of our experiments, a SS strategy would apply, because subjects regulated velocity to experimenter-defined targets.

A direct relationship between inertial torque, movement velocity, and amplitude of the antagonist activity produced during a SS strategy response has been previously documented (Gottlieb, Corcos, & Argawal, 1989). This finding is consistent with additional results indicating an inverse relationship between impulse variability and velocity (Newell et al., 1982) and decreased VE of timing as dynamic force increases. Although none of these kinetic or neuromuscular variables were directly measured in the present study, collectively these results are consistent with our finding that low-velocity and low-force movements, both of which occurred in the present study during short movements, resulted in greater response variability. Thus, regulation of speed toward the low end of the speed spectrum would be predicted to result in greater VE of timing.

This prediction was confirmed empirically in Experiment 1. A stronger link between SS strategy usage and timing accuracy is required, however, and could be established by examining the EMG patterns of the agonist(s) and antagonist(s) across the entire velocity spectrum. According to predictions made by Gottlieb et al. (1989), for SS strategies of single-joint movements, one should observe two general features in the agonist-antagonist burst patterns: one, the scaling of the initial rate of excitation of the agonist and antagonist to movement velocity; the other, durations of the agonist and antagonist bursts that are invariant within a velocity condition. Specifically, at slow movement velocities the rate of the initial burst of the agonist (and antagonist) should be lower than those for higher movement velocities. If this hypothesis is correct, then a possible source of high VE error at slow velocities is the difficulty of consistently reproducing (or estimating) the correct amplitude of the initial agonist and antagonist bursts.

Another key feature of the SS strategy is the temporal regulation of the antagonist muscle as the kinematic characteristics of the task change. This adaptation role of the antagonist has been found to be the determining factor in the use of both reciprocal activation and coactivation in response to changes in external loading (Simmons & Richardson, 1992). Whether the antagonist and, to a greater extent, the use of SS strategies play a critical role in reducing timing error as movement velocity increases is an issue requiring experimental confirmation.

Finally, Experiment 1 established that CE remained relatively constant about the zero error value across the entire velocity spectrum. Somewhat surprisingly, the CE function did not reflect a pattern of response bias predicted by range effects (Ellson & Wheeler, 1947). That is, in the absence of other biasing factors, one would expect slow-velocity movements to be underestimated and high-velocity movements overestimated. This pattern of response biasing was noted by Newell et al. (1993, Experiment 1) but differed from the CE function initially proposed by Hancock and Newell (1985), who predicted a curvilinear function of negative bias from 0% to 50% of maximum velocity, followed
by essentially a linear increase in positive response bias as maximum velocity was approached. Why CE remained invariant in Experiment I is not immediately apparent. On average, all subjects were able to be fairly accurate at slow velocities, but they appeared to have difficulty in being consistent from trial to trial, as was reflected by high VE scores.

The temporal CE results of Experiment 2 are more difficult to interpret in terms of the CE function. At 6% of maximum movement velocity, temporal CE was negatively biased, but it became positive at all remaining velocities tested.

Because a 50% of maximum movement velocity condition was not included, it is impossible to assess the form of the temporal CE function across the middle of the velocity range. However, based on the CE results at low- and high-velocity values in Experiment 2, and the temporal CE results of Experiment 1, we concluded that the CE error function proposed by Hancock and Newell (1985) cannot be supported because CE was predicted to increase at near-maximal velocities (Hancock & Newell, 1985; Newell et al., 1993). Without further investigation, using possibly more complex movement tasks, we hesitate to give an explanation of why the predictions of Hancock and Newell (1985) were not realized.

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