Effects of target location and uncertainty on reaching movements in standing position

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Abstract

The effects of target location and uncertainty of target position on reaching movements while standing were investigated. Ten healthy, right-handed adults stood facing a 17" touchscreen. They were instructed to press with their right index fingertip a push bottom and touch the center of the target displayed on the screen after it was lighted on, moving quickly their arm. The target was shown either ipsi- or contralateral to the right arm and either in a certain or uncertain position. Reaction time (RT), movement time (MT), and radial error (RE) were assessed. Results revealed shorter RT (≈ 35 ms) and smaller RE (≈ 0.19 cm) for certain than for uncertain condition and slightly longer RT (≈ 8 ms) and MT (≈ 18 ms) for reaches towards the contralateral target. In conclusion, the findings of this study showing the effect of uncertainty of target location as well as target position are also applied to arm reaching in standing position.

UNITERMS: Reaction time; Movement time; Accuracy; Target uncertainty; Upper extremity.

Introduction

Many arm reaching movements are frequently performed in standing position in our everyday life. To successfully perform those movements the central nervous system (CNS) considers the information about hand and target position for planning the reaching movements as well as to make the necessary anticipatory postural adjustments in advance (BONNETBLANC, MARTIN & TEASDALE, 2004; LEONARD, BROWN & STAPLEY, 2009; MARTIN, TEASDALE, SIMONEAU, CORBEIL & BOURDIN, 2000). Indeed, several studies have reported that individuals perform different postural adjustments of the whole body when on-line adjustments of the hand are needed (LEONARD, GRITSENKO, OUCKAMA & STAPLEY, 2011; MARTIN et al., 2000). While the postural adjustments during arm reaching movements in standing are well known as the maintenance of the equilibrium is necessary for the success of the task, the effects of target uncertainty on hand trajectories are not so clear. For example, MARTIN et al. (2000) reported that the temporal outcomes of the hand movements (i.e., reaction and movement time) were not affected by the target uncertainty; but the amount of postural adjustments, observed by the amplitude of trunk bending, increased. On the other hand, more recent studies revealed that participants took more time to reach the target when the final target position was uncertain (FAUTRELLE, BERRET, CHIOVETTO, POZZO & BONNETBLANC, 2010; LEONARD et al., 2011). However, no effect on reaction time was observed. In these studies at least one target was always lighted on at the beginning of the trial and the effects of target location uncertainty may be due to the fact that participants planned the movements in advance toward that target position. It is still unclear the effects of target uncertainty on the outcome of the hand when the stimulus about the target position (i.e., one of two targets is lighted on) is given only after the trial starts. Thus, the present study sought to investigate the effect of target location uncertainty on reaching movements performed in a standing position when participants have more than one option of target location. Particularly, in the present study, only variables related to arm reaching planning (reaction time) and movement outcome (movement time and radial error) were assessed as postural adjustments under uncertainty conditions of arm reaching have been well described in the literature (BONNETBLANC, MARTIN &

TEASDALE, 2004; LEONARD et al., 2011; MARTIN et al., 2000). Reaching movements of the right, dominant arm were investigated under certain (target location was well known prior the trial starts) and uncertain (target location was known only when the trial started) conditions. The uncertainty investigated in the present study was slightly different than those reported in the previous studies as no target was lighted on prior the trial starts and then participants needed to wait for the trial's onset to detect the stimulus and plan the movement. This is similar to the choice reaction time paradigm performed in sitting position (ROSENBAUM, 1980). Longer reaction and movement time were observed for the uncertain than certain condition during arm reaching performed by seated participants (FREITAS & SCHOLZ, 2009; HANSEN, GLAZEBROOK, ANSON, WEEKS & ELLIOTT, 2006; MIESCHKE, ELLIOTT, HELSEN, CARSON & COULL, 2001; ROSENBAUM, 1980). FREITAS and SCHOLZ (2009) reported that the time to initiate the arm movement (the reaction to an imperative stimulus was not stressed to the participants) towards an uncertain target was approximately 65 ms longer than the onset time of the arm movements towards a target well known in advance, but no effect on movement time was observed. Based on the literature about the effect of target uncertainty on sitting position, it was hypothesized that longer time to start the movement and to reach the target and greater target error should be observed for uncertain condition as participants did not have time to plan their movements in advance as in the certain condition. In addition, regardless of the uncertainty in target location, it was also expected that longer movement time should be associated with smaller spatial errors as predicted by FITT's law (1954). That is, if participants moved faster they should present more error at the target location. On the other hand, participants performing slow movements could have more time to make on-line adjustments of the hand trajectory and then the error at the target location could be smaller.

Besides the investigation of uncertainty on target location, another novelty of the study is the investigation of whether the effect of target location (i.e. ipsilateral and contralateral to the moving arm), well described on the literature for sitting position, is also preserved when reaching movements are performed while standing. Overall, individuals performing movements toward ipsilateral target in a seated position took less time to achieve the target and made less error in the target position compared to contralateral targets (BOULINGUEZ, NOUGIER & VELAY, 2001; GORDON, GHILARDI & GHEZ, 1994; MIESCHKE et al., 2001). Several explanations have been given to these advantages of ipsilateral target such as the involvement of less degree of freedom [DOF,(DOUNSKAIA, WISLEDER & JOHNSON, 2005)], less inertial resistance (GORDON, GHILARDI & GHEZ, 1994), and interhemispheric communication (VELAY & BENOIT-DUBROCARD, 1999; VELAY, DAFFAURE, RAPHAEL & BENOIT-DUBROCARD, 2001). Thus, based on the literature about the effect of target direction on arm reaching during sitting position, it could be expected to see shorter reaction and movement time as well as less spatial error to the target when placed ipsilaterally to the arm. However, different from seated position, when reaching in a standing one, the whole body DOF could be used to reach the same target location and the effect of target position may be not so evident.

Method

Participants

Ten healthy right-handed adults (all males, mean age ± SD: 25.8 ± 4.9) participated in the present study. Hand dominance of the participants was determined by the Edinburgh handedness inventory (OLDFIELD, 1971). All participants performed the tasks with their dominant arm after they had signed the informed consent approved by the University's Human Subjects Review Board. The study was performed in accordance with the declaration of Helsinki.

Experimental procedure

The experimental set-up is presented on FIGURE 1. The participants stood, in a comfortable position, with their feet apart and the right arm positioned ahead while the left arm was kept extended to their body side. Participants' feet position were marked on the floor and reproduced across trials. A 17-inch touchscreen monitor (17" LCD Desktop Touchmonitor Elo, Tyco Electronics, Menlo Park, CA, USA) was placed directly in front of the participants at a distance equal to 85% of the distance from the acromion process of the shoulder to the tip of the index finger of the right arm (i.e., upper-limb length). The height of the monitor was set in such way that the two stationary targets displayed on the screen were aligned with the half of the length of the humerus (upper arm maintain in full extension). All participants reported that they could comfortably reach the targets and touch the screen. The touchscreen was used to record the contact location of the index finger at the monitor. The two 2.5-cm diameter circular targets were set at left and right extremities of the screen (26 cm apart). At the beginning of each trial both targets were displayed on dark green color (targets were 'off'). The target to be reached changed to a light green color (target was 'on').

For all trials, participants started with their right index finger in contact with a push bottom switch fixed on a tripod with adjustable height. The tripod was set at 50% of the distance between the participant and the monitor and the height of the switch was at navel level and centered on the participants' midline. From the same initial position, participants were instructed to reach and touch the 'on' target displayed on the screen monitor. An auditory signal indicated that the trial started and the target could change its color any time within the next four seconds. Participants were told that it was a reaction time task and they should move as soon as the target turned 'on' and reach it as fast and accurately as possible.

Each participant performed two task conditions: certain, in which the participant knew in advance the target location (simple reaction time task) and uncertain, in which the location to be reached was not known prior to the trial beginning (choice reaction time task). For the first condition, they performed two blocks of 10 trials of reaching towards the same certain target location (right or left target, respectively, ipsilateral or contralateral to the right arm), with half of participants moving initially toward the left target and half starting their movements toward the right target. For the second condition, they did not know which target should be reached until one of them changed its color at the time of trial started. In the latter condition, participants performed 30 trials. In 20 trials they reached towards both the ipsilateral or contralateral targets and in 10 trials the target did not light on (catching trials). These trials were used to reduce the chances of anticipation. For each participant, the order of the trials was randomized using a customized LabView™ program (National Instruments). The order of the three blocks of trials was balanced among participants. A five-minute break was allowed between the blocks. Fatigue was never reported by the participants.

The data collection as well as target presentation were done using a customized LabView™ program. Each trial started by the experimenter and finished when the participant touched the screen. Trials were repeated later in the same block if the participants' reaction time was less than 100 ms or more than 500 ms. Time series of the voltage signal from the switch, target position and index finger position during the touch were recorded for posterior analysis.

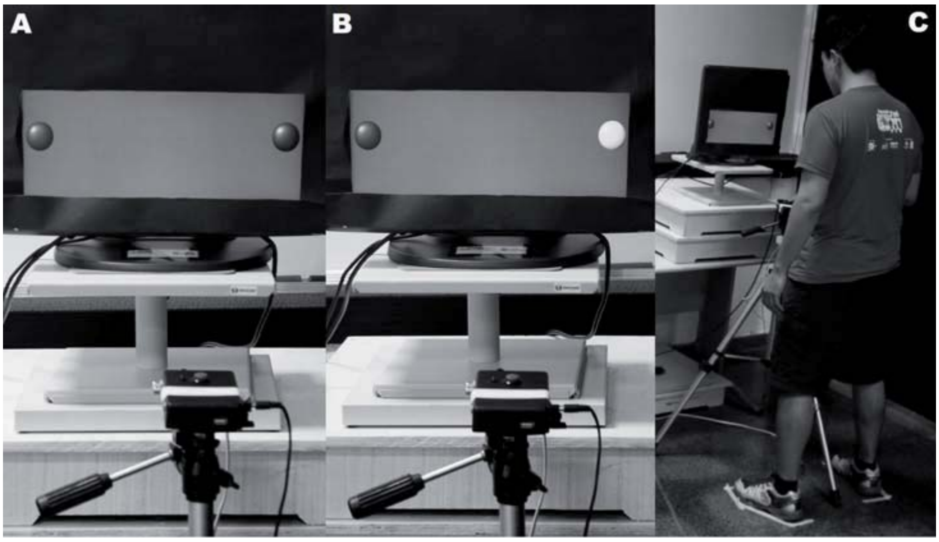

FIGURE 1 - Location of ipsilateral and contralateral targets before (A) and after (B) trial started. C, participant's position at the movement onset.

Data and statistical analyses

Data analysis was performed using a customized LabView™ routine to compute the following dependent variables: reaction time, movement time, and radial error. The reaction time was determined by the time interval from the moment that the target became 'on' to the instant of time that participants' index finger moved from the initial position (the switch was released). The movement time was defined by the time interval that the switch was released to the time that participants' index finger touched the screen. The radial error was defined based on the coordinates of the finger location obtained using the touchscreen monitor. The radial error was calculated by measuring the mean resultant distance of each finger location related to the center of the target position.

Although 10 reaches of each target under each condition were performed, only five of them were used for analysis. The first three trials of each condition were given for familiarization with the target and condition and removed from the analysis. Then, the remaining seven trials were searched and the five trials showing the shortest reaction time were selected. All three dependent variables of the selected trials were used for comparisons between target location and condition.

Statistical analyses were performed in SPSS 16.0 (SPSS Inc., Chicago, USA). The effects of target location (ipsilateral vs. contralateral) and condition (certain vs.uncertain) on all dependent variables were evaluated using two-way repeated measures analyses of variance (RM-ANOVA). Pearson correlation tests were performed to assess the relationship between movement time and radial error. The level of significance was set at $p < .05$.

Results

The average results of reaction time, movement time and radial error are presented in FIGURE 2. The first RM-ANOVA indicated that reaction time for the uncertainty condition was significantly longer (approximately 35 ms) than the certain condition ($F(1,9) = 10.34$; $p = 0.011$). In addition, an effect of target location was also revealed by the RM-ANOVA, i.e., longer reaction time was observed when reaching the contralateral (left) target compared to the ipsilateral (right) one ($F(1,9) = 7.34$; $p = 0.024$). There was no significant target location by condition interaction on the reaction time ($F(1,9) = 1.2$; $p > 0.5$).

For the movement time, the RM-ANOVA revealed only a marginal effect of target location ($F(1,9) = 5.06$; $p = 0.051$) but no effect of target uncertainty ($F(1,10) = 1.62$; $p = 0.23$). Although a slightly increase in movement time (approximately 13 ms) was observed when reaching only to the contralateral target, a significant target location by condition interaction was not revealed ($F(1,9) = 3.3$; $p > 0.05$).

Finally, the RM-ANOVA for the radial error revealed a significant effect of condition ($F(1,9) = 7.33$; $p = 0.024$), with radial error being larger for the uncertain condition, but not on target location ($F(1,9) = 0.5$; $p > 0.49$) or target location by condition interaction ($F(1,9) = 2.31$; $p > 0.16$).

Pearson correlation analyses between movement time and radial error showed that the relationship between these variables is also affected by target uncertainty (FIGURE 3). For the certain condition, correlation coefficients between movement time and radial error were not significant for both target locations ($r < -0.49$, $p > 0.15$). On the other hand, for the uncertain condition, significant relationships were observed between movement time and radial error for the ipsilateral ($r_{(8)} = -0.71$, $p = 0.021$) and contralateral ($r_{(8)} = -0.87$, $p = 0.001$) targets.

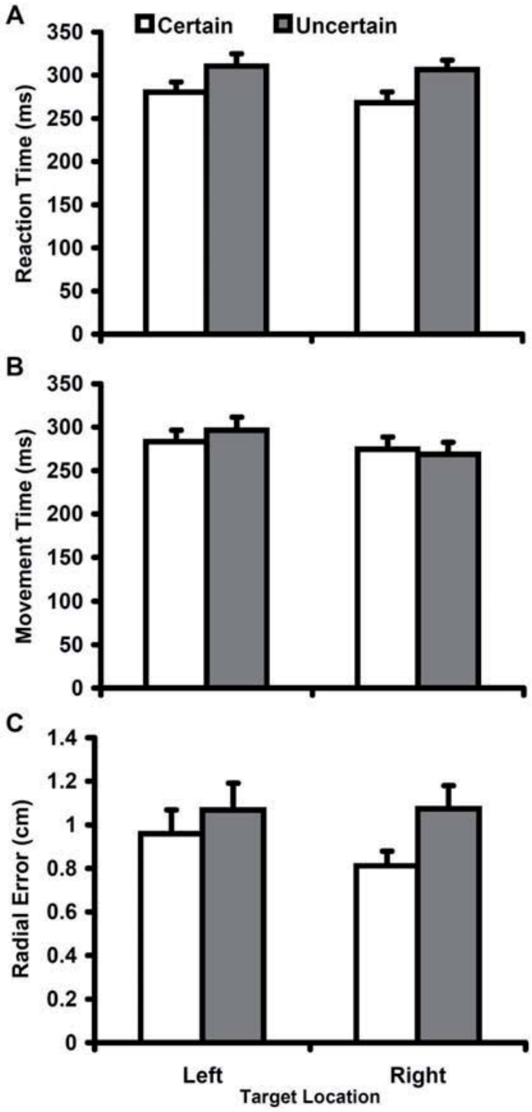

FIGURE 2 - Average across-subjects reaction time (A), movement time (B), and radial error (C) for the certain (white fill) and uncertain (dark gray fill) for each target location (left and right). Error bars depict standard errors.

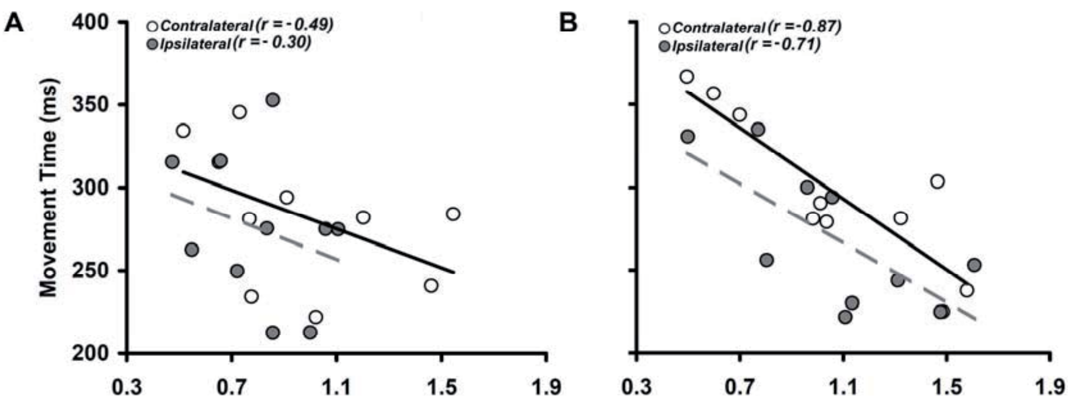

FIGURE 3 - Relationship between movement time and radial error (in A and B, respectively for certain and uncertain conditions). The correlation coefficients (r) are displayed for both conditions and target locations.

Discussion

The aim of the study was to investigate the effect of target uncertainty on temporal measures (i.e., reaction and movement time), as well as on spatial errors in reaching movements in human standing. The uncertainty on target location led to longer reaction time and more spatial errors, regardless of target location. These results confirm the first hypothesis that if participants waited for the stimulus on the target to plan the hand movement, the reaction time should be longer (Rosenbaum, 1980). Namely, the advantage for the well known target location on reaction time is due to the fact that less spatial information is needed to be considered during the motor planning while more spatial information have to be processed after the target was 'lighted on' for uncertain condition. Even though the reaction time was longer for the uncertain condition and more time could be spent for planning the movement towards the target, the accuracy on target location did not reduce in that condition. In the contrary, the spatial error was greater with target uncertainty. In fact, the increase in spatial variability with target uncertainty was reported before (Georgopoulos, Kalaska & Massey, 1981). Interestingly, a significant relationship was observed between movement time and spatial errors only for the uncertain condition. This suggested that some adjustments on hand trajectory were necessary after movement had started and, then, small errors could be observed. That is, movements performed in a longer time reached the target with greater accuracy, consistent with the classical Fitt's law relationship (1954). Because this relationship between movement time and radial errors was not significant ($r_{(8)} < -0.49$) for the certain condition, it can be suggested that the knowledge of the target position prior to the movement onset reduces the need for on-line corrections.

To our knowledge only few studies investigated the reaction and movement time of the hand reaching for a target during standing position (Hyde & Wilson, 2010; Leonard et al., 2011; Martin et al., 2000). In Hyde and Wilson study (2010) the main aim was to investigate the effect of double-step paradigm on children with developmental coordination disorder in sitting position. Moreover, the authors asked to healthy children to perform the same arm reaching movements towards a target that could or not jump from initial position while standing and observed an effect of target uncertainty (jump vs. no-jump target) only on the movement time (i.e., increased duration of more than 280 ms when the target was uncertain). Leonard et al. (2011) also reported increased movement duration with increased target uncertainty. Conversely, Martin et al. (2000) reported that both reaction and movement time were not affected by the target uncertainty. Overall, our findings do not reproduce the findings of either study as longer reaction time but not movement time was observed. It is possible that differences in target distance and the use of more joints (e.g., trunk and hip) and, consequently, more DOF needed to be controlled may explain the differences [85% of the full extended arm was used in the present study while Martin et al. (2000) and Leonard et al. (2011) used equal or longer distance than the full extended arm].

In addition to the target uncertain, both reaction and movement time were affected by the position of the target to be reached. That is, longer reaction and movement time were needed to reach the left, contralateral target compared to the right, ipsilateral one. These results extended the findings from the literature about the effect of target location on sitting position to a standing one. Several studies on sitting position reported that movements performed towards ipsilateral targets (same field of the hand) are generally faster (shorter duration) than contralateral targets (hand moves across the body midline) (Carson, Chua, Goodman, Byblow & Elliott, 1995; Dounskaia, Wisleder & Johnson, 2005; Gordon, Ghilardi & Ghez, 1994; Mieschke et al., 2001; Velay & Benoit-Dubrocard, 1999; Velay et al., 2001;). Three explanations have been used to justify the effect of target position on movement time and/or reaction time in a sitting position that could also explain the findings of the present study. First, the differences in movement time between ipsilateral and contralateral targets are due to some biomechanical constraints with some ipsilateral advantage as observed for sitting position (Dounskaia, Wisleder & Johnson, 2005). For planar movements in a sitting position, Dounskaia, Wisleder and Johnson (2005) reported an advantage for ipsilateral targets related to the patterns of joint coordination; that is, the involvement of only fewer DOF (mostly elbow motion) as well as smaller amount of joint motion towards that target compared to contralateral target. In addition, ipsilateral targets have lower inertial resistance than the contralateral target that could affect the movement speed and accuracy (Gordon, GHILARDI & GHEZ, 1994). However, we have found no differences in spatial error between ipsilateral and contralateral targets. One explanation could be that our participants could freely move their arms while in the study of GORDON, GHILARDI and GHEZ (1994) participants' arm was in contact with a horizontal surface and then more frictional forces, in particular, for contralateral targets, could affect the targeting error. In contrast, in GORDON, GHILARDI and GHEZ (1994) gravitational forces did not play a role on the movements as they played on the current study. More functional, unconstrained movements were used here because they are more representative of daily living activities and, also, in the practice of sports (e.g., tennis and badminton).

A second explanation about the temporal differences with respect to target location is related to the central integration of information (MIESCHKE et al., 2001). In accordance with this hypothesis, less time is spent for on-line corrections at the late phase of the movement trajectory if the target is homolateral to the arm. Finally, the fact that the reaction time is shorter for movements on the ipsilateral target may be explained by the intrahemispheric communication where the spatial target location and the arm movement are in the same hemisphere (VELAY & BENOIT-DUBROCARD, 1999; VELAY et al., 2001). Alternatively, based on this hypothesis, reaching contralateral targets, in which the arm crosses the midline of the body, would require more interhemispheric communication and then more time for motor planning (VELAY & BENOIT-DUBROCARD, 1999). However, other studies should be done to test these hypotheses in more details.

In conclusion, the current study extended some reported findings about the effect of uncertainty on target location during sitting position to a standing posture, such as, increased reaction time and spatial errors when the target location was uncertain. In addition, reaching movements performed while standing were affected by the target location (ipsilateral vs. contralateral) similarly to sitting position. Further studies from our group are in execution to investigate how uncertainty (whether target position is or not well known prior trial onset) and target location (ipsilateral vs. contralateral) affect the anticipatory postural adjustments as well as the hand trajectory characteristics in a standing position.

Resumo

Efeitos da localização do alvo e da incerteza em movimentos de alcance na postura ereta

Os efeitos da localização do alvo e da incerteza quanto à posição do alvo em movimentos de alcance foram investigados. Dez adultos permaneceram em pé em frente a um monitor sensível ao toque. Eles foram instruídos a pressionar com o dedo indicador direito um interruptor e tocar o centro do alvo apresentado no monitor após ele acender, movendo o membro superior rapidamente. O alvo foi mostrado ipsi ou contralateralmente e os participantes tinham ou não certeza sobre a posição do alvo. O tempo de reação (TR) e movimento (TM) e o erro radial (ER) foram avaliados. Os resultados revelaram menor TR (≈35 ms) e ER (≈0,19 cm) para a condição de certeza e maiores TR (≈8 ms) e TM (≈18 ms) para os moimentos ao alvo contralateral. Concluindo, esses achados mostraram que os efeitos da incerteza da localização e a posição final do alvo podem ser aplicados para movimentos de alcance na posição ereta.

UNITERMOS: Tempo de reação; Tempo de movimento; Acurácia; Incerteza do alvo; Membro superior.

Resumen

Los efectos de la ubicación de la diana y la incertidumbre en los movimientos de alcance en la posición vertical

Los efectos de la ubicación de la diana y la incertidumbre acerca de la posición de la diana en los movimientos de alcance fueron investigados. Diez adultos sanos y diestros estaban frente a una pantalla táctil de 17". Se les instruyó para presionar un interruptor con el dedo índice derecho y tocar el centro de la diana que aparece en la pantalla después de haber sido iluminado, moviéndo rápidamente su miembro superior. La diana fue mostrada ya sea ipsi o contralateralmente y los participantes tenían o no certidumbre sobre la posición de la misma. El tiempo de reacción (TR), el tiempo de movimiento (TM), y el error radial (ER) fueron evaluados. Los resultados revelaron ser más cortos TR (≈ 35 ms) y RE menor (≈ 0,19cm) en la condición de certeza y mayores TR (≈ 8 ms) y TM (≈ 18 ms) en los movimientos hacia la meta contralateral. En conclusión, los hallazgos de este estudio que muestra los efectos de la incertidumbre de la ubicación de la diana, así como la posición de la diana se aplican también a movimientos de alcance en la posición erecta.

Palabras clave: Tiempo de reacción; Tiempo de movimiento; Precisión; Incertidumbre de la diana; Extremidad superior.

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