Proprioceptive acuity varies with task, hand target, and when memory is used

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Abstract. Participants completed a series of seven tasks to assess proprioceptive acuity of each hand. Proprioceptive localization was fairly accurate and precise. Constant error and precision differences were found as a function of the task, movement of the hand target, the hand being localized, and localization from memory.

Keywords: Proprioception, reach, reproduction, estimation, task factors

1 Introduction

Although planning a reach to a proprioceptive target (e.g. a hand) incorporates proprioceptive information from the target and the reaching hand, reach tasks are often used as means to explore proprioceptive acuity [e.g. 1, 2, 3]. To circumvent this problem, Jones et al. [4] presented a novel proprioceptive estimation task in which participants indicated the felt location of a hand target (either left or right) relative to visual references or their body's midline. They sought to determine if behavioural differences would arise between a task in which the central nervous system (CNS) used proprioceptive information to plan a goal directed movement to the hand target and a more perceptual task in which no such planning was required. Much like visual information [5], research has suggested differential processing of proprioceptive information for perception and action [6]. Jones et al. [4] found no differences across these two task types. Our purpose was to (1) systematically compare this proprioceptive estimation task to a reach task and (2) to expand on the findings of Jones et al. [4] by comparing this estimation task to a spatial reproduction task (described below) using the same subjects and the same target locations. Our third, novel, aim was to examine if proprioceptive acuity would differ between online and remembered proprioceptive localization in our estimation task. While decays in proprioceptive memory have been shown in reach tasks [7], it was unknown if such decays would also occur when the proprioceptive information was not used to guide a goal directed movement. Our fourth aim was to compare the left and right hand-targets and active and passive placement of the hand-target prior to localization.

2 Method

2.1 Subjects

Fifteen self- reported right handed participants (9 males; Mean age = 22.2 yrs) volunteered to participate in the present experiment.

2.2 Experimental setup and procedure

A schematic of the experimental set up is shown in Figure 1. Participants sat on a height adjustable chair in front of a 90 cm high table (Fig. 1A and C). Participants rested their head on a chin rest located 40 cm above the table top (not shown in figure). Participants grasped the vertical handle of a two-jointed robot manipulandum (Interactive Motion Technologies Inc., Cambridge, MA) with their unseen hand (either right or left); the thumb rested on top of the robot handle (1.4 cm in diameter) and the handle was at approximately waist level (Fig. 1A and C). The robot manipulandum either moved the hand passively, from the start position (body midline, 23.5cm in front of the body; shown in 1D) in a single direction to one of the target positions (12 cm from the start position, in front of the body midline, or 5 cm left or right of body midline; Fig. 1 B and D), or restricted participants' active movement along a straight constrained path until the hand reached the target location (constrained paths shown in 1D). In our proprioceptive estimation tasks, a computer screen projected visual references (1cm in diameter, Fig. 1B) onto a reflective surface above the robot handle (Fig. 1A). A touch screen® (Keytec Inc., Garland, TX) was used to record reach endpoints in our reach tasks (Fig. 1 C and D). Participants could see their reaching arm in the dimly lit room. The target hand/arm was covered using a cloth in all tasks.

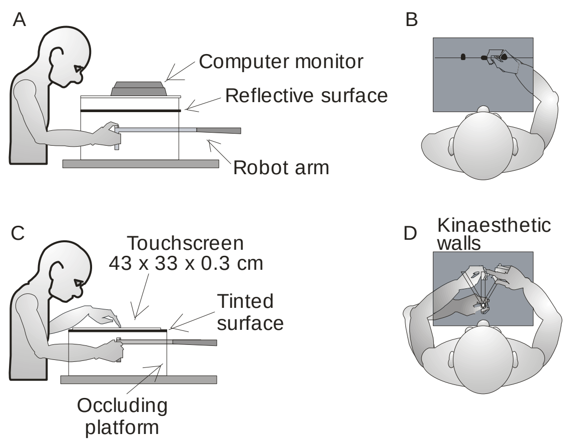

Fig. 1. (A) Side view of the experimental setup used for the proprioceptive estimation tasks. (B) Above view of the visual reference locations for the proprioceptive estimation tasks (same as target locations used in the reaching and reproduction tasks). (C) Side view of the experimental setup used in the reaching and reproduction tasks. (D) Above view of the target locations for the reaching and reproduction tasks.

Participants localized the unseen left or right hand using one of three task types: estimation, reach, or reproduction. In the proprioceptive estimation tasks, the hand target was actively or passively moved from the start position to a location to the left or right of one of three visual references (Fig. 1B). The visual reference appeared once the hand target reached this designated location, and participants indicated if the felt position of the hand was to the left or right of this reference (a 2 alternative forced choice task, 2AFC) [4]. In the remembered proprioceptive estimation task, participants actively placed and returned their hand to the start location before the visual reference appeared; participants indicated if the remembered location of their hand was to the left or right of this reference. In the proprioceptively guided reach tasks, the hand target was actively or passively moved from the start position to one of the three target locations (same as reference marker locations). Participants then reached with the opposite hand to the felt location of the hand target, or in the case of the remembered reach task (always active movement), reached to the remembered location of the hand target (Fig. 1D). In our reproduction task, participants reproduced the spatial location of the hand target using the same hand (always active movement and remembered). Participants actively moved the hand target (guided by the robot) to a target position and then returned it to the start. Constraints on movement (applied by the robot) were then removed; participants moved the hand target back to where they felt it had been using the robot. For the reaching and reproduction tasks, subjects moved to each target with each hand 40 times, for a total of 240 trials for each of the four tasks.

2.3 Assessing proprioceptive localization accuracy and precision

In our estimation tasks, a 2AFC adaptive staircase algorithm was used to adjust the position of the hand target across trials depending on the subject’s pattern of left or right responses [see 4]. For each reference location there were two corresponding staircases, for which the hand target began either 3 cm left or right of the reference marker, which were adjusted independently and randomly interleaved (three pairs of staircases – left and right for each reference - each made up 50 trials, for a total of 150 trials for each estimation task). We fitted a logistic function to the responses for each reference marker (pair of staircases), for each participant, in each condition. Thus, for each reference marker, we computed the bias (the point of 50% probability), which is a measure of accuracy, and the uncertainty (the difference between the positions where the hand was judged left or right of a reference marker 84% of the time) which is a measure of precision [see 8]. In the reaching and reproduction tasks, the horizontal difference between the actual location of the hand target and the reach or reproduction endpoint was computed.

We conducted two 2(hand: left or right hand) x 2(task: estimation or reach) x 2(movement: active or passive) x 3(target: left, center, right) RM ANOVAs to compare both biases and precision across the estimation and reach tasks. We use separate RM ANOVAs to compare accuracy and precision among the remembered tasks (reach, estimation, reproduction). Alpha was set at 0.05 and pairwise comparisons were Bonferroni corrected.

3 Results

Figure 2 displays average biases (solid symbols) as a function of task (bar color), target location (shape of the symbols), for the left hand-target (top) and right hand-target (bottom). If participants perfectly estimated the felt location of the hand target, the symbols would fall on the horizontal black line at zero. The length of each box represents the precision of localization. In the proprioceptive estimation paradigms (green bars), the ends of the box are the locations where participants judged the hand target to be left (bottom of the box) or right (top of the box) of the target location 84% of the time (encompassing the middle 68% of the distribution of estimates). In our reach and reproduction tasks, the ends of the box represent the bias ± 1 standard deviation (also the middle 68% of the distribution) [8].

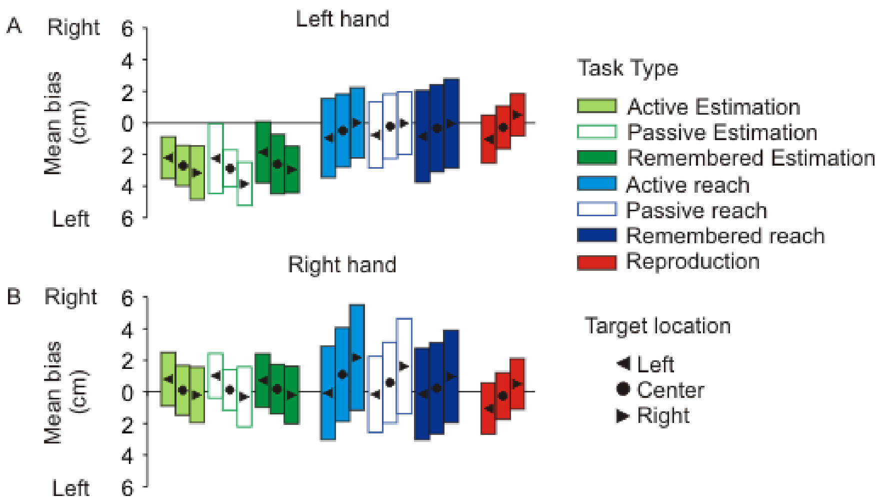

Fig. 2. Average biases (in cm) for the left (A) and right (B) hand targets as a function of task type, movement, and target location.

3.1 Task type

Our first aim was to compare the three measures of proprioceptive acuity. Overall, horizontal errors were deviated more leftward in the estimation tasks than in the reach and reproduction tasks. Reaches were also significantly less precise (blue bars) than estimations (green bars) and reproductions (red bars). As discussed below, these differences between conditions also varied with hand target and target position.

3.2 Localization from memory

Our second aim was to examine proprioceptive localization from memory. Participants were less precise when reaching to the remembered location of a proprioceptive target (dark blue bars) than when reaching online (light blue solid and open bars). No differences were found between online and remembered estimation conditions (light solid and open, and dark green bars). When comparing among remembered tasks (remembered estimation – dark green solid bars, remembered reach – dark blue solid bars and reproduction – red bars), no accuracy differences were found. But, remembered reaches were significantly less precise than reproductions and remembered estimations, although reaches were found to be less precise than estimations and reproductions overall (as stated above).

3.3 Hand target

In our active and passive reach, and estimation tasks, horizontal errors for the left hand were biased to the left (green and blue bars top panel) and horizontal errors for the right hand were biased to the right (green and blue bars bottom panel). Overall, reaches to the right hand (left hand reaching) were significantly less precise than reaches to the left hand (right hand reaching).

3.4 Active and passive movement of the hand target

No differences in horizontal error or precision were found between the active and passive conditions in our reach and estimation tasks.

3.4 Target position

Horizontal errors were deviated more leftward for the right target location (rightward pointing triangles) and more rightward for the left target location (leftward pointing triangles) in our active and passive reach (light blue and dark blue open bars), and reproduction tasks (red bars). Precision did not differ across the target positions.

4 Discussion

This is the first comprehensive comparison between reach and reproduction tasks, and our estimation task. Overall, while participants were fairly accurate and precise when localizing an unseen hand, we found that proprioceptive acuity differed across tasks and task parameters. Reaches were significantly less precise than estimations and reproductions, regardless of whether active or passive movement was used, or localization occurred from memory. This finding suggests that proprioceptively guided reach tasks (goal directed movement tasks) may elicit noisier estimates of hand target position. For example, processing proprioceptive information about the target and reaching hand, and the need to synthesize that information to plan a goal directed movement, may introduce more variability for proprioceptive guided reaching. As such, unless the primary aim of a study is to examine sensory processing for goal directed movements, measurement methods that are perceptual (such as our estimation task) may be more appropriate for drawing general conclusions about how well we can localize a body part in space. Our results suggest a slight disadvantage (in precision) when localizing a proprioceptive target from memory in a reach task [9, 12]. Greater variability was also found in the remembered reach task as compared to the other remembered tasks, but this could not be separated from the overall greater variability found for reaches. Research has previously reported that reaches made to the left hand are deviated leftward and reaches made to the right hand are deviated rightward [2, 3, 4, 10], but it has been unclear whether such biases would persist if the proprioceptive localization task did not include a goal directed movement. We and Jones et al. [4] have found that these biases are consistent in our estimation task. These biases may not be due to the reaching hand; participants seem to truly perceive their left hand to be more leftward and their right hand to be more rightward. The discrepancy between previously reported accuracy differences between active and passive placement of the hand target [1, 13] and our findings may be because of the method used to place the hand target in our task. Our robot manipulandum limits noise introduced into the somatosensory system from extraneous movements (e.g. as compared to when a hand is passively moved by an experimenter, or self-guided using tactile or instruction cues). Also, active and passive placements of a proprioceptive target do not always differ [4, 14]. Contrary to some reach tasks [3], we did not find any differences in precision across target positions. Although like others [11], we did find differences in accuracy: errors were biased to the right for the left target and left for the right target, regardless of hand target.

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