Position Sense Testing: Influence of Starting Position and Type of Displacement

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Objective: To assess the effect of starting position, target position, and various types of limb displacement on repositioning tests commonly used for clinical evaluation of rehabilitation.

Setting: Controlled laboratory environment.

Participants: Sixteen healthy volunteer subjects.

Main Outcome Measure: Absolute error, i.e., the absolute difference between target and replicate positions.

Design: Each subject performed four testing procedures consisting of different types of limb displacement (active, passive, and passive during antagonist muscle contraction). For each procedure, horizontal movements were performed ipsilaterally about the right glenohumeral joint from one intermediate starting position (40°) and two extreme starting positions (0° and 80°). Four fixed target positions (16°, 32°, 48°, 64°) were presented for each starting position. The subjects were required to replicate target position after returning to the respective starting position.

Results: Lower repositioning errors occurred with active displacement procedures compared with passive, and with the intermediate starting position compared with the extreme. Target position, however, had no effect on repositioning errors.

Conclusions: Starting position and type of displacement should be considered in interpretations and comparisons of data from clinical studies.

Key Words: Kinesthesia; Method; Proprioception; Shoulder; Rehabilitation.

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In the last decade, proprioceptive testing has markedly increased as a way to evaluate rehabilitation after joint injury and as a research tool for investigating sensorimotor mechanisms. The term proprioception was originally coined by Sherrington in 1906 to describe the sense of limb position and movements subserved by deep receptors in muscles, tendons, and joints. It is currently acknowledged that proprioception is a complex entity encompassing several different components, such as the sense of position, velocity, movement detection, and force, and that the afferent signals that give rise to them may well have origin in different types of receptors. Consequently, injuries of one type (eg, stroke) may present deficits for a particular proprioceptive component, whereas traumatic injuries such as ligament tears might affect another component. Accordingly, current studies on proprioception have investigated one or several sensations as isolated entities. A better understanding of the various sensations is needed before an adequate overall assessment of proprioception can emerge. In the present study our focus is on “position sense,” herein defined as the awareness of the actual position of the limb.

Position sense has been assessed in several clinical studies. The tests usually involve some type of position matching procedure, in which a target joint position is presented and the subject (patient or control) must match that position. The absolute difference between target and matching joint positions is often used as a measure of position sense accuracy. General conclusions about position sense accuracy for a particular joint, for example, the knee, are often drawn, and comparisons between studies made, with little regard to factors within the test design that may influence the outcome of individual studies. A recent review attributed such experimental factors as a possible explanation to differences in results between studies. In particular, the influence of factors such as the range or direction of motion (starting to target position) on position sense accuracy are scarcely considered when interpreting results from a particular study or when relating between studies.

The sensation of movement detection is markedly enhanced if the muscle is contracted. This enhancement is most likely caused by an increased sensitivity of muscle spindles. It could be that the awareness of position sense is also enhanced when the limb is passively positioned while the antagonist muscle is contracted. This possibility has not been investigated. For that matter, increased spindle afferent activity during muscle activation may suggest an enhanced position sense accuracy when the tests are performed actively rather than passively. A few researchers have investigated this possibility, but with conflicting results. Roy and Diewert reported that subjects replicated movement extent more accurately after active target presentation than after passive. Koelsch however, found no difference between the two types of target presentation. For the replication aspect, Voight and coworkers suggested better accuracy when the arm was actively repositioned, whereas Koelsch found no difference between active and passive repositioning. A more systematic approach is thus required to clarify discrepancies in previous studies and to further elucidate how these factors (varying types of limb displacement during target presentation and replication) influence position sense accuracy.

The objective of this study was to assess the impact of
starting position, target position, and different types of limb
displacement on the outcome of limb repositioning tests.
Specifically, in a group of normal subjects, the accuracy of
repositioning the arm was determined for horizontal abductions
and adductions about the glenohumeral joint, using various
starting and target positions in four testing procedures. The
displacements (target presentation/replication) of these proce-
dures were (1) Active-Passive, (2) Passive-Passive, (3) Semipas-
sive-Semipassive (passive during antagonist muscle contrac-
tion) and (4) Active-Active.

METHODS

Subjects
Sixteen healthy subjects, 8 men and 8 women (age 23 ± 3yrs),
participated in the study. All subjects were right handed and had
no history of injury or current problems with the shoulder or
arm. Subjects received verbal and written descriptions of all
procedures and the testing was performed after informed
consent was signed. The study was approved by the ethics
committee of the Faculty of Medicine at the University of
Umeå.

Testing Apparatus
A schematic of the apparatus is illustrated in figure 1. Briefly,
the fully automated system was composed of a steady car chair®
and a motorized apparatus for the arm. The rig and the chair
were adjusted so that the rotation axis of the rig was congruent
with the center of the glenohumeral joint. The rig was equipped
with a DC-servomotor controlled by personal computer (PC). A
receiver attached beneath the apparatus and a stationary electro-
magnetic transmitter (FASTRAK®) were used to monitor orien-
tation of the rig for determination of target and matching
positions. A hand-held switch in the subject's left hand signaled
the control PC to stop rotation of the rig when pressed. Data
were sampled on a PC-80586 computer.

Testing Procedure
While seated, blindfolded, with their right arm in the
motorized rig (fig 1A), subjects were required to match a
previously presented target position for horizontal abduction
and adduction of the glenohumeral joint. All movements were
performed on the right hand side of the body within an 80°
range of motion that likely minimized input from the joint
capsule receptors most active at extended joint positions.17
Thus, movements were performed from starting positions of 0°,
40°, and 80° to target positions of 16°, 32°, 48°, and 64°, as
illustrated in figure 1B. Consequently, when starting at 0°, all
movements were horizontal abductions, whereas for the 80°
starting position only adduction was performed. For the 40°
starting position, both adduction (to 16° and 32°) and abduction
(to 48° and 64°) were performed. On a given day for a particular
subject, the initial starting position was predetermined ran-
domly. Once determined, all target positions were completed
(in randomized order) before another starting position was
used.

Four testing procedures, also performed in randomized order,
were presented for all subjects, but on different days (separated
by at least one day, but sometimes by several weeks depending
on subject availability). Before each procedure, a training
session with detailed verbal instructions was provided for
familiarization. All instructions were prerecorded and provided
to the subject through headphones by the computer-controlled
system. The procedures were as follows.

(I) Passive-active (Pas-Act). For this procedure, the arm
was passively moved at 19° per second to a predetermined

Fig 1. (A) Schematic of blindfolded subject seated in the testing device with the right arm resting on the motorized apparatus. Headphones
were used to emit white noise to eliminate auditory cues and to administer verbal instructions when required. A receiver attached beneath
the rig continuously collected data of rig movement relative to a fixed transmitter. A button in the subject's left hand was pressed to indicate
completion of a matching movement. (B) Overhead view depicting testing movements. Thick lines represent starting positions; dotted lines
represent target positions. Arrows indicate direction of movement for a particular starting position.

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target position. The arm remained at this position for five seconds (same duration for all trials in all procedures) and was then passively returned at 39° per second to the starting position. After remaining at the starting position for three seconds (same duration for all trials in all procedures), the subject actively moved the arm in an attempt to match the target position. When the subject considered the arm to be at the target position, he or she pressed the button held in the left hand, thereby registering the matching position.

(2) Passive-passive (Passive). The same type of passive movement to the target position and back to the starting position as Pas-Act was performed. The arm was then passively moved at 9° per second and stopped when the button was pressed by the subject, indicating recognition of the target position. The lower velocity of this movement was used to minimize the use of time as a cue.

(3) Semipassive-semipassive (Semipassive). While the arm was passively moved (as for Pas-Act) to a target position, subjects maintained a light torque (SNm) by resisting in the opposite direction of the movement. Before testing, the subjects were trained to perform the right amount of resistance by visual feedback of the torque by means of a lighted (LED) display. The subjects were instructed to relax during the return to the starting position. The arm was then moved passively at 19° per second, again while the subject maintained a light torque throughout the movement. As in Passive test, the movement was stopped when the subject pressed the button to indicate recognition of the target position.

(4) Active-active (Active). From the starting position, the subject actively moved the arm until a command to "Stop" was given. The apparatus was then inched and the arm remained at this position for five seconds. The subject then actively returned to the starting position. An active attempt to match the target position followed (as for Pas-Act).

Data Analysis

For each testing procedure (Pas-Act, Passive, Semipassive, Active), each subject performed six trials for each of the 12 combinations of starting and target positions (0° to 16°, 0° to 32°, ..., 80° to 64°). The absolute errors—that is, the absolute values of the differences between target and matching positions—from the six replications of each combination of starting and target position were averaged. These data were analyzed by means of a three-way repeated measures analysis of variance (ANOVA 4 X 4 X 3 design) to determine effects attributable to testing procedure, target position, and starting position. If significant main effects were present, post-hoc Tukey test was used to delineate differences. For all tests, p < .05 was considered significant. To get an idea about directional bias, the average absolute errors were calculated from the six replications of each combination of starting and target position. Positive actual errors reflected target overshooting and negative values reflected undershooting. Data in the text are presented as mean ± 1 standard deviation (SD) and in graphs as mean ± 1 standard error (SE).

RESULTS

In figure 2 the absolute errors, averaged for all subjects, are displayed for all combinations of testing procedure, starting position, and target position. The three-way ANOVA revealed significant differences in absolute error due to testing procedure (p < .02) and starting position (p < .001). However, the absolute error did not differ due to target position (p = .17). Furthermore, the interaction effect of Procedure × Starting position (p < .05) was significant. Starting position × Target position (p = .05), Procedure × Target position (p = .48), and Procedure × Starting position × Target position (p = .18) were not significant. In figure 3, the average absolute error for each testing procedure is shown. Post-hoc analysis revealed that the absolute error was significantly lower for the Active procedure than for the Passive procedure (p < .02). The other comparisons were not significant, although that of Active versus Pas-Act approached significance (p = .05). In regard to starting position (combining all procedures and target positions), the post hoc analysis revealed that the absolute error for the 40° starting position (3.2 ± 1.9°) was lower than for 0° (4.3 ± 2.0°) and 80° (4.6 ± 2.3°) (p < .001 for each comparison), whereas no difference was found between 0° and 80° (p = .11).

By observing the actual errors, we could see a general trend of overshooting. This trend was greatest when the target position was closer to the starting position, and less or absent when the target position was farther from the starting position. For some testing procedures, the greater distances between starting and target position actually presented an undershoot. An example of these trends is presented in figure 4, where the
FIG 3. Absolute errors for testing procedures. Data are expressed as mean ± SE for 16 subjects, three starting positions, and four target positions. *Significant difference between the Active and Passive procedures.

actual errors, averaged for all subjects, are shown for each combination of starting and target position for the Pas-Act procedure.

DISCUSSION

The results of the present study indicated that repositioning accuracy for horizontal arm movements is influenced by the type of limb displacement during target presentation and repositioning, and also by the starting position. Target position, however, had no impact on repositioning accuracy. We had surmised that limb displacement during muscle activation would enhance position sense accuracy, in part because of increased afferent input from muscle spindles. In the present study, such an effect would produce a lowest-to-highest error hierarchy as: (1) Active, (2) Semipassive, (3) Pas-Act, and (4) Passive. This was largely confirmed (fig 3), although not significant for each post-hoc comparison—a significant difference was only found between the Active (active presentation/active replication) and the Passive (passive presentation/passive replication) procedures. Previous studies employing similar arm movements investigated differences arising from either the type of target presentation or the type of replication. For a study in which only active replication was used, Roy and Diewert found a lower absolute error for active target presentation than for passive. In this regard, our result for the comparison between the Active and Pas-Act procedures, approaching significance, lends support to their finding. It should be noted, however, that the study by Roy and Diewert focused on movement extent by altering the starting position before replication. In another study entailing almost the same displacement pattern as our study, no difference was found between active and passive presentation.

We found no difference between active and passive repositioning of the limb when the target was presented passively ( Passive vs Pas-Act). This finding is in line with the study by Kelso. Voight and colleagues, on the other hand, suggested active repositioning to be more accurate than passive, although no statistical evidence was provided. As alluded to in the introduction, the lower absolute error for the Active testing procedure may be related to an increased sensitivity of muscle receptors when the muscle is loaded. Also, this finding may be interpreted through such concepts as efference copy, central efferent monitoring, and corollary discharges as discussed by Kelso. However, the applicability of these concepts to the present study may be questionable since the target positions were defined by the experimenter (constrained), which did not allow the subjects to plan their movements. Differing methods may also contribute to the differences between testing procedures. For example, during active replication in the present study, subjects were allowed to adjust the matching position before pressing the button, whereas for Passive and Semipassive replication subjects were required

FIG 4. Actual errors (overshoot/undershoot) for starting positions of 0°, 40°, and 80° and target positions of 16°, 32°, 48°, and 64° for the Pas-Act testing procedure. The plot indicates that overshooting tended to decrease as the distance between starting and target position increased. Data are expressed as mean ± SE for 16 subjects.
to press the button during movement. Although such methods are commonly used for active and passive replication, the importance of such a disparity has not been assessed.

The reason for the greater accuracy at the 40° starting position for all test procedures is not readily apparent; however, it could be speculated that movements from 40° started with the antagonist muscle more stretched (ie, longer) than from the 0° and 80° starting positions. It is probable that a major part of the proprioceptive afferent inflow from muscles arises from the movement antagonists, since muscle spindles fire more during muscle elongation than during shortening.18 For the first part of the movements from the 0° and 80° starting positions, the antagonistic muscles were in a shortened state, during which it is likely that their spindle afferents did not fire;19 whereas, for the 40° starting position, the afferents might have fired during the entire movement, thus providing better inflow of movement information. Alternatively, the lower absolute error from 40° may be related to the subject’s understanding of the range over which he or she will be tested. From 40°, the possible magnitude of movement was obviously lower than from the 0° and 80° starting positions—movements from 40° to full abduction were shorter than from 0° to full abduction. According to a hypothesis by Scott and Loeb,19 the sensor gain of muscle spindles may be adjusted to optimize the input of sensory information. Thus, if a test involves random repositioning of the joint over an extended range of motion (as for the 0° and 80° starting positions), then the subject (unconsciously) would select a low fusimotor gain to avoid saturation of the spindle activity near the extremes of the test range, resulting in a lower resolution of the position information from the spindles.

In the present study, from a particular starting position, target position had no effect on repositioning accuracy. This suggests that receptors providing static position sense information respond similarly regardless of the location of the limb. For the sensation of movement detection, it was shown that the awareness was enhanced for movements toward extreme joint positions, where joint receptors are activated.20,21 In the present study, these types of receptors were probably not activated, especially since we did not use extended target joint positions. Several studies have focused magnitude of displacement as a possible determinant of repositioning accuracy when investigating differences attributable to target position. In this context, the present study concurs with some of these studies,22,23 but conflicts with others.15-24,25 However, since our experimental design was primarily directed at investigating effects due to starting position, target position, and type of displacement, it is difficult to isolate the impact of magnitude of displacement. Furthermore, movement direction had no effect on repositioning accuracy in the present study. In contrast, Fridén and coworkers10 found a greater accuracy for knee flexion than for knee extension when assessing the subjects’ ability to replicate movement extent.

Most clinical studies employ absolute error as a measure of repositioning accuracy. Under this condition, the facets of the data that are described by actual (constant) and variable error (SD) are disregarded. In fact, data that present similar absolute error may show quite dissimilar characteristics when both actual and variable error are considered. It is possible that certain injuries may present deficits for only one facet of repositioning, which may not be revealed by absolute error. For example, whiplash patients were recently characterized as “overshooters” of the target, as revealed by a positive actual error, when attempting to reproduce head position.26 Variable error, on the other hand, may provide a less biased estimate of repositioning accuracy. Thus, it is suggested that future clinical investigators consider these options when assessing position sense tests.

CONCLUSION

The aim of the present study was to assess the impact of starting position, target position, and different types of limb displacement (active, passive, and passive during antagonist muscle contraction) on position sense tests used for clinical assessment. The study indicates that starting position and type of displacement influence the outcome of these tests, and therefore these variables should be taken into account when interpreting results and when relating between studies. The low absolute errors for the Active test and the intermediate starting position may make these conditions more sensitive to detect small changes and, therefore, make them preferable in clinical situations. Also, the lack of difference in error attributed to target positions may be important in position sense testing for patients with joint instability whose range of motion is likely limited by pain. Our study focused on the shoulder joint, and the study population was of a limited age range. We assume our findings may apply to other joints, but future studies of the present type are needed to confirm this assumption. We purposely chose a limited age range of subjects to minimize variability since it has been shown that position sense accuracy is age dependent.11,27,28 Therefore, other age groups, especially the elderly, who displayed reduced proprioceptive ability, should be addressed in future studies. Also, further research is required to identify other factors that may affect the outcome of repositioning tests.

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