The Informational Properties of the Throwing Arm During Anticipation of Goal-Directed Action

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Abstract

We examined the informational value of biological motion from the arm in predicting the location of a thrown ball. In three experiments, participants were classified as being skilled and less skilled based on their actual performance on the task (i.e., using a within-task criterion). We then presented participants with a range of stick figure representations and required them to predict throw direction. In Experiment 1, we presented stick figure images of a full body throwing action, right throwing arm plus left shoulder or throwing arm only. Participants were able to anticipate throw direction above chance under all conditions irrespective of perceptual skill level, with the perceptually skilled participants excelling under full body conditions. In Experiment 2, we neutralized dynamical differences in motion to opposing throw directions from the shoulder, elbow or wrist of the throwing arm. Neutralizing the wrist location negatively affected anticipation performance in all participants reducing accuracy to below chance. In Experiment 3, we presented the wrist marker location alone or the upper section of the throwing arm (shoulder-elbow). Participants were able to successfully anticipate above chance in these latter two conditions. Our findings suggest that motion of the throwing arm contains multiple sources of information that can help facilitate the anticipation of goal-directed action. Perceptually skilled participants were superior in extracting informational value from motion at the local and global levels when compared to less skilled counterparts.

Key words: *Localized Information Pick-up; Biological Motion; Skill; Perception.*

Public Significance Statement

The ability to read a thrower's direction is important for developing catching and striking skills. Skills that are key to success in many face-paced ball sports. In this study, multiple sources of information where identified which good perceivers of a throwers direction are able to use in order to achieve this skill.

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Bourne, Bennett, Hayes, Smeeton, and Williams (2013) reported that participants could anticipate the future direction of a ball throw when presented with stick figure images containing biological motion only. More specifically, the use of a manipulation involving spatial neutralization identified biological motion from the throwing arm as the critical information underpinning these anticipation judgments. The finding that biological motion from the throwing arm was the key information underpinning anticipation of a throw supported earlier published work involving detailed biomechanical analysis of the arm during throwing (e.g., Fradet et al., 2004; Joris, van Muyen, van IngenSchneau, & Kemper, 1985; Schorer, Fath, Baker & Jaitner, 2007; Wagner, Pfusterschmied, Klous, von Duvillard, & Müller, 2012). However, while information from the motion of the arm has been shown to be crucial when attempting to anticipate ball direction in fast ball sports (Huys, Cañal-Bruland, Hagemann, Beek, Smeeton & Williams, 2009; Huys, Smeeton, Hodges, Beek & Williams, 2008; Shim, Carlton & Kwon, 2006; Williams, Huys, Cañal-Bruland & Hagemann, 2009), it has equally been suggested that anticipation may be based on the extraction of biological motion information spread globally, rather than locally, across different parts of the body (Bourne et al. 2013; Huys et al. 2009; Williams et al. 2009).

Thus far, researchers extolling the superiority of global over local information extraction strategies have exclusively used full body displays to investigate the informational properties of local dynamics. In this paper, we refer to 'local' information as motion from closely paired dot or marker stimuli such as within a single limb, whereas 'global' information emanates from relations between markers spread across the body (c.f., Huys et al. 2009; Watanabe & Kikuchi, 2006; Williams et al., 2009). Full body stimuli are valid for determining the value to anticipation of globally extracted information, but such stimuli may be less suitable for determining the informational value of localized motion. Huys et al. (2009) outlined how manipulation of localized motion within full body displays results in changes to the global dynamics of the display. Using Principal Component Analysis (PCA), they analysed the kinematics of information from the arm as skilled tennis players executed forehand drives to different locations on the court. They found that removing the differences between local marker trajectories of the shot directed to two different locations still affected the global dynamics, as identified using PCA. Under these circumstances, it is problematic to determine if variance in anticipation performance is due to changes in the information extracted locally or globally because of the interconnections between the two.

In the present paper, we report three experiments that collectively quantify the value of dynamical information from localized areas when compared to a whole body display during the anticipation of a ball-throwing task. A ball-throwing task was chosen because it is a fundamental movement skill common to numerous sports (e.g., cricket, baseball, softball, handball). The ability to predict the intended destination of a throw is therefore key to many ball sports and potential an important component of superior performance (Aglioti et al., 2008; Bourne et al. 2013; Muller & Abernethy, 2012). In Experiment 1, we present information from the throwing arm only (r-shoulder, r-elbow, r-wrist and two line segments), throwing arm plus left shoulder condition (l-shoulder, r-shoulder, r-elbow, r-wrist and three line segments), and a full body control condition (14 points and 14 line segments) as stick figure stimuli. We identified groups of participants who were perceptually skilled and perceptually less-skilled at the task of anticipating ball throw location using a within-task criterion. In Experiment 2, we neutralized the three marker locations within the throwing arm individually. Performance on the three neutralized conditions was compared to a control condition to determine how local motion from individual markers influenced the informational value of the throwing arm. In Experiment 3, we examined whether the minimum information necessary for anticipation of ball throwing is contained in a single marker location. Participants were presented with a segment of the throwing arm (r-shoulder, r-elbow and one line segment), an individual location (r-wrist) or a control condition (r-shoulder, r-elbow, r-wrist and two line segments).

A secondary aim across all three of the experiments presented was to determine if the errors made by perceptually skilled or perceptually less-skilled participants followed systematic patterns driven by the informational value of motion. Any variance in the proportion of different types of errors made (side, height or complete) as a factor of perceptual skill would highlight the nature of differences in the judgment processes. An understanding of error patterns may help to better identify the specific nature of the information extracted by perceptually skilled and less-skilled participants. At present, it is not known whether perceptually skilled participants simply make fewer errors than perceptually less-skilled individuals, whether the relative proportions of errors do not differ, or whether perceptually skilled participants become more accurate in anticipating a specific aspect of ball direction such as side or height. Linking stimulus type, response accuracy and error distributions as a factor of skill may provide new insights into how participants anticipate throwing actions.

Experiment 1

We examined whether information from the throwing arm was sufficient to enable participants to anticipate above chance levels. A pictorial representation of the type of image presented to participants is shown in Figure 1. We predicted that presenting information from the throwing arm only would be sufficient for participants to anticipate above chance levels (25% accuracy) in perceptually skilled and perceptually less-skilled participants. As perceptually skilled participants have shown a tendency to extract globally-located motion within a stimulus (Experiment 2), we hypothesized that perceptually skilled participants would perform significantly below control levels when presented with information from the arm or shoulder-arm only. Furthermore, perceptually skilled participants were expected to perform better in the arm-shoulder condition than arm only condition because of the increased access to global information. We did not expect the perceptually less-skilled participants to be negatively influenced by changes in the display conditions due to their suggested reliance on local arm information only.

Methods

Participants

Participants were male athletes (N = 40) with a mean age of 19.05 years (SD = 0.96 years). These athletes had spent an average of 9.99 years (SD = 3.91) regularly engaged in a variety of sports at school, university, club, county or international level. We recruited a relatively large group of athletes and, in keeping with the recommendations made by numerous researches (e.g., Williams & Ericsson, 2005), we grouped participants into high- and low-performing based on empirical data (i.e., actual performance on the test) rather than using subjective criteria such as the competitive level at which participants were performing, or their achievement and experience levels. The latter criteria may not be predictive of the ability of participants to anticipate the direction of ball throw, particularly since the perception of ball throwing is fundamental to many ball sports. We used the same strategy for creating skill groups across all three experiments. Participants gave their informed consent prior to taking part and the experiment was carried out in accordance with the ethical guidelines of the lead institution.

Apparatus and test stimulus production

The test stimuli were point light stick figures of throws generated in Matlab (Matlab R2007b, The Mathworks) and saved in AVI format. The stimuli were generated using the same three-dimensional motion data as outlined in Bourne et al. (2013). A detailed description of the motion data capture and processing procedures are reported in Bourne, Bennett, Hayes and Williams (2011).

The stimulus clips were created from an original penalty throw (7-meter throw) to one of four targets: top left (TL); top right (TR); bottom left (BL); and bottom right (BR). The location of each target was defined relative to the viewing position of the participant. Three conditions were represented in stick figure format: control (14 point/14 segment stick figure minus ball); right arm (r-shoulder, r-elbow and r-wrist linked by two line segments); and right arm plus left shoulder (l-shoulder, r-shoulder, r-elbow and r-wrist linked by three line segments). The data manipulations necessary to create the right arm and right arm plus left shoulder were achieved by modifying the raw x,y,z coordinate data that were subsequently fed into Matlab to generate point light stick figures. Forty clips were created for each of the three conditions and combined within Matlab to generate two test films, each consisting of 60 clips (N=120 clips in total). The viewing perspective represented that experienced by a goal-tender attempting to save the throw. The trials were sequenced randomly within and across the test films such that each film contained an equal number of stimulus clips for each condition. All clips lasted two seconds and each one was temporally occluded at the point the thrower released the ball. A blank screen was presented after each clip and the inter trial interval was three seconds. We constructed a practice film involving 12 clips using the same procedure as the test film.

Procedure

We tested participants as a group. The practice and test films were presented on a 2m (h) x 3m (w) projection screen using a Sony VPL-EW130 3000 ANSI Lumens 1280 x 800 projector (Sony Inc, Tokyo Japan). The participants sat between 3 and 10m from the screen such that the image subtended an average visual angle of 24° in the vertical and 35° in the horizontal axis. We informed participants that they would be shown handball penalty throws to one of the four different targets. They were asked to imagine that they were between the thrower and the intended goal in an area that is usually occupied by a goal-tender and to anticipate the target that the ball would be thrown towards. Participants were informed that the stimuli would involve full body, right arm plus left shoulder or right arm only right-handed stick figures constructed around black markers and line segments, but with no ball flight information.

Insert Figure 1 about here

We instructed participants to make their anticipation judgment immediately after viewing each clip by means of a pen-and-paper response. After this initial instruction, and prior to data collection, the group responded to 12 clips of known target locations to allow familiarization with the test conditions. A short break was given before the presentations of test films, during which participants were free to ask questions. The two 60-clip test films were presented with a break of four minutes in between, with each session lasting approximately 25 minutes.

Data analysis

For each participant, we calculated the number (c) of correct answers for each of the four targets. In addition, when an incorrect response was recorded, the type of error (side, height or complete judgment where both side and height were inaccurate) was reported. We calculated the relative percentage of side, height or complete judgement errors by condition for each perceptual skill group.

Using everyone's response accuracy score (correct judgment) in the control condition (i.e., within-task criterion), participants were classified as high, medium or low performing. Specifically, participants were ranked 1- 40, after which a tertile split approach was applied to give the following perceptual skill groups: 1-14 = perceptually skilled; 15-26 = intermediate; 27-40 = perceptually less-skilled. The data from the intermediate group were discarded so as to leave two groups clearly discriminated based on their actual skill level on the task rather than more subjective criteria related to experience and achievement within any one sport. The use of an on-task criterion to separate participants into groups has regularly used as an approach in psychology for some time (Alf & Abrahams, 1975; Feldt, 1961; Preacher et al., 2005; Shanks, 2016).

Sample sizes were calculated using G*Power (Version 3.1.9.3; Buchner et al., 2017). They were based on the effect sizes for the perceptual skill main effects and perceptual skill by visual condition interactions observed in Huys et al (2009). A total sample size of 6 (Actual power = 0.997) was needed for the main effect of perceptual skill and a total sample size of 14 (Actual power = 0.953) was needed for the perceptual skill by visual condition interaction.

Non-normally distributed response data (*c*) were transformed using Bartlett's modified arcsine transformation, $p' = (360/2\pi)\arcsin\left(\sqrt{(c+3/8)/(n+3/4)}\right)$, where n represents the number of trials in the condition (cf., Zar, 1996). We entered the resulting p' values into a mixed design ANOVA with condition (control, right arm and right arm plus left shoulder) as the repeated measure and perceptual skill levels (skilled, less skilled) as the between-participants factor. The non-normally distributed percentage distribution of error data were transformed using the arcsine transformation

($p' = \arcsin\sqrt{p}$,) and entered into separate ANOVAs having the same independent variables and levels as the ANOVAs on response accuracy data. Where we noted a violation of the sphericity assumption, the degrees of freedom were adjusted using the Huynh-Feldt correction. Significant main or interaction effects were further analysed using pairwise comparisons and the alpha level of significance adjusted for multiple comparisons using the Bonferroni correction method. In addition, to examine whether any of the conditions resulted in response performances below chance levels, we compared response accuracies to the 25% (10 correct responses) guessing criteria using single sample t-tests. All response accuracy means and standard deviations reported in the text are percentage representations of the original response data.

Results

Effect of manipulation condition on response accuracy

A number of single sample t-tests indicated that participants anticipated target location at levels significantly ($p < .01$) above chance (25%) under all conditions, irrespective of perceptual skill levels. However, our ANOVA revealed a significant main effect for perceptual skill levels [$F(1, 26) = 11.66$, $p = .002$] and condition [$F(2, 52) = 13.918$, $p = .00001$. These effects were superseded by a significant perceptual skill level x condition interaction [$F(2, 52) = 25.534$, $p = .000009$]. The skilled group's response accuracy was significantly higher ($p = 1.69 \times 10^{-11}$) than that of the less-skilled group in the control (66.6% vs. 39.6%) condition. In addition, the perceptually skilled group exhibited a significant decrease in response accuracy under the arm (M = 53.8%, SD = 12.1%, $p = .00005$) and arm + shoulder (M = 55.4%, SD = 10.4%, $p = .00006$) conditions compared to the control condition (M = 66.6%, SD = 6.6%). For the perceptually less-skilled group, the arm + shoulder (M = 43.4%, SD = 7.7%) condition resulted in a significantly increased response accuracy scores when compared to the control condition (M = 39.6%, SD = 6.0%, *p*= .04). The group means, standard deviations, and significant group differences are presented in Figure 2.

Insert Figure 2 and Table 1 about here

Percentage distribution of errors

The perceptual skill groups varied in how their errors were distributed. There was a significant main effect of perceptual skill levels [F(1, 26) = 7.614, *p*= .01] for the relative percentage of side errors. The side errors accounted for a higher proportion of errors in the perceptually less-skilled group than the perceptually skilled group (34.12% (50/120 trials) vs. 27.28% (33/120 trials). In addition, for the relative percentage of height errors, there was a significant main effect of perceptual skill level [F(1, 26) = 9.097, *p*= .006], as well as a significant perceptual skill level x condition interaction [F(2, 52) = 5.602, *p*= .006]. The height errors accounted for a larger percentage of the perceptually skilled group's errors under control (56.49% (23/40 trials) vs. 45.55% (18/40 trials)) and arm (63.65% (25/40 trials) vs. 48.09% (19/40 trials)) conditions compared to their perceptually less-skilled counterparts. Finally, there was a significant main effect of perceptual skill level [F(1, 26) = 4.476, *p*= .04] for the relative percentage of complete judgement errors. The perceptually less-skilled group exhibited a higher proportion of complete judgement errors than the perceptually skilled group (20.00% (24/120 trials) vs. 13.98% 17/120 trials). We present the relative percentages of error types in Table 1.

Discussion

When presented with full body, right arm plus left shoulder and right arm only stick figure stimuli, participants across all perceptual skill levels recorded anticipation scores significantly above chance. We conclude that it is possible to extract and use 'local' information to facilitate anticipation. These findings support those reported in Bourne et al. (2013), where the authors inferred that the arm was of localized informational value for anticipating throw direction (see also Huys et al. 2008/2009; Shim et al. 2006; Williams et al. 2009).

We report that the association between the presence of motion in the display from areas other than the throwing arm and anticipation is skill dependent. The perceptually less-skilled participants did not benefit from additional information provided in the full body stick figure display compared to the throwing arm. However, they did perform significantly better than control in the arm plus left shoulder condition. Notably, in previous work (Bourne et al., 2013), perceptually less-skilled participants showed significant increases in response accuracy when shoulder motion was neutralized. The authors interpreted this latter finding to be an indication that perceptually less-skilled participants were sensitive to, or distracted by, motion from areas other than the throwing arm, but were not necessarily skilled enough to extract useable information from these areas. We suggest that our perceptually less-skilled participants were more sensitive to global motion and may be able to extract some of this information from more simplistic stimuli. Since previous published reports have linked the global extraction of information with skilled anticipation (Huys et al. 2009; Williams et al. 2009), it makes intuitive sense that perceptually less-skilled participants would ideally draw information from global motion. Yet, the less-skilled participants were unable to use this global information fully, possibly because they lacked situational knowledge, which in turn inhibited their interpretation of motion, rather than a lack of sensitivity to motion per se. In this respect, Jackson and Morgan (2007) reported increased anticipation accuracy to be associated with a greater awareness of the information used for anticipation judgments in a tennis task.

As expected, the perceptually skilled participants performed significantly better under control conditions than when presented with arm only and arm plus shoulder stimuli. The results confirm the positive relationship between the extraction of information from 'global' motion and accuracy of anticipation judgments in perceptually skilled participants. This conclusion was inferred in previous literature (Huys et al. 2009; Williams et al. 2009), although limitations in the methods used previously has prevented firm conclusions being drawn in regard to the use of local strategies. In the present experiment, by creating "true" local information stimuli we can reasonably conclude that global motion offers perceptually skilled participants more informational value than localized arm motion when anticipating goal-directed throwing.

Notwithstanding the skill-based methods in Experiment 1, a potential limitation of the group-based testing protocol is acknowledged. Those who were closer to the screen stimulus appeared on would have seen the image with a larger visual angle. The visual information may have been perceived more readily.

The proportional distribution of errors recorded differed across skill groups. Perceptually skilled participants are generally less likely to make a complete misjudgement of target, and more likely to judge the side of the goal accurately. The existence of significantly different patterns of errors between skill groups suggests that extracting information globally may be associated with more accurate judgements regarding which side of the goal the ball is thrown. Whether this pattern is robust under various stimulus conditions is examined in the remaining experiments.

Experiment 2

In Experiment 1, we reported that motion from the throwing arm provided enough information to enable anticipation above chance levels. In this second experiment, we determine how the three marker locations of the arm contributed to the informational value of such biological motion. We presumed that the informational value of marker locations is manifest mainly in their contribution to relative motion couplings (cf., Cutting & Proffitt, 1982). However, we were less clear as to whether the contribution to a relative motion coupling (for anticipation purposes) is weighted equally across locations. In Experiment 2, we examined whether the contribution from the three throwing arm marker locations influenced the informational value of the throwing arm differently. We employed a version of the neutralization manipulation reported by Bourne et al. (2013). Under this neutralization manipulation, based on the data from PCA, the marker location trajectories were averaged across target location. As such, the contribution of the marker location to the throw direction differences in the relative motions patterns were removed while the general (non-throw specific) relative motion pattern of the marker location remained. This neuralization manipulation allowed us to perturb the relative motion pattern (Wilson & Bingham, 2008) rather than manipulate cue information and have a more general effect on the relative motion pattern.

We predicted, based on findings previously reported within the observational learning literature (e.g., Hayes, Hodges, Huys & Williams, 2007; Hodges, Williams, Hayes & Breslin, 2007), that neutralization of wrist (end effector) motion would reduce anticipation judgments to chance levels, irrespective of perceptual skill levels. Furthermore, neutralizing either the shoulder or elbow motion was predicted to significantly reduce performance compared to control conditions for all participants, though performance was not expected to fall to chance levels. Finally, we predicted that the perceptually skilled participants would maintain a significant advantage over their perceptually less-skilled participants in the shoulder and elbow neutralized conditions due to more robust, and all encompassing, information extraction strategies.

Methods

Participants

Participants were male athletes (N = 28) with a mean age of 19.68 years (SD = 2.76 years). They had been regularly engaged in sport for a mean of 12.75 years (SD = 3.88 years) at school, university, club, county or international level. All participants were familiar with the throwing action. Participants gave their informed consent prior to taking part and the experiment was carried out in accordance with the same ethical guidelines of the lead institution as in Experiment 1. None of the participants took part in Experiment 1.

Apparatus and test stimulus production

Using the same general procedures described in Experiment 1, stick figure test stimuli were generated to provide video representations of the right throwing arm (r-arm, r-shoulder and r-wrist linked by two line segments) (see Figure 1). Anticipation accuracy was assessed under 4 conditions: control (r-shoulder, r-elbow and r-wrist linked by two line segments); right arm with r-shoulder neutralized; right arm with r-elbow neutralized; and right arm with r-wrist neutralized. Neutralized motion was represented as an average time series of multiple throws to four targets for that thrower only. Forty clips were created per condition and combined within Matlab to generate two test films consisting of 80 trials each (N=160 trials in total). The trials were sequenced randomly within and across the test films such that each film contained an equal number of stimulus clips for each condition. Each clip lasted two seconds. A blank screen was presented after each clip and the inter clip interval was three seconds.

We constructed a practice film involving 12 clips using the same procedure as the test film.

Procedure

The data collection procedures were the same as in Experiment 1. The two 80-clip test films were presented with a break of four minutes in between, with each data collection session lasting approximately 30 minutes.

Data analysis

The response scoring and error recoding procedures were identical to Experiment 1. All participants were classified as either high, medium or low performing based on their response accuracy under control conditions using the same within-task criterion used in Experiment 1. Specifically, participants were ranked 1-28, after which a tertile split approach was applied to give the following perceptual skill groups: 1-10 = perceptually skilled; 11-18 = intermediate; 19-28 = perceptually less-skilled. The data from the intermediate group were discarded in order to create two distinct groups in regards to their skill on the task. The statistical analysis and reporting procedures were identical to those used in Experiment 1.

Results

Effect of manipulation condition on response accuracy

Participants anticipated target location at levels significantly ($p<.01$) above chance (25%) under all conditions except the wrist neutralized condition, where performance was significantly below chance levels ($p <.01$). However, there were significant main effects for perceptual skill level [$F(1, 18) = 11.499$, $p= .003$] and condition [$F(3, 54) = 64.669$, $p= 7.03 \times 10^{-13}$]. These main effects were superseded by a significant perceptual skill level x condition interaction [$F(3, 54) = 4.497$, $p= .007$]. The perceptually skilled group's response accuracy was significantly higher than that of the perceptually less-skilled group in the control (51.0% vs. 38.8%, p= .000003) and shoulder neutralized (52.3% vs. 39.5%, p= .003) conditions. The perceptually skilled group exhibited a significant decrease in response accuracy under the wrist neutralized condition (M = 16.3%, SD = 9%, p= 3.0 x 10^{-7}) compared to control (M = 51%, SD = 4.4%). An identical pattern was observed for the perceptually less-skilled group, where response accuracy under wrist neutralized conditions (M = 19%, SD = 4.9%, p= 0.000005) was significantly reduced compared to control (M = 38.8%, SD = 3.6%). We present the group means and standard deviations in Figure 3.

Insert Figure 3 about here

Percentage distribution of errors

No significant main effects were observed for perceptual skill level, or perceptual skill level x condition interactions in the relative percentage of side or complete judgement errors. For the relative percentage of height errors, there was a significant main effect of perceptual skill level [F(1, 18) = 5.8747, p= .0249], and a significant perceptual skill level x condition interaction [F(3, 54) = 2.9399, p= .041]. The height errors accounted for a larger percentage of the skilled group's errors under control (57.48% (23/40 trials) vs. 43.20% (17/40 trials), p= .007) and shoulder neutralized (61.84% (25/40 trials) vs. 49.01% (20/40 trials), p= .049) conditions compared to their perceptually less-skilled counterparts. We present the proportional distribution of errors in Table 2.

Insert Table 2 about here

Discussion

While both skill groups were able to maintain performance at control levels when we neutralized the shoulder and elbow, they performed significantly below chance level when we neutralized the wrist motion. In addition, perceptually skilled participants maintained their advantage over perceptually less-skilled counterparts under control and shoulder neutralized conditions. The pattern of errors made did not differ to that observed in Experiment 1, with perceptually skilled participants making more errors in height judgment, while the errors recorded by the perceptually less-skilled participants did not differ in distribution across height and side.

In Experiment 2, we showed that motion of the wrist makes an important contribution to the informational value of throwing arm biological motion. We expected, based mainly on findings pertaining its contribution to observational learning (e.g. Hayes, Hodges, Huys & Williams, 2007; Hodges, Williams, Hayes & Breslin, 2007), the superior informational contribution from the wrist over other locations. The high informational contribution of the wrist location relates, at least in part, to the kinetic chain involved in the handball throw. Fradet et al. (2004) and Joris et al. (1985) outlined how energy travelling across the kinetic chain in handball throws is imparted to the ball to shape ball flight. In the present experiment, the wrist location is the most proximal marker location to the ball and may provide the best representation of the aggregated forces imparted onto the ball.

The procedure of neutralizing information from the wrist was expected to reduce performance to chance level, and as such, it is not clear why performance was significantly worse than chance. The neutralized wrist location may have contained information that was confounding to participants, so rather than guessing the intended target participants were deceived into thinking the motion conveyed target specific information. One method of testing this hypothesis would be to run similar experiments where the participants are required to rate confidence in their judgment. This latter approach has been used previously as a tool to determine the effectiveness of deceptive stimuli (Jackson, Warren & Abernethy, 2006; Smeeton & Williams, 2012).

The identification of the wrist as the only location associated with significant reductions in anticipation performance as part of the arm relative motion coupling provide some evidence that the minimum information necessary to anticipate is observed in the wrist location. The methods applied in the present experiment highlighted the wrist as a significant contributor to the informational value of arm relative motion, but not as the critical information provider. If we assume a minimization process was followed in the present experiment, as advocated by Cutting and Proffitt (1982), absolute marker location motions would likely be superseded as a perceptual variable by throwing arm relative motion. We cannot directly link the observed performance decrements to wrist absolute motion if this is not perceived. We examine whether the wrist of the throwing arm contains the minimum information necessary for anticipation in Experiment 3.

Experiment 3

The results of Experiments 1 and 2 suggest that motion information emanating from the right wrist location makes the most important contribution to the anticipation of goal-directed throwing. However, we could not identify whether the local information necessary for anticipation is available within the wrist location when viewed in isolation. In Experiment 3, we addressed this issue and explored whether wrist location absolute motion was a consistent source of information for anticipation judgments. Additionally, we designed a second reduced information stimulus to help determine if the concept of a minimum information marker location was applicable to anticipation of handball throwing. Specifically, the shoulder and elbow locations of the throwing arm were combined (r-shoulder, r-elbow linked by a single segment) and presented, thus providing a non-wrist dependent coupling in the throwing arm. We hypothesized that perceptually skilled participants would be able to anticipate target direction above chance levels when presented with information relating to wrist displacement. Although this skill advantage is reported previously under more complex stimulus conditions, it was felt that perceptually skilled participants were most likely to have the task specific knowledge to extract pertinent information from wrist absolute motion. We predicted that the performance of the perceptually skilled group would be significantly below control levels due to the loss of information from relative motion. We expected that perceptually less-skilled participants would perform no better than chance under the same conditions due to the impoverished nature of the wrist only stimuli making the display too hard to interpret for their level of expertise. In addition, as a consequence of the findings of Experiment 2, we predicted that neither the perceptually skilled nor perceptually less-skilled participants would anticipate above chance levels when presented with upper arm segment information only.

Methods

Participants

Participants were male athletes (N = 39) with a mean age of 19.13 years (SD = 1.17 years). These individuals had engaged regularly in sport for an average of 11.86 years (SD = 3.30 years) at school, university, club, county or international level. All participants were familiar with the throwing action. Participants gave their informed consent prior to taking part and the experiment was carried out under the ethical guidelines of the lead institution, which were identical to Experiments 1 and 2. None of the participants took part in Experiment 1 or 2.

Apparatus and test stimulus production

Using the same general procedures described in Experiment 1, stick figure test stimuli were generated to provide video representations of the right throwing arm control condition (r-shoulder, r-elbow, r-wrist and two line segments), the upper arm (r-shoulder, r-elbow and a single line segment), and the r-wrist location in isolation (Figure 1).

Forty clips were created per condition and combined within Matlab to generate two test films consisting of 60 trials each (N=120 trials in total). The order of trials was sequenced randomly within and across the test films such that each film contained an equal number of stimulus clips for each condition. Each clip lasted two seconds. A blank screen was presented after each clip and the inter clip interval was three seconds. We constructed a practice film involving 12 clips using the same procedure as the test film.

Procedure

The data collection procedures were identical to those outlined in Experiment 1.

Data analysis

The response scoring and error recoding procedures were identical to those employed in Experiment 1. Participants were either classified as high, medium or low performing based on their response accuracy in the control condition using the within task criterion. Specifically, participants were ranked 1 to 39, after which a tertile split approach was applied to give the following perceptual skill groups: 1-15 = skilled; 16-24 = intermediate; 25-39 = perceptually less-skilled. We discarded the data from the intermediate group so that only data for the skilled and perceptually less-skilled groups were analysed and reported. The statistical analysis and reporting procedures were the same as in Experiment 1.

Results

Effect of manipulation condition on response accuracy

Participants anticipated target location at levels significantly above chance (*25%*) under all conditions. However, there were significant main effects for perceptual skill level [$F(1, 26) = 11.663$, $p = .002$] and condition [$F(2, 52) = 13.918$, $p = .00001$], which were superseded by a significant perceptual skill level x condition interaction [$F(2, 52) = 25.534$, $p = 1.88 \times 10^{-8}$]. The skilled group's response accuracy was significantly greater than that of the perceptually less-skilled group in the control condition (48.9% vs. 30%, $p = 1.39 \times 10^{-9}$), but not under either manipulated condition. The skilled group exhibited a significant decrease in response accuracy under the upper limb (M = 31.6%, SD = 7.1%, $p = 1.06 \times 10^{-7}$) and wrist conditions (M = 37.1, SD = 8.7%, $p = .00005$) compared to control (M = 48.9%, SD = 6.4%). There was no significant difference between the response accuracy of the perceptually less-skilled group under any condition. The group mean response accuracy scores and standard deviations are presented in Figure 4.

Insert Figure 4 about here

Percentage distribution of errors

No significant differences were observed across skill groups in the relative percentage of side errors, nor were any group x condition interactions observed. A significant skill group x condition interaction was observed for relative percentage of height errors [$F(1, 54) = 6.258$, $p = .015$]. The height errors accounted for a significantly larger percentage of the skilled group's errors under upper limb condition (42.59% (17/40 trials), $p = .005$)

compared to their perceptually less-skilled counterparts (32.23% (13/40 trials)). Finally, a significant difference between skill groups was observed for the relative percentage of complete judgement errors [$F(1, 27) = 4.2545$, $p = .0489$]. The complete judgement errors accounted for 28.65% (34/120 trials, $p = .035$) of total errors for the perceptually less-skilled group compared to 24.50% (29/120 trials) for their skilled counterparts. We present the percentage distribution values in Table 3.

Discussion

Our findings suggest that both the wrist and the upper limb provide enough information to facilitate anticipation significantly above chance, irrespective of participant perceptual skill levels. Although the wrist or upper arm locations are unlikely employed in isolation in ecologically representative situations, displaying the wrist in this manner has added to our understanding of how biological motion informs anticipation. First, the findings indicate that relative motion is not necessary when anticipating from biological motion and that absolute motion can convey sufficient information. Although Cutting and Proffitt (1982) suggest that absolute motion is rarely perceived due to primacy of relative and common motion couplings in a display, the present findings indicate that absolute motion can be extracted as an informational property for anticipation, even if it is rare that the situation would occur. Furthermore, findings suggest that perceptually less-skilled participants do not necessarily draw additional benefit from relative motion within a stimulus if it contains pertinent absolute motion. Performance under wrist only conditions was not significantly worse than performance under control (3-location coupling) or upper segment (2-location coupling) conditions. This finding may be limited to situations where the alternative relative motion couplings are simplistic, as in Experiment 3, and thus it remains to be verified with more complex relative motion stimuli.

The notion that a minimum information extraction strategy is observed for perceptually less-skilled participants was supported by the findings of Experiment 1, where a full-body stimulus offered no additional benefit over the arm only condition. These observations indicate that perceptually less-skilled participants may find a salient source of information such as the wrist in a more complex stimulus and stick solely with this source even when more information is available. Whether this source of information is a single location or a relative motion coupling may be situation dependant. Such an information extraction strategy is in direct opposition to what is observed for skilled participants in the present experiment. Skilled participants appear to make use of additional information from a stimulus, as is demonstrated by the increased performance shown under increasingly complex relative motion couplings.

Participants were not as reliant on the presence of wrist motion in the present experiment as expected. Participants did not differ in judgement accuracy when presented with the upper arm coupling segment or the wrist location so the idea of the wrist as a critical information provider can be rejected. The anticipator seems to have multiple opportunities to extract motion of informational value from the throwing arm.

General Discussion

We have shown that the throwing arm provides sufficient and necessary information for anticipation of goal-directed action. Localized motion contained within the three throwing arm locations was sufficient to inform anticipation judgments above chance level. In the present research, we have therefore shown that it is possible to employ a local information extraction strategy and be able to anticipate with reasonable levels of accuracy. Furthermore, in Experiment 3, we demonstrated that a single end effector location is informative to both perceptually skilled and perceptually less-skilled participants. However, the anticipation judgments of perceptually skilled participants were compromised under these conditions and the overall level of anticipation accuracy was low for both skill groups.

The value of additional markers and relative motion couplings within a stimulus appears to be in offering observers the opportunity to strengthen judgment processes that already operate above chance levels. The differences in information extraction between skill groups has traditionally been discussed in the context of ‘local’ vs. ‘global’ information, where local refers to motion from closely paired dot or marker stimuli such as within a single limb, and global information emanates from relations between markers spread across the entirety of a full body stimuli (c.f. Abernethy & Zawi, 2007, Abernethy, Zawi & Jackson, 2008; Huys et al. 2009; Muller et al., 2007; Muller et al., 2010; Watanabe & Kikuchi, 2006; Williams et al., 2009). In Experiments 1 and 2, we reported that the proposed difference in information extraction between perceptually skilled and perceptually less-skilled anticipators at the global level is also present when anticipating based on what would be traditionally deemed ‘local’ information sources. Therefore, the global vs. local phenomenon when viewing the full body may be one representation of a wider perceptual ability to discriminate information. The existing literature offers some useful findings against which to consider the mechanisms underpinning the perceptual skill differences observed in the present paper. Principal component analysis of both tennis (Huys et al., 2008) and handball throwing (Bourne et al., 2010) has reported differences between similar movement patterns to be represented by small shot/throw specific dynamics represented across multiple co-varying body regions. Smeeton, Huys, and Jacobs (2013) suggest that when learning to anticipate participants may become more sensitive to these global shot specific dynamics through exposure to local, co-varying body regions. In their experiments, Smeeton and colleagues found that the improvements in learning evident when training to anticipate specific body regions was transferred to anticipating regions not present during the training period. The authors suggest that through learning about shot specific differences at particular body regions the participants became sensitive to the region independent shot specific dynamics. Thus, when faced with other co-varying body regions, the same dynamic patterns are extracted. The work of Smeeton et al. (2013) suggests that the perceptual skill differences identified in the present experiments may be representative of a stronger sensitivity to region independent dynamics in the perceptually skilled group. Furthermore, the increased performance of the skilled group in more global situations could be representative of a strengthened judgment in the face of increased co-varying body regions representing the shot specific dynamics. It is difficult to conclude this in the present case without stronger triangulation between the underpinning dynamics of the throw, training stimulus of the participants and the stimuli generated in the present experiments.

Our conclusions regarding the value of the wrist marker location during anticipation imply that the processes of anticipation are underpinned by flexible information extraction. In the current paper, Experiments 2 and 3 independently pinpointed the wrist location as a principal provider of information for anticipating throwing. However, motion from the wrist does not need to be present for anticipation of goal-directed throwing (i.e., sufficient but not necessary). Participants were able to anticipate the target equally well when presented with the wrist only or upper arm.

The pen and paper response methodology used here has been criticised by some (Araujo & Davids, 2015; Muller et al., 2015; Van der Kamp et al., 2008). The view is that the functional links between perception and action are not coupled in a way that offers action fidelity (Pinder et al., 2011), where this is concerned with matching the mode of response in the experimental task with that typically used in the natural environment. Although considerable debate exists, the argument from some authors is that response modes such as pen and paper and button push tasks offer experimental control (for a discussion, see Broadbent et al., 2014). However, in this paper our aim was to identify the informational value of local biological motion coupling and pen and paper response offers no constraint to limit this information pick up and consequently, these findings remain of interest to those concerned with understanding the perception of biological motion. The relative efficacy of using paradigms with and without an action component should continue to be examined empirically in order to provide more concrete guidance on this issue.

In summary, we report anticipation judgements above chance level under changing display conditions in the present paper, which suggests a complex interaction between biological motion perception and anticipation. Both relative motion couplings and absolute marker location trajectories appear to hold informational value for anticipation. The extent to which these motion types inform anticipation of goal-directed throwing appears skill dependant and perceptually-skilled participants are characterised by an ability to extract more information from the complex relative motion couplings. The mechanism underlying this skill-based difference is unclear, but may relate to a variable ability to the same shot specific dynamics from multiple co-varying body locations.

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Legends for Figures

Figure 1. Pictorial representations of the five stick figure display stimuli configurations. NB. The right arm display configuration was manipulated to create the three neutralized conditions presented in Experiment 3.

Figure. 2 Mean response accuracy and standard deviations for perceptually skilled and perceptually less-skilled participants under control, arm-shoulder and arm display conditions. Asterisks (*) denote that the response accuracy of the perceptually skilled participants was significantly better than their perceptually less-skilled counterparts. Delta (Δ) symbols denote a significant difference between the manipulation condition and the control condition.

Figure. 3. Mean response accuracy scores and standard deviations for perceptually skilled and perceptually less-skilled participants under control, shoulder neutralized, elbow neutralized and wrist neutralized conditions. Asterisks (*) denote that the response accuracy of the perceptually skilled participants was significantly better than their perceptually less-skilled counterparts. Delta (Δ) symbols denote a significant difference between the manipulation condition and the control condition.

Figure. 4. The mean response accuracy scores and standard deviations of perceptually skilled and perceptually less-skilled participants under control, shoulder-elbow and wrist only display conditions. Asterisks (*) denote that the response accuracy of the perceptually skilled participants was significantly better than their perceptually less-perceptually skilled counterparts. Delta (Δ) symbols denote a significant difference between the manipulation condition and the control condition.

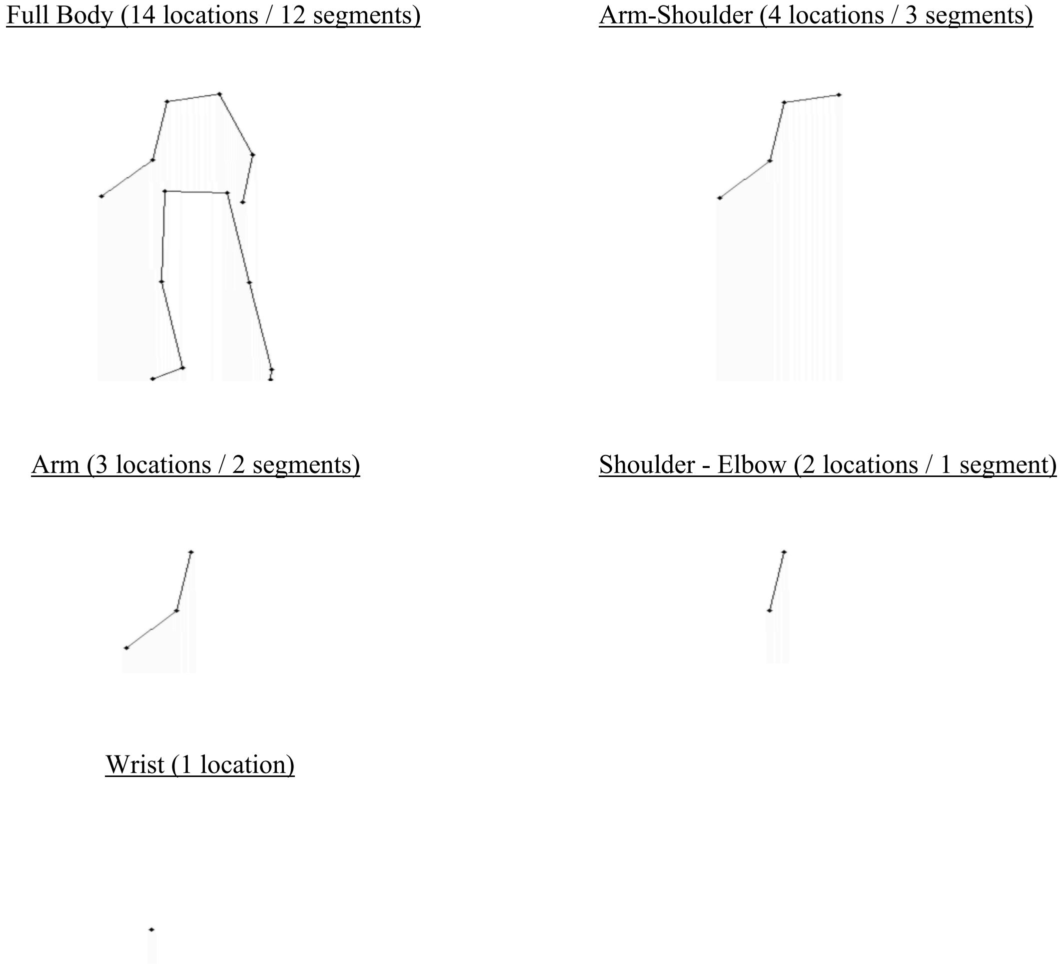
Full Body (14 locations / 12 segments)
Arm-Shoulder (4 locations / 3 segments)
Arm (3 locations / 2 segments)
Shoulder - Elbow (2 locations / 1 segment)
Wrist (1 location)

Figure 1

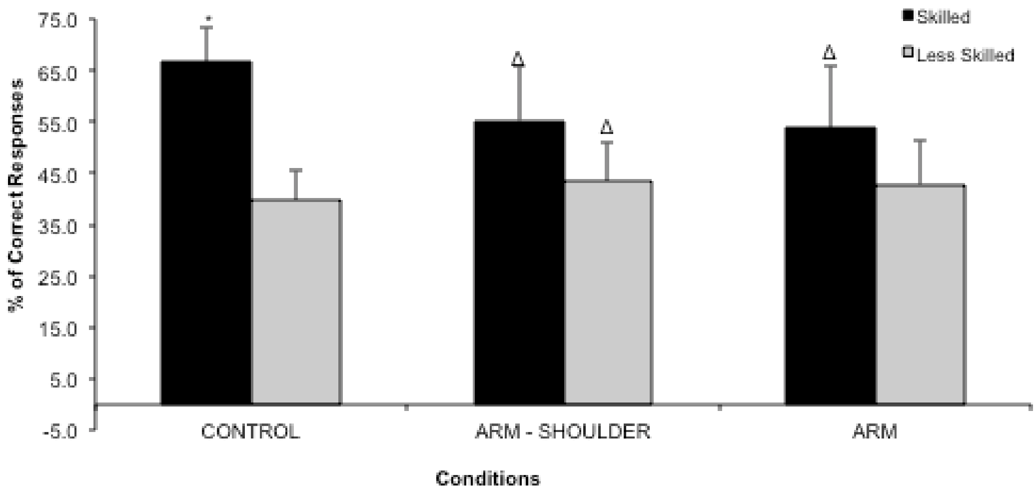
% of Correct Responses
75.0
65.0
55.0
45.0
35.0
25.0
15.0
5.0
-5.0
CONTROL
ARM - SHOULDER
ARM
Conditions
Skilled
Less Skilled

Figure 2

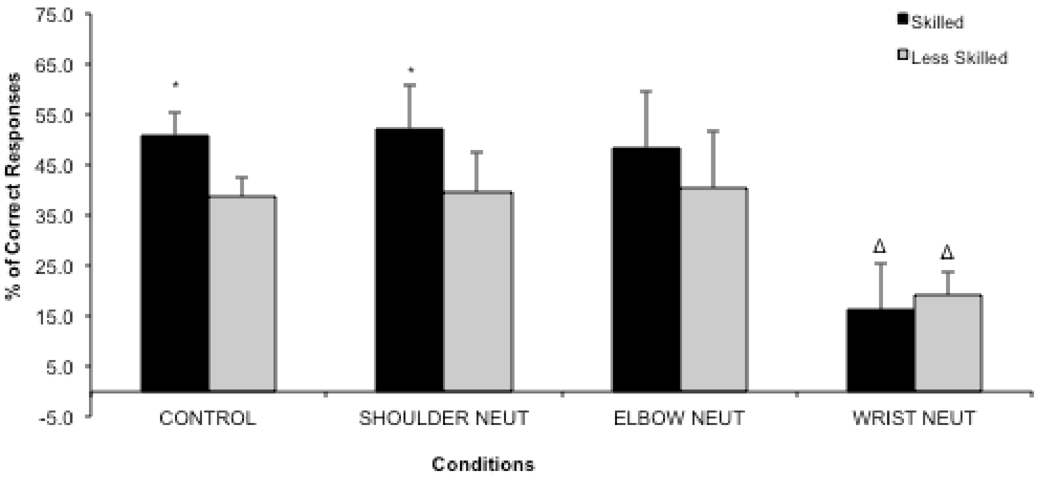

Figure 3

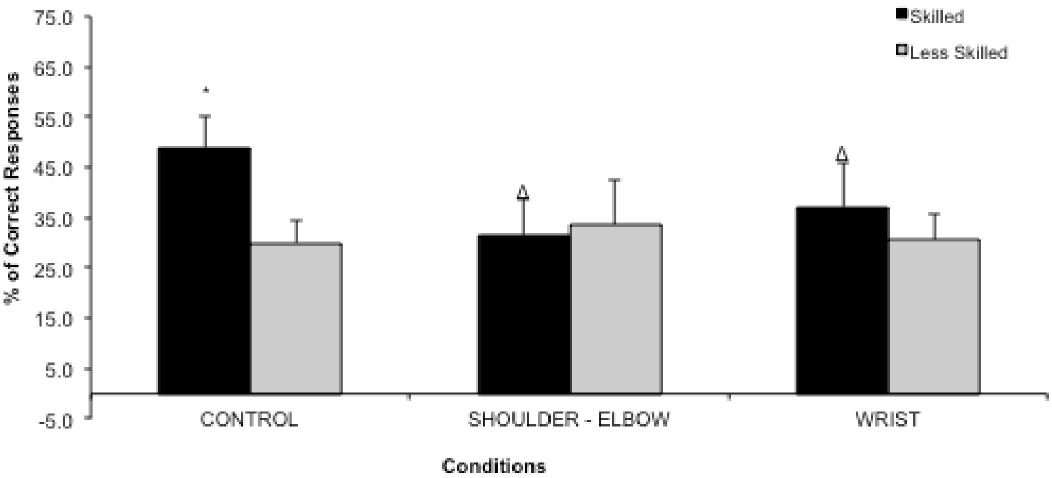

Figure 4

Legends for Tables

Table.1. Percentage distribution of errors under control, right arm plus left shoulder and right arm only conditions. The relative percentage is the proportion of total errors made that fell into a specific category.

Table. 2. Percentage distribution of errors under control, shoulder neutralized, elbow neutralized and wrist neutralized conditions. The relative percentage is the proportion of total errors made that fell into a specific category.

Table. 3. Percentage distribution of errors under control, shoulder-elbow, and wrist conditions. The relative percentage is the proportion of total errors made that fell into a specific category.

		% Distribution of Errors			
		Mean		s	
		Perceptually skilled	Perceptually less-skilled	Perceptually skilled	Perceptually less-skilled
% Side Errors	CONTROL	24.01	32.80	11.13	9.96
	ARM+ L_SHOULDER	31.99	37.45	11.88	8.95
	ARM	25.85	32.09	10.96	8.36
% Height Errors	CONTROL	56.49	45.55	16.41	9.89
	ARM+ L_SHOULDER	56.08	43.99	16.00	10.20
	ARM	63.65	48.09	12.93	8.99
% Complete Judgment Errors	CONTROL	19.50	21.64	13.46	9.59
	ARM+ L_SHOULDER	11.93	18.56	6.49	8.02
	ARM	10.51	19.81	10.82	9.33

Table 1

		% Distribution of Errors			
		Mean		s	
		Perceptually skilled	Perceptually less-skilled	Perceptually skilled	Perceptually less-skilled
% Side Errors	CONTROL	22.29	34.91	10.12	12.53
	SHOULDER NEUT	23.12	30.82	12.28	11.18
	ELBOW NEUT	40.92	40.23	12.78	10.42
	WRIST NEUT	37.68	36.15	8.26	10.56
% Height Errors	CONTROL	57.48	43.20	8.31	12.11
	SHOULDER NEUT	61.84	49.01	11.68	16.02
	ELBOW NEUT	38.91	36.67	10.31	10.62
	WRIST NEUT	21.22	24.08	9.66	8.90
% Complete Judgment Errors	CONTROL	20.23	21.89	10.62	7.56
	SHOULDER NEUT	15.04	20.17	11.77	15.25
	ELBOW NEUT	20.18	23.10	10.39	6.67
	WRIST NEUT	41.10	39.77	4.00	9.77

Table 2

		% Distribution of Errors			
		Mean		***s***	
		Perceptually skilled	*Perceptually less-skilled*	*Perceptually skilled*	*Perceptually less-skilled*
% Side Errors	*CONTROL*	28.26	32.68	9.30	12.10
	SHOULDER - ELBOW	33.37	34.94	11.31	9.32
	WRIST	38.61	30.69	9.76	10.89
% Height Errors	*CONTROL*	47.24	40.30	9.69	15.23
	SHOULDER - ELBOW	42.59	32.23	7.99	9.99
	WRIST	36.42	43.21	7.41	9.29
% Complete Judgment Errors	*CONTROL*	24.50	27.02	6.62	10.43
	SHOULDER - ELBOW	24.04	32.82	8.88	12.23
	WRIST	24.97	26.10	9.92	10.45

Table 3