THE EFFECTS OF MARKER SIZE ON THE ACCURACY OF THE ARIEL PERFORMANCE ANALYSIS SYSTEM (APASTM)

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INTRODUCTION

The motion analysis systems that are on the market today are designed to analyze motion automatically. In order for this to occur, a marking system must be used. Marking systems are used to estimate joint centers or other anatomical landmarks (Greaves, 1995). These markers are illuminated to provide a sharp contrast with the background, in order for the computer to effectively determine the position of these markers as they move through space (Greaves, 1995)

Marker position is commonly determined by calculating the centroid of a cluster of pixels that are above a specified light threshold (Greaves, 1995; Pedotti & Ferrigno, 1995). Each pixel represents a distinct point in space (Calvert & Bruderlin, 1995), designated by a unique pair of Cartesian coordinates (Pedotti & Ferrigno, 1995). Within the digital image, each pixel is assigned a threshold value, which is determined by the light intensity of the image at that particular location (Pedotti & Ferrigno, 1995). The centroid of a marker is calculated by averaging all the x,y coordinates within a cluster of pixels above the specified threshold value, to obtain one x,y coordinate pair (Winter et al., 1972). As the marker size increases, the number of pixels available to calculate the centroid also increases.

Marker size should be as large as practical in order to increase the accuracy of the centroid calculation (Safaee-Rad, Shwedyk, & Quanbury, 1990; Winter et al., 1974). Winter et al. (1972) suggests that a marker should be at least 5x5 pixels, whereas Macleod, Morris, and Kyser (1990) suggest that a marker size of at least 4x4 pixels is adequate.

Little information has been published examining the effect of marker size on the accuracy of a system. Winter et al. (1974) calculated that a marker 4 pixels in diameter, will produce a mean error that is 3% of the markers diameter. The purpose of this study was to examine the effect marker size has on the accuracy and precision of the Ariel Performance Analysis System at different angular velocities. It is hypothesized that the accuracy of the APAS system will decrease as marker size decreases and as angular velocity increases.

METHODS

An inverted T-shaped pendulum was used to collect data under static and dynamic conditions. Four sets of eight retro-reflective markers (0.64, 0.95, 1.27, and 1.91cm in diameter) were attached to the pendulum. The distances between these markers were measured to the nearest mm, using a standard tape measure. Using these distances, twelve reference angles were calculated trigonometrically.

Two 60 Hz Panasonic S-VHS camcorders were used to collect kinematic data, at a shutter speed of 11500 sec. The optical axis of each camera formed a 45 deg. angle with the plane of trajectory of the pendulum. This setup produced a between-camera angle of 90 deg. The pendulum was illuminated by two, 250 watt halogen lamps, one lamp was directed along the optical axis of each camera.

The pendulum was filmed in a static position, and at 3 different release positions. The pendulum was released at 45, 90, and 120 deg. relative to vertical. The purpose of the increasing release positions was to increase the angular velocity of the pendulum. The initial release position was verified by an angle locator. The static position was filmed for approximately 30 seconds. Ten trials of each angular velocity were filmed. This was repeated using the four different marker sets, producing 16 different conditions (4 markers by 4 positions).

DATA ANALYSIS

The Ariel Performance Analysis System (APAS) was used for all data analysis. Twenty frames were grabbed for the static position and represented one trial. These twenty frames were auto-digitized 10 times to produce 10 independent trials. Thirty frames of each of the dynamic trials were grabbed and auto-digitized. The two digitized views were converted to 3-D coordinates using a Direct Linear Transformation (DLT). The transformed data was filtered using a double pass recursive Butterworth digital filter. A cutoff frequency of 6 Hz was used to filter the data.

Twenty frames of each dynamic trial, as well as the twenty frames of the static trials, were used for data analysis. Frames one through nine of each dynamic trial consisted of the last nine frames of the downswing. Frame 10 was the last frame before the pendulum passed the vertical position. The next ten frames were the first ten frames of the upswing.

STATISTICAL ANALYSIS

An average angle over the 20 frames was computed and subtracted from the reference angle. The absolute value of this deviation was used to produce an absolute error score (ABERROR). This was repeated for all 12 angles for every trial of each condition. A Mixed Effects ANOVA model was used to evaluate the data. Release position and marker size were treated as fixed effects: with four levels each. Angle variable was treated as a random effect with 12 levels.

To calculate the inter-trial variability the reconstructed angles were subtracted from the reference angle for each frame. These deviations were then averaged over each condition for each frame. This resulted in 20 average frame deviations for each condition.

RESULTS

The mean ABERROR values and standard deviations for each condition (marker X position) are listed in Table 1. Statistical significance was found in the ANOVA of marker [$F(3,1893) = 6.39$, $p < 0.00031$ and position [$F(3,1893)= 350.41$, $p \leq 0.0001$]. The interaction between marker and position was non-significant [$F(9,1893) = 1.83$, $p < 0.0581$.

Table 1. Absolute error (ABERROR) for marker, by position

	Marker A (0.64 cm)		Marker B (0.95 cm)		Marker C (1.21 cm)		Marker D (1.91 cm)	
Position	M	SD	M	SD	M	SD	M	SD
1 (Static)	0.63	0.45	0.58	0.39	0.61	0.40	0.54	0.30
2 (45 deg)	0.56	0.47	0.52	0.32	0.54	0.40	0.49	0.30
3 (90 deg)	0.31	0.20	0.37	0.23	0.31	0.24	0.28	0.16
4 (120 deg)	0.24	0.18	0.25	0.15	0.21	0.15	0.21	0.13

Note. ABERROR = Reference angle subtracted from the average angle of the 20 frames.

Comparison tests indicate that markers 1-3 were all statistically different from marker 1. Significance levels decreased from $p < 0.001$, $p < 0.003$, and $p < 0.0106$ for markers 1-3 respectively. The least squared means of marker indicate that as the marker size increased, the deviations, on average, decreased (0,4339, 0.4299, 0.3833, and 0.3833 deg) from marker 1 to marker 4 respectively.

The effects of position on the inter-trial variability of marker 4 is shown in Figure 1. Position 1 (static), regardless of marker size, consistently overestimated the angle. Position 2 (45 deg release position) also overestimated, but was more variable than Position 1. Positions 3-4 (90 and 120 deg release position) went through a cycle of under estimation, to over estimation, and back. This indicates a large degree of variability depending upon where it was during its trajectory. The greatest deviations were seen in frames 8-9 for all remaining position regardless of marker size. This maximum deviation, regardless of release position, also decreased as marker size increased.

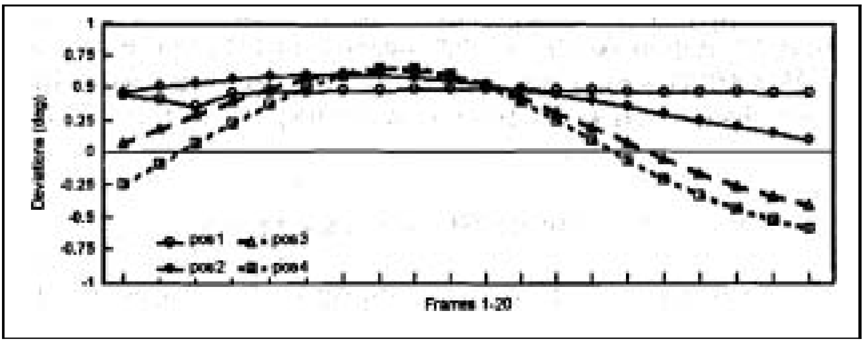

Figure 1. Inter-trial variability of Marker 4.

DISCUSSION

The effect of marker size on the accuracy of a system has been reported infrequently (Walton, 1986; Winter et al., 1974). No reported studies could be found that examined how marker size effects the accuracy of the system. The purpose of this study was to examine the effects marker size has upon the accuracy of the APAS system.

MARKER SIZE

Marker size was shown to have a statistical significant effect upon the ABERROR. Examination of the least square means for each marker shows that as the marker size increased the deviation decreased. When comparisons were made between the different markers, the only significant comparisons found were between marker 4 and markers 1-3. Lack of significance may be attributed to the fact that the ABERROR did not always linearly decrease for a particular position. For example, the ABERROR decreased from 0.6 deg for marker 1, position 1 to 0.58 deg for marker 2, position 1, but then increased to 0.61 for marker 3, position 1.

INTER-TRIAL VARIABILITY

Graphs of the frame by frame deviations resembled a bell shaped curve, positions 3 and 4 more so than position 2. Frame 10 represents the point in time when the pendulum was at the low point of its swing. At this point the pendulum should be at or near its maximum velocity. As the velocity of the pendulum increases, frames 1-10, the deviations increased in magnitude. As the velocity of the pendulum decreased, frames 11-20, the deviations decreased in magnitude.

Frame 9 represented the maximum deviation for markers 1 and 4, whereas markers 2 and 3 had a maximum deviation at frame 8. As marker size increased the maximum deviation, regardless of position, always decreased in magnitude. The pendulum, by frame 8 and 9, should have been nearing its maximum velocity. If this is indeed the case, the system is producing the greatest deviations at the highest velocities. This can be seen by looking at the deviations at these two frames.

Statistically, as the marker size increase the accuracy increased, but' analysis of the frame by frame deviations does not indicate this. As the pendulum approaches maximum velocity, frame ten, the maximum deviation occurs, regardless of marker size. Whereas at the beginning and the end of the trial the deviations are much smaller. A possible interpretation might be that increases in angular velocity are canceling out some of the possible benefits of the larger marker size. Even though the large marker sizes are more accurate statistically, they still experience a decrease in accuracy at increasing angular velocities. If this is indeed the case, this might explain the bell shaped curves which represent the frame by frame deviations of the dynamic trials.

CONCLUSION

The results of this study indicate that marker size does have an effect upon the accuracy of the APAS system. As the marker size increases from 0.64 cm to 1.91 cm, the average deviation decreases from 0.43 deg to 0.38 deg. Though these differences were statistically significant, they can probably be considered clinically non-significant. This is due to the fact that these results are very comparable to the results of Klein and DeHaven (1995) and Wilson et al. (1997). Each concluded that their results were clinically non-significant.

Based upon the results of this study, it would seem that even though marker size does have an effect upon the accuracy of the APAS system, these effects are very small. Marker size, in most cases, is probably not a determining factor in the accuracy in most motion analysis situations. If the motion being analyzed consisted of very fine movement then it may be a determining factor. In most cases any marker size will give fairly accurate results when using the APAS system.

REFERENCES

Calvert, T. W., & Bruderlin, A. (1995). Computer graphics for visualization and animation. In P. Allard, I. A. F. Stokes, & J. P. Blanchi (Eds.), Three-dimensional analysis of human movement (pp. 101-126). Champaign IL: Human Kinetics.

Greaves, J. O. B. (1995). Instrumentation in video-based three-dimensional systems. In P. Allard, I. A. F. Stokes, & J. P. Blanchi (Eds.), Three-dimensional analysis of human movement (pp. 41-55). Champaign IL: Human Kinetics.

Klein, P. J., & DeHaven, J. J. (1995). Accuracy of three-dimensional linear and angular estimates obtained with the Ariel Performance Analysis System. Arch Phys Med Rehabil, 76, 183-189.

Macleod, A., Morris, J. R. W., & Kyster, M. (1990). Highly accurate video coordinate generation for automatic 3d trajectory calculation, In J. S. Walton (Ed.), Image-based motion analysis (pp. 12-18). Bellingham WA: SPIE- The International Society for Optical Engineering.

Pedotti, A., & Ferrigno, G. (1995). Optoelectronic-based systems. In P. Allard, I. A. F. Stokes, & J. P. Blanchi (Eds.), Three-dimensional analysis of human movement (pp. 57-77). Champaign IL: Human Kinetics.

Safaee-Rad, R., Shwedyk, E., & Quanbury, A. O. (1990). Three-dimensional measurement system for functional arm motion study. Med. & Biol. Eng. & Comput., 28,569-573.

Walton, J. S. (1986). The accuracy and precision of a video-based motion analysis system. In B. G. Ponseggi (Ed.), High Speed Photography, Videography, and Photonics IV, (pp.251-263). Bellingham WA: SPIE-The International Society for Optical Engineering.

Wilson, D. J., Smith, B. K., & Gibson, J. K. (1997). Dynamic accuracy of reconstructed angular estimates using the Ariel Performance Analysis System. Physical Therapy, In press.

Winter, D. A., Greenlaw, R. K., & Hobson, D. A. (1972). Television-computer analysis of kinematics of human gait. Computers and Biomedical Research, 5,498-504.

Winter, D. A., Quanbury, A. O., Hobson, D. A., Sidwall, H. G., Reimer, G., Trenholm, B. G., Steinke, T., & Shlosser, H. (1974). Kinematics of normal locomotion-A statistical study based on TV data. J. Biomechanics, 7,479-486.