DOES AN EXTRA MASS IMPROVE THE ARM SWING SPEED?

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This study investigated the effect of adding extra mass on individual segments during the performance of an arm swing task in the horizontal plane. The amount of extra mass was 0, 25, 50, 75, and 100% of the mass of the segment on which the extra mass was placed (upper arm or forearm). The variables studied were arm swing speed (hand speed), positive muscle impulse, and system moment of inertia (MOI). The purpose was to see if adding extra mass sped up or slowed down the arm swing and why. Twenty subjects were instructed to produce their maximum hand swing speed over the target point during the horizontal non-dominant arm swing. It was found that the forearm extra mass elicited a significant decrease in the arm swing speed, while the upper arm added mass did not cause decreases in arm speed. Rather, moderate amounts of extra mass at the upper arm (25 and 50% extra mass) induced slight, although not significant, increases in arm swing speed (0.66% and 1.41% increase, respectively). These increases in speed were accompanied by small increases in both the positive muscle impulse and the system MOI with the upper arm extra mass. Significant increases in the system MOI accounted for the significant swing speed drop caused by the forearm extra mass. It was concluded that extra mass is not always detrimental to the arm swing speed. Extra mass added close to the axis of rotation either makes no difference or may actually help swing speed.

KEY WORDS: arm swing, moment of inertia, extra mass, open kinetic chain principle.

INTRODUCTION:

Kicking, throwing, and striking utilize the same biomechanical principle (i.e., the open kinetic chain principle). It is characterized by a sequential order of segmental rotations from proximal to distal segments (Kreighbaum & Barthels, 1990; Putnam, 1991). The goal of the open kinetic chain principle is to maximize the distal end speed (e.g., kicking speed, throwing speed, and striking speed).

Athletes often use additional masses on their body during training or warming-up. It is believed that additional mass stimulates the musculotendon system and prepares athletes for improved performance. Ankle weights and a donut on a bat are examples of an extra mass placed distally. It may be expected that distal extra mass reduces the distal end speed due to increased system MOI. The effect of extra mass located proximally is less clear. Southard (1998) found adding extra mass on the upper arm resulted in a higher throwing velocity than extra mass placed on the forearm or hand. However, no other study confirmed his results. The goal of this study was to investigate the influence of extra mass on speed of a horizontal arm swing by systematically manipulating the amount and the location of the mass. In addition to the kinematic effect of extra mass, changes in the underlying kinetic characteristics, such as the joint-specific system MOI and positive muscle impulse, were examined.

METHOD:

Twenty college students (10 males and 10 females) from the ASU Kinesiology Department (including athletes and non-athletes) participated in this study. Participants were instructed to produce maximum hand swing speed over a target point with a swing of the non-dominant arm in the horizontal plane. The non-dominant arm was used to mimic the baseball bat swing of the leading arm motion. Extra mass was located either at the center of mass (CM) of the upper arm or forearm. Five levels of extra masses were used: 0, 25, 50, 75, and 100% of the upper arm and forearm mass, respectively. The exact amount of extra mass in each condition is shown in Table 1. Eight trials were performed in each condition.

The electro-optical motion measurement system (Optotrack®, NDI, Canada) was used to record three-dimensional position data (300 Hz of sampling rate). Five markers were placed on the trailing shoulder, the leading shoulder, the elbow, the wrist, and the imaginary target (Figure 1).

Table 1 Conditions Associated with the Amount (kg) and Location of Extra Mass

	Upper Arm Extra Mass		Forearm Extra Mass	
	Mean	STD	Mean	STD
0%	0.0	–	0.0	–
25%	0.502	0.101	0.300	0.060
50%	1.004	0.202	0.600	0.120
75%	1.506	0.302	0.900	0.181
100%	2.008	0.403	1.201	0.241

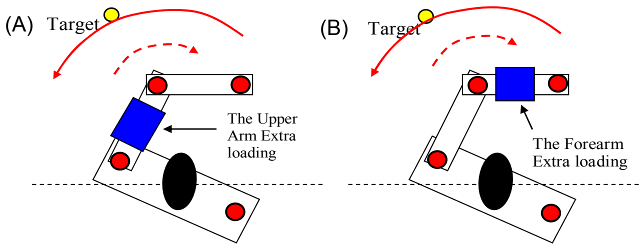

Figure 1: Extra mass and Optotrack marker locations during the arm swing: (A) the upper arm extra mass and (B) the forearm arm extra mass.

Kinematic Analysis: The arm swing speed was selected at the maximum linear velocity of the hand around the target. Data from only three trials of the highest speed were used for further analyses.

Inverse Dynamics: A three-segment model (including the trunk, upper arm, and lower arm) was used for kinematic and kinetic analyses. Anthropometric parameters were evaluated as described by deLeva (1996). Based on kinematic data and anthropometric parameters, inverse dynamic analysis was performed (Hoy & Zernicke, 1986; Dounskaia, Ketcham, & Stelmach, 2002). The components of the equation of motion at each joint were grouped as NT, IT, and MT ($NT = MT + IT$), where the NT was the net torque (or resultant torque) ($(I_i + m_i r_i^2)\ddot{\theta}_i$, i = each segment) and the IT was the interaction torque generated by tangential acceleration ($I_i\ddot{\theta}_i$, i = each segment), radial acceleration ($r_i\dot{\theta}_i^2$, i = each segment), and Coriolis forces ($\dot{\theta}_i\dot{\theta}_j$, i, j = each segment) due to segmental inertia. The MT was the muscle torque attributed to active muscle contraction and passive resistance of the connective tissues. The MT was calculated by the subtraction of IT from NT (NT – IT).
Two dependent variables were tested statistically for each joint (trunk, shoulder, and elbow). These were (1) positive muscle impulse and (2) the system moment of inertia. The positive muscle impulse was obtained with the integral of the positive MT as in Dounskaia et al. (2002). The system MOI represented the instantaneous rotational resistance of all the mass distal to that joint (i.e., the joint's system). It was calculated using the parallel axis theorem to transfer the individual segment moments of inertia to the particular joint in question and then summing up each segment's contribution to the total system MOI for a given joint.

Statistical Analysis: A two-way repeated measures ANOVA was performed on each dependent measure (arm swing speed, averaged positive muscle impulse, and the system MOI) with $p < .05$ indicating significance.

RESULTS:
A 2 × 5 (Location × Mass Amount) repeated measures ANOVA on the arm swing speed found a significant interaction ($F(76, 4) = 40.9$, $p < .01$) (Figure 2). For the upper arm extra

mass, the main effect of an extra mass did not reach the significance level ($F(76, 4) = 2.44$, $p = .054$). Although not statistically significant, the swing speeds at the 25 and 50% extra mass amounts were slightly faster (0.66% faster and 1.41% faster, respectively) than at the 0% extra mass amount (8.83 ± 1.66 m/s). In contrast, for the forearm extra mass, there was a significant main effect of the extra mass amount ($F(76, 4) = 79.5$, $p < .01$). Each 25% extra mass amount significantly reduced the arm swing speed except between the 50 and 75% extra mass amounts (Figure 2).

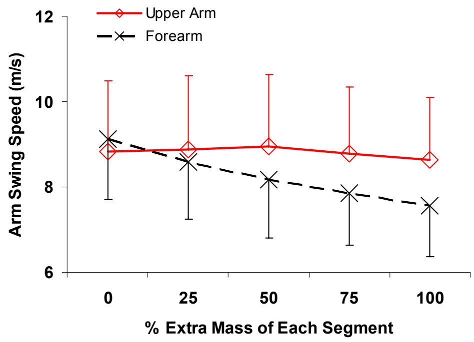

Figure 2: The dependence of arm swing speed on the location and amount of the extra mass.

At each joint, a 2 × 5 (Location × Mass Amount) repeated measures ANOVA applied to the positive muscle impulse data demonstrated significant interactions (Figure 3). At all joints, the forearm extra mass elicited a significant increase in the positive impulse. However, the upper arm extra mass did not affect the positive impulse much.

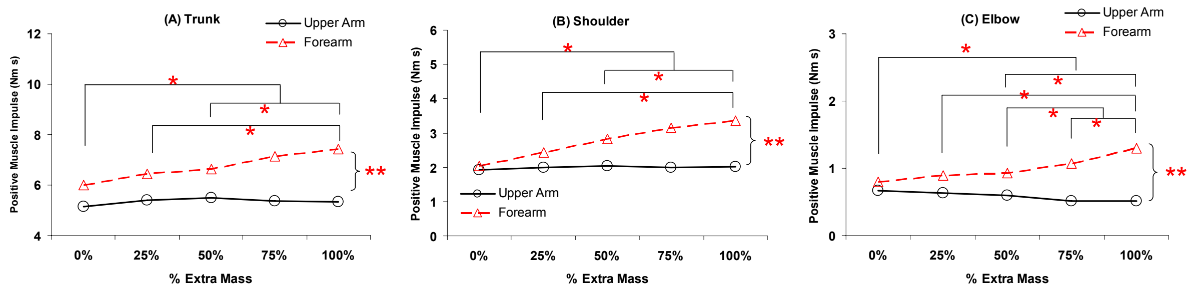

Figure 3: The dependence of the averaged positive muscle impulse on the location and amount of the extra mass. *Significant mean difference was detected among extra mass levels. **Significant main effect of location was found.

A significant interaction between location and mass amount was also found for the system MOI for all three joints (Figure 4). Even though the absolute amount of the forearm extra mass was smaller than that of the upper arm extra mass, it created a much larger MOI than the upper arm extra mass did. For example, the 100% of the forearm mass (1.201 kg) was quite smaller than the 100% of the upper arm mass (2.008 kg). Nevertheless, it produced a greater increase (82.4%) in the shoulder system MOI than the 100% of the upper arm mass did (20.9% increase) (Figure 4 (B)).

DISCUSSION:
This study investigated the effect of adding extra mass on individual segments during the performance of an arm swing task in the horizontal plane. Adding mass to the forearm significantly reduced the swing speed, even though the positive muscle torque significantly increased. This effect can be accounted for by the significant increase in the system MOI. The system MOI is a function of the mass and of the squared distance of mass location to the axis of rotation. For this reason, the influence of the location overpowered the influence of the mass amount.

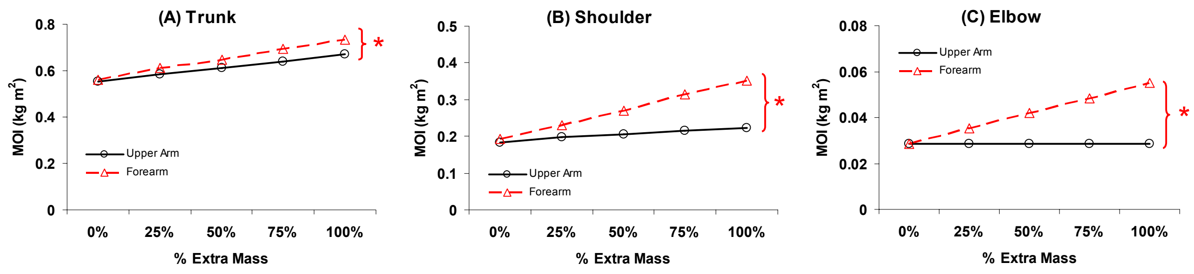

Figure 4: Changes in joint-specific system MOI by the location and amount of the extra mass. *Significant interaction was detected.

In contrast, adding extra mass to the upper arm provided only non-significant influence on the dependent measures. This result provides only limited support for the Southard's finding (1998) that proximally located mass results in movement speed increases. The discrepancy might be due to the usage of the non-dominant hand in the current study. Sainburg (2002) noticed that non-dominant arm is inferior to dominant arm in regulating interaction torques and consequently produces less efficient control and coordination of inter-segmental dynamics than dominant arm does.

Nevertheless, the current study shows a possibility for the performance improvement with placing moderate amount of mass on the upper arm segment (e.g., 25 and 50% of the upper arm mass). The present study may have important applications to baseball bat swing. Baseball players might consider using an additional device on the arm (e.g., elbow protector) during the bat swing. Many players use it for the purpose of injury prevention but it might also help generate additional bat speed depending on its mass. Thus it would be meaningful if this result could be applied to a sport-specific skill like baseball batting.

CONCLUSION:

This study has demonstrated that the swing speed drop as a result of adding extra mass to the forearm even though muscle effort for movement production increases. Indeed, the positive muscle torque was proportionally scaled up but the rotational resistance at each joint overpowered the positive muscle torque. A plausible reason for this effect is the increased system MOI due to the larger dependence of the MOI on the distance of the extra mass location to the axis of rotation than on mass amount. Baseball players should consider adding extra mass proximally (like a weighted upper arm or elbow pad) because there doesn't appear to be any performance penalty and it may actually help create a faster swing (e.g., with 25% and 50% extra mass on the upper arm).

REFERENCES:

deLeva, P. (1996). Adjustment to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*, 1223–1230.

Dounskaia, N., Ketcham, C. J., & Stelmach, G. E. (2002). Commonalities and differences in control of various drawing movements. *Experimental Brain Research, 146*, 11–25.

Hoy. M. G., & Zernicke, R. F. (1986). The role of intersegmental dynamics during rapid limb oscillations. Journal of Biomechanics, 19, 867–877.

Kreighbaum, E., & Barthels, K. M. (1990) *Biomechanics: A Qualitative Approach for Studying Human Movement* (3rd ed.) (pp. 596-664), New York, NY: Macmillan Publishing Company.

Putnam, C. (1991). A segment interaction of analysis of proximal-to-distal sequential segment motion patterns. *Medicine and Science for Sports and Exercise, 22*, 130–144.

Sainburg, R. L. (2002). Evidence for a dynamic-dominance hypothesis of handedness. *Experimental Brain Research, 142*, 241–258.

Southard, D. (1998). Mass and velocity: Control parameters for throwing patterns. *Research Quarterly for Exercise and Sport, 69*, 355–367.