A MODEL FOR ASSESSING THE CONTRIBUTIONS OF HAND FORCES AND TORQUES TO THE SPEED OF A SWINGING IMPLEMENT: APPLICATION TO THE FIELD HOCKEY HIT

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INTRODUCTION

The motions of any striking implement are determined by the force and torque exerted by the hands on it and by the force of gravity [1]. However, the contributions of these factors to an implement's final speed have never been quantified.

The goal of this study was to develop a theoretical model for the analysis of the roles of hand force, hand torque and weight in the generation of the speed of any selected point on a swinging implement, and to apply it to the field hockey hit.

METHODS

The velocity of any point P on the implement other than its center of mass, G, can be broken down into the absolute velocity of G ($\mathbf{v}_G$), and the velocity of P relative to G ($\mathbf{v}_{P/G}$). The velocity of G is generated by the forces acting on the implement: force **F**, applied by the hands at the mid-grip position, and the weight of the implement, **W**. (See Figure 1.) The relative velocity $\mathbf{v}_{P/G}$ is linked to the angular motion of the implement, and therefore ultimately results from the torques acting about G: the mid-grip couple **T** exerted by the hands, and the torque produced by force **F** about G.

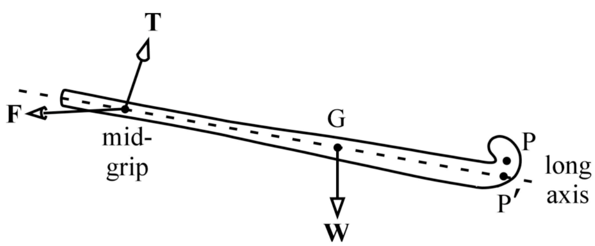

Figure 1: Free-body diagram of a field hockey stick, including the locations of all points used in the model.

In the model, **F** is separated into $\mathbf{F}_N$ and $\mathbf{F}_L$, its components normal and parallel to the longitudinal axis of the implement. **T** is similarly broken down into $\mathbf{T}_N$ and $\mathbf{T}_L$. The roles of these factors and of **W** during any given period are calculated as follows. To assess contributions to the linear acceleration of G, each force is divided at every instant by the mass of the implement, and the resulting acceleration vector is projected onto the current $\mathbf{v}_G$ vector. The acceleration is considered positive or negative, depending on whether the projected vector points in the same direction as $\mathbf{v}_G$ or opposite to it. These projected accelerations are integrated over the period to compute cumulative contributions to the change in the magnitude of $\mathbf{v}_G$. The contribution of each force to the final $\mathbf{v}_P$ is obtained by multiplying its contribution to $\mathbf{v}_G$ by the cosine of the final angle between $\mathbf{v}_G$ and $\mathbf{v}_P$.

To calculate contributions to $\mathbf{v}_{P/G}$, each contributing torque is integrated over the period to calculate an angular impulse. The latter is separated into components normal and parallel to the implement's longitudinal axis at the end of the period. This yields contributions to changes in "somersaulting" and "twisting" angular momentum, respectively. Each is divided by the corresponding moment of inertia to calculate contributions to somersaulting and twisting angular velocity. A linear velocity contribution is calculated for each angular velocity as the cross-product of the angular velocity with the position vector pointing from G to P at the end of the period. The projection of this linear velocity onto the final $\mathbf{v}_P$ gives the contribution of the corresponding torque to $\mathbf{v}_P$.

This model was applied to the downswing of hits by eight female collegiate field hockey players. The DLT method was used to determine the 3D motion of the stick. Inverse dynamics was used to calculate the mid-grip force and torque.

The point selected for analysis in the field hockey application was P′, the point on the stick's longitudinal axis closest to P, the center of the hitting surface. (See Figure 1.) The reason for this decision was that accurate estimates of the moment of inertia of each stick about its longitudinal axis were not available. This made it impossible to measure the effects of the twist rotation of the stick. The latter, however, plays only a minor role in a field hockey hit: the impact speeds of P and P′ differed by 0.7±0.7 m/s.

RESULTS AND DISCUSSION

The speed of point P′ at impact was 28.7±3.4 m/s. The contributions from the forces and torques applied to the stick during the downswing accounted for 27.1±2.9 m/s of this amount. The main positive contributions during this period came from the longitudinal force (54±9%) and from the normal torque (62±18%). Weight made a very small positive contribution (4±1%), and the normal force made a rather small negative contribution (-19±9%). The negative contribution of the normal force was due largely to its effect on the stick's rotation: when this force is in the direction of the hit, the associated torque about G causes a backward linear acceleration of P′ relative to G that more than outweighs the beneficial linear acceleration of G.

CONCLUSIONS

The impact speed of a point near the distal end of the field hockey stick is produced in approximately equal proportions by the pull along the length of the stick and by the couple applied at the mid-grip. The effects of weight and of the force component perpendicular to the stick are much smaller.

REFERENCES

1. Vaughan CL. *Biomechanics VII-B*, University Park Press, Baltimore, 325-331, 1981.