# KICKING SPEED AND LOWER EXTREMITY KINEMATICS

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Most human movements may be performed over a wide range of speeds. To produce changes in overall movement speed, alterations must occur in the frequency and/or amplitude of the movement (Grillner et al., 1979; Nilsson et al., 1985). In running, for example, increases in speed are produced by increases in the frequency and length of the stride (Cavanagh and Williams, 1982) but these parameters do not change at the same rate. During the swing phase of running, the initiations of hip flexion and extension relative to contralateral foot touch down remain constant across speeds while knee flexion and extension occur significantly earlier as speed increases. The amplitudes of knee flexion and hip flexion and extension increase significantly with speed (Nilsson et al., 1985). Gielen et al. (1985) examined the movement trajectory, velocity and acceleration patterns of a single joint arm flexion movement performed at different movement speeds. Movement parameters were scaled in time and amplitude and were found to have similar shapes independent of movement amplitude and time. Hollerbach and Flash (1982) considered a more complex two segment horizontal arm movement and showed that movement speed could be controlled by scaling the time dependent joint moment patterns. It was suggested that the segment velocities and accelerations could be similarly scaled. Other investigators have examined the kinetic patterns of movements performed at different speeds and have suggested that these parameters are not scaled in the same manner as the segment kinematics. During the swing phase of running the resultant joint moments at the hip and knee were found to account for significantly larger percentages of the changes in each segment's angular velocity as running speed increased (Putnam, 1984). The magnitude of the hip resultant joint moment was also found to increase at a faster rate than that of the knee as kicking velocity increased (Zernicke and Roberts, 1978).

The purpose of this study was to examine the relationships among temporal and kinematic parameters across a range of kicking speeds, where kicking speed is specified by the final foot velocity. The kinematics of the lower extremity are primarily explained by the angular velocities of the thigh and the lower leg. Therefore, if changes in the movement speed are achieved by scaled increases or decreases in the segment motions then these changes should be observed in the angular velocities of these segments. Furthermore, if there is a perfect scaling of this movement there should be a constant value by which the segmental angular velocities are multiplied.

## METHODS

Four male college level soccer players performed full instep kicks using a one step approach at three different movement speeds. Movement speed was defined on the basis of the linear velocity of the ankle at impact. This was monitored by two infra-red photo-electric cell pairs connected to a timer and placed 0.15 m apart at the height of the ankle at ball contact. Subjects were trained to perform consistently at slow, medium and fast speeds. Following training, six trials of each subject at each speed were filmed. All trials were filmed at 300 frames/s except for the slow kicks which were filmed at 200 frames/s. Three trials for each subject and each speed were selected from the film for analysis based on final ankle velocity.

The lower extremity was modelled as a two segment system composed of the thigh joined to the lower leg and foot by a pin joint at the knee. The lower leg and foot was treated as a single rigid segment refered to as the shank. The joint centers of these segments, the hip, knee and ankle, were digitized from the film data and smoothed using a digital filter. Angular velocities and accelerations were determined from the displacement data using finite differences. Selected temporal and kinematic variables were entered into a twoway ANOVA for repeated measures over speeds and trials.

To allow for comparisons between kicks of different durations, all speeds were scaled as a percent of total movement time. The total movement time was defined as the time from the start of forward (positive) shank angular velocity until the frame before ball impact. Mean angular velocity curves were then generated from the data of all trials performed at each speed. The average angular velocities for the thigh and shank at each speed were determined. A ratio of the average angular velocities of one speed to another was used to calculate a constant by which the magnitudes of the curves could be scaled. In Figure 1, an example is given where a scaled slow angular velocity curve was produced from a fast curve.

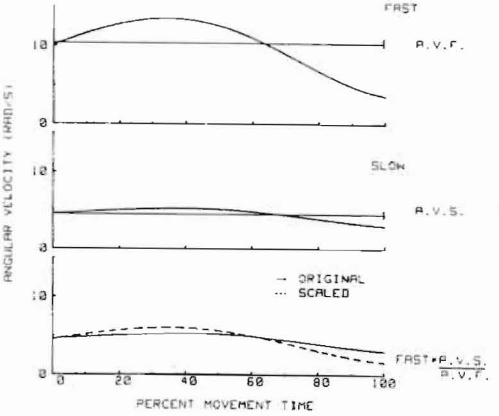

Figure 1. Example of scaling a fast speed thigh angular velocity curve into a slow speed curve.

Initially, the ratio of the average angular velocity of the slow curve to the fast was calculated (A. V. S. /A. V. F. in Figure 1). Each value of the fast velocity curve was then multiplied by this scale constant to produce a new curve which had the same average angular velocity of the actual slow curve but the characteristics of the fast movement.

## RESULTS AND DISCUSSION

Representative motions for the slow, medium and fast speed kicks at every 20 percent of the total movement time are illustrated in Figure 2. Average foot velocities at ball contact and the standard deviations for all trials at each speed are given. These speeds were significantly different.

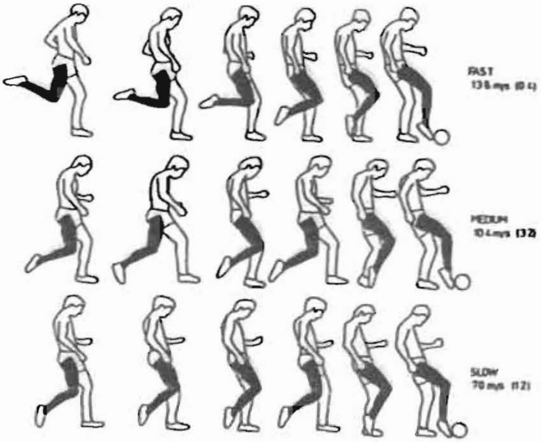

Figure 2. Illustration of a representative motion for slow, medium and fast speed kicks. The first figure is at the initiation of shank forward rotation and each figure following is at every 20 percent of the total movement time until ball impact.

The final linear ankle velocity reached during a kick is predominantly determined by the speed of rotation of the thigh and shank. The final angular velocity of the shank was significantly different across speeds but the final angular velocity of the thigh remained the same (Figure 3). Therefore the contribution of the final shank angular velocity to increases in foot speed appears to be much greater than that of the thigh. This was also found by Macmillan (1975). While the final thigh angular velocity does not play a large role in determining foot speed at impact, the maximum velocity reached during the course of the kick increased significantly as kicking speed increased, demonstrating the importance of the speed of forward thigh rotation in determining kicking speed (Putnam, 1983; Roberts et al. , 1968).

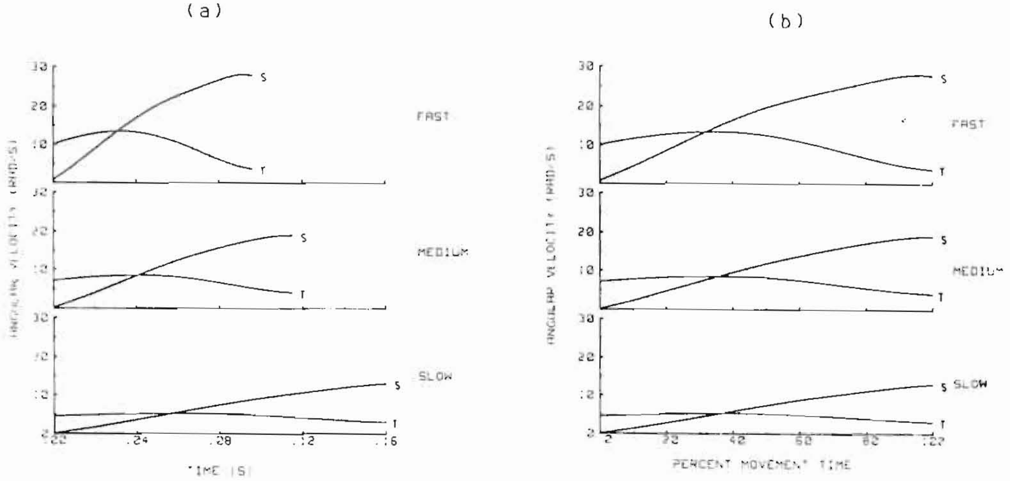

Figure 3. Mean shank (S) and thigh (T) angular velocity-time curves for slow, medium and fast kicking speeds. Curves are expressed as functions of (a) actual time and (b) percent of total movement time.

In spite of these differences in the magnitudes of the thigh and shank angular velocities, a common sequence of lower extremity segment motions was observed for all kicking speeds. This sequence is illustrated in Figure 3(b), where all angular velocity curves have been expressed as a percent of total movement time. (Total movement time is defined as the start of forward shank angular velocity until the frame prior to ball impact and was significantly different across speeds.) The thigh initially rotated forward in the direction of the movement and increased in angular velocity, while the shank rotated so as to decrease the angle between the segments. Between 35 and 40 percent of the movement time, the angular velocity of the thigh decreased and the shank reversed direction increasing in angular velocity until ball contact. The time of peak thigh angular velocity was not significantly different across speeds. The knee started to extend between 32 and 36 percent movement time and this was also not significantly different across speeds. Although peak thigh angular velocity and the initiation of knee extension do not occur at the same time, they appear to be related regardless of the speed at which the movement is performed. This finding is consistent with those of Phillips et al. (1983) and Zernicke and Roberts (1976). In summary, there is a temporal relationship among the start of forward shank angular velocity, time of maximum thigh velocity, time of knee extension and ball impact which remains consistent across speeds. This relationship exists despite significant differences in the segment orientations and angular velocity magnitudes which occur across speeds throughout the majority of the kick (Figures 2 and 3).

If a fast movement is performed with a certain average angular velocity, to decrease the speed of the movement the average segmental angular velocities over the movement phase must be reduced. If we assume that different movement speeds are caused by a scaling of the angular velocity-time curves, to scale a fast movement to a slower one, each segmental angular velocity of the fast movement would have to be reduced by a ratio of the slow average angular velocity to the fast (Figure 1). The scaled slow version of the fast curve would have the same average angular velocity as the slow curve but would follow the characteristics of the fast speed curve.

The results of scaling the thigh and the shank angular velocities of the fast movement to produce a scaled version of the slow and medium speeds are presented in Figure 4(a). For the first 62 percent of the movement the magnitudes of the actual curves for both the thigh and shank are less than those predicted by a perfectly scaled version of the fast curve. For the last 38 percent of the movement the actual curve magnitudes are greater than the scaled curves. Therefore, if the medium and slow speed kicks were to be perfectly scaled versions of the fast speed kick, both segments would have had to be accelerated to a greater extent for the first 62 percent movement and to a lessor extent for the last 38 percent of the movement. This, together with the similarity in the scale constants between the thigh and shank (Table 1) suggests that when movement speed is changed, both segments appear to be altered in a similar manner.

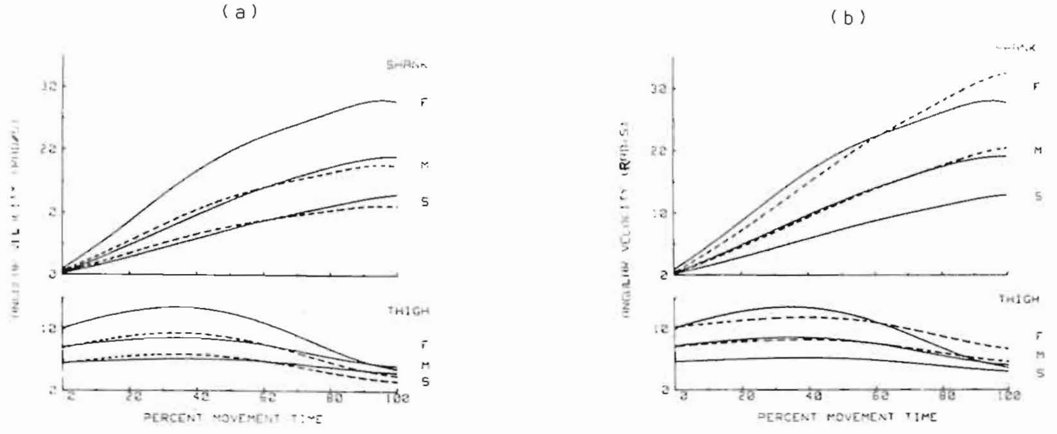

Figure 4. Mean shank (S) and thigh (T) angular velocity expressed as a percent of total movement time. The actual experimental curves are in solid lines and the predicted scaled version in dashed lines. In (a) the fast movement has been scaled to a medium and slow movement and in (b) the slow movement has been scaled to a medium and a fast movement.

The results of scaling the slow curve to predict the fast and medium curves (Figure 4(b)) demonstrate that there is much more variability between the actual and scaled fast curves than between the actual and scaled medium curves. The differences between the scaled and actual curves of the segment angular velocities are expressed as the root mean square (RMS) difference in Table 1. To facilitate comparisons of the RMS values across scaling procedures, they were divided by the average angular velocity of the respective scaled curve. This normalized value shows how the scaled curve differs from the actual curve, independent of the average velocity of the scaled and actual curves. The normalized RMS values for scaling a fast movement to a medium movement or fast to a slow movement, or vice versa, are higher than those when scaling a medium to a slow movement. This reinforces the finding that the medium and slow movements are much more similar to each other than either one is to the fast. The normalized RMS differences for the shank are lower than those of the thigh, indicating that the shapes of the shank angular velocity curves are more similar across movement speeds than the shapes of the thigh angular velocity curves.

TABLE 1

AVERAGE ROOT MEAN SQUARE (RMS) DIFFERENCES, NORMALIZED ROOT MEAN SQUARE DIFFERENCES AND SCALE CONSTANTS FOR THE THIGH AND SHANK FROM ALL SCALING PROCEDURES.

| | Thigh | | | Shank | | |
|---|---|---|---|---|---|---|
| Procedure | RMS | Normalized | Scale | RMS | Normalized | Scale |
| Fast to Slow | 0.72 | 0.158 | 0.44 | .074 | 0.105 | 0.40 |
| Slow to Fast | 1.61 | 0.158 | 2.25 | 1.86 | 0.105 | 2.51 |
| Fast to Med. | 0.76 | 0.107 | 0.69 | 0.76 | 0.068 | 0.63 |
| Med. to Fast | 1.09 | 0.107 | 1.44 | 1.21 | 0.068 | 1.59 |
| Med. to Slow | 0.24 | 0.052 | 0.64 | 0.27 | 0.039 | 0.63 |
| Slow to Med. | 0.37 | 0.052 | 1.56 | 0.43 | 0.039 | 1.58 |

## SUMMARY

There is a consistent temporal pattern for movements performed at different speeds which is independent of the segment configuration and velocities. While the results of this study do not demonstrate a perfect scaling of the angular velocity curve as suggested by Gielen et al. (1985) and Hollerbach and Flash (1982), there is a strong degree of scaling across speeds. The segmental angular velocity-time patterns are more similar between the slow and medium speed kicks than between either the slow and medium kick and the fast kick. This suggests that the fast speed movements are somewhat different when compared to slower ones (Zernicke and Roberts, 1978). The relationship between the scaled and actual curves were similar for the thigh and the shank and indicate that as movement speed changes the alterations in the segment motions may be related.

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