USE OF THE KINEMATIC CHAIN IN THE FENCING ATTACKING LUNGE

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ABSTRACT: Proximal to distal sequencing has been demonstrated in a variety of movements as an optimal solution to generating maximal propulsion. This study aimed to identify whether the kinematic chain is used in the fencing attacking lunge. Six novice and four expert fencers completed attacking lunge movements. Kinematic data were captured, and joint angular velocities compared. The expert group demonstrated a proximal to distal sequence in the rear leg which was not as evident in the novices, resulting in a significantly greater ankle extension velocity (564 ± 132 $°.s^{-1}$ expert versus 273 ± 184 $°.s^{-1}$ novice; $p<0.05$). This sequential pattern capitalizes on the design of the human musculoskeletal system, allowing for greater forward sword velocity to be achieved. The kinematic chain of the rear leg has an optimal solution adopted by expert fencers in the attacking lunge skill.

KEY WORDS: angular velocity, biomechanics, sport.

INTRODUCTION: In the fencing attacking lunge significantly greater sword velocity in elite athletes has been attributed to more than arm extension velocity alone, with the sword arm's movement in coordination with the lunge movement distinguishing expert from novice fencers (Yiou & Do, 2000). Rear knee range of motion and peak rear hip flexion have been identified as significant predictors of sword velocity, as well as lead hip flexion in a 'kick out' type action (Bottoms et al., 2013). Kinematic and electromyography data have empirically supported that the rear leg extensor muscles activate mainly in the propulsive phase of the attacking lunge (Guilheim et al., 2014) with this activation following a temporal sequence in the rear leg with more distal muscles, such as plantarflexors in the ankle, firing later.

The kinematic chain can be used in a proximal to distal sequence, allowing for utilization of velocities generated in the proceeding segment. Mathematical modelling has identified the effectiveness of the lower limb rigid body chain in turning joint segment angular velocity into effective linear center of mass velocity (Bobbert & van Soest, 2001). Use of a sequential kinematic chain has not been investigated in forward propulsive movements such as the fencing attacking lunge. The aim of this investigation was to determine if more skilled performers used a sequential kinematic chain in the rear leg. This research would benefit coaches and athletes by providing important information on the determinants of successful fencing lunge performance.

METHODS: Ten healthy participants (6 novice; age 22 ± 10 years, 178 ± 8 cm, leg length 96 ± 6 cm, mass 74.6 ± 16.2 kg, and; 4 expert; age 24 ± 14 years, height 181 ± 5 cm, leg length 99 ± 0 cm, mass 72.0 ± 15.3 kg) with a minimum of 1 year experience fencing (average 7.5 ± 10.7 years) agreed to take part in this study. The expert lunge participants were all competitive above regional level (3 national). Data collection took place in one day, with participants completing 7 lunges toward a 15 x 15 cm target marked on the chest of an opponent. Each participant stood a self-selected distance (2.19 ± 0.07 m expert and 2.01 ± 0.03 m; $p<0.05$) from the target deemed their competitive distance. The participant was then instructed to sit in the 'on guard' position, and to lunge and strike the target center "quickly and accurately" upon reacting to an auditory signal. A total of 59 passive retro-reflective markers of 10mm diameter were placed on the participant in anatomical landmarks according to an adapted Cleveland gait model, with an additional 3 on the sword and 4 on the target. Marker tracking was completed using 12 cameras operated through Cortex v5.0.2 software (Motion Analysis Corporation, Santa Rosa, CA). A custom written MATLAB code (R2013b, Mathworks, Natick, MA) was used to analyze each trial from the onset of sword movement (defined as horizontal sword velocity >0.2 $m.s^{-1}$), up until target contact. Target contact was defined as the peak increase of horizontal target marker velocity that occurred with sword impact on the target. Reaction time was determined from the auditory signal until first sword movement, with total movement time being from sword movement until target contact. Horizontal sword velocity was obtained from a marker placed 50 mm from the base of the sword. Lunge distance was determined as the maximal forward displacement of the lead foot in the sagittal plane, normalized by leg length. Joint angles and angular velocities were calculated for the sword arm elbow, and rear leg hip, knee and ankle. Temporal variables were identified as the occurrence of joint angular velocity local maxima presented as percentages of the whole movement for the sword arm elbow as well as the rear hip, knee and ankle. Rank scoring was assigned according to the temporal sequence of maximal joint angle extension for elbow, hip, knee and ankle respectively for each subject and presented as group averages. Once normality was tested according to Vincent (2005), data between groups were compared using independent t-tests with alpha level set at 0.05.

RESULTS: There were no significant differences in reaction time (0.21 ± 0.11 s expert versus 0.21 ± 0.03 s novice; $p>0.05$) or movement time (0.70 ± 0.03s expert versus 0.69 ± 0.09s novice; $p>0.05$). Peak horizontal sword velocity was significantly greater in the expert group (3.21 ± 0.22 $m.s^{-1}$ expert v 2.63 ± 0.29 $m.s^{-1}$ novice; $p<0.05$) and the expert group had a greater lunge distance measured from front foot displacement (1.12 ± 0.07 leg lengths expert versus 0.83 ± 0.15 leg lengths novice; $p<0.05$).

There were no significant differences in peak elbow or peak hip extension velocity between the groups (table 1). The expert group demonstrated significantly greater peak ankle extension velocity. The expert group also displayed greater, but not significant, peak knee extension. The expert group average peak extension times occurred later than the novice group, starting with the peak elbow angular extension velocities occurring at 68 ± 33% for expert and 61 ± 19% for novice. The SDs for the timings were large particularly given the small sample, and so although the mean values do not show a clear kinematic sequence, the ranked data show a better sequential pattern data for the experts of elbow, hip, knee and ankle.

Table 1: Kinematic variable local maxima peaks for novice and expert groups (means ± SD).

Joint Variable	Novice	Expert
Elbow angle (°)	157 ± 3	160 ± 2
Hip angle (°)	153 ± 6	150 ± 8
Knee angle (°)	162 ± 3	171 ± 7
Ankle angle (°)	117 ± 13	137 ± 13*
Elbow angular velocity (°.s^{-1})	293 ± 115	293 ± 72
Hip angular velocity. (°.s^{-1})	120 ± 62	116 ± 58
Knee angular velocity. (°.s^{-1})	287 ± 80	430 ± 118
Ankle angular velocity. (°.s^{-1})	273 ± 184	564 ± 132*
Elbow peak velocity time (%)	61 ± 19	68 ± 33
Hip peak velocity time (%)	71 ± 11	77 ± 11
Knee peak velocity time (%)	70 ± 9	75 ± 8
Ankle peak velocity time (%)	76 ± 10	79 ± 8
Elbow rank (goal of 1)	2.5 ± 1.6	1.5 ± 1.0
Hip rank (goal of 2)	2.2 ± 0.5	2.5 ± 1.0
Knee rank (goal of 3)	2.0 ± 1.0	2.5 ± 1.0
Ankle rank (goal of 4)	3.3 ± 0.6	3.5 ± 1.0

* $p<0.05$ between novice and expert.

The time series of the rear leg angular velocities (figure 1) show a clear sequential kinematic chain in the expert group. The sequential extension of the hip, knee and then ankle (dotted line) show an increase in extension magnitude with each proceeding segment, culminating in the ankle joint demonstrating the greatest extension velocity (564 ± 132 °.s^{-1}). In the novice group the knee had the greatest magnitude (287 ± 80 °.s^{-1}) with the ankle extension lower (273 ± 184 °.s^{-1}) than the knee and occurring shortly after peak knee extension.

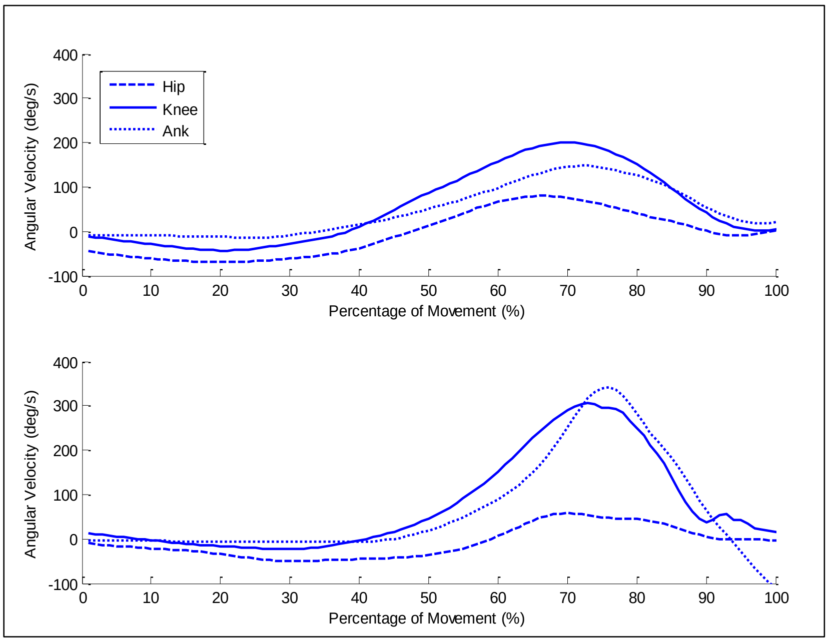

Figure 1: Kinematic chain for novice (top) and expert (bottom) showing group average hip, knee and ankle angular velocities as a percentage of movement from movement initiation (0%) to target contact (100%).

DISCUSSION: The peak joint angular velocity ranking demonstrates that the expert group individually used kinematic sequencing to a greater extent than the novice group, This accounts for the significantly greater horizontal sword velocity (3.21 v 2.63 m.s^{-1}; expert v novice; $p<0.05$) and lunge distance (1.12 v 0.83 leg lengths; expert v novice) that demonstrated that the expert group were more skilled in the attacking lunge technique. No significant differences in elbow extension, and extension velocity were found between the groups. This is in line with previous research suggesting that the additional velocity is developed through the lower extremities (Yiou & Do, 2000). In addition, the large SDs of both groups' elbow extension velocity times (± 33 °.s^{-1} expert v ± 19 °.s^{-1} novice) demonstrate the individual variability in elbow movement selection. This is perhaps explained with the arm controlling the aim of the sword; therefore the timing at which the elbow extends is variable between subjects to allow for adjustments so that accuracy can be maintained. This is particularly important in a combative sport where an opponent can defend and counter.

Although there are no significant differences in hip and knee angular velocity, there is a proximal to distal increase of angular velocity from the hip to knee in both groups, which is more evident in the expert group. A key difference in the expert group is that this increase of angular velocity continues distally to the ankle resulting in a significantly greater ankle extension velocity (564 ± 132 °.s^{-1} expert v 273 ± 184 °.s^{-1} novice; $p<0.05$). As a group, the expert individual ranking averages scored 1.5 ± 1, 2.5 ± 1, 2.5 ± 1 and 3.5 ± 1 for the elbow, hip, knee and ankle, respectively, showing that on an individual level the expert group followed a sequential movement pattern initiated with the elbow and then in a proximal to distal pattern in the rear leg. The novice group rank averages scored 2.50 ± 1.64, 2.17 ± 0.45, 2.00 ± 1.00 and 3.33 ± 0.55 suggesting that the novice performers did not have a set sequential pattern.

Mathematical modelling by Bobbert and van Soest (2001) demonstrated that hip, knee and then ankle extension in a sequential pattern is optimal in explosive jumping movements. In particular the timely extension of the ankle, the smallest and most distal segment with the lowest inertia, is pivotal in achieving maximal jump height. This supports the findings of this study, with the expert participants demonstrating significantly greater ankle extension velocity and marginally later in the movement than the novice (79 ± 8% expert versus 76 ± 10% novice). Although the previous findings have been demonstrated on a vertical movement, the theoretical underpinning of a closed kinematic chain in the lower extremities is transferable to the forward propulsive movement of the rear leg in the fencing lunge investigated in this study. The proximal to distal sequencing capitalizes on the design of the human musculoskeletal system. It helps to restrain the angular velocities of the more proximal segments thereby helping to reduce their negative effect on the vertical acceleration (Bobbert & van Soest, 2001). This prevents takeoff before the larger, proximal musculature has been able to produce work over the full working range. The hip angular velocity profiles (figure 1) support this, with the expert group's hip extension velocity remaining positive throughout the movement. Additionally, biarticular muscles such as rectus femoris and gastrocnemius allow proximal muscles to trigger distal segments so that they can be used more timely and effectively. The elastic tendons of the plantar flexors can be loaded, with knee extension also stretching the biarticular gastrocnemius. The Achilles tendon lengthens and is loaded with elastic potential energy This is then released with subsequent plantar flexor extension (Bobbert & van Soest, 2001; Kurokawa et al, 2003). This explains the greater knee extension and subsequent ankle angular velocity shown in this investigation, with expert fencers generating greater forward velocity.

CONCLUSION: This study highlights that the kinematic chain plays a pivotal role in the propulsion of the fencing attacking lunge, as an effective solution to maximize horizontal sword velocity. The ankle joint has been demonstrated as a pivotal joint in the fencing attacking lunge, allowing for utilization of accumulated angular velocity in the lower extremities distributed in a timely manner to the smaller, more distal segments. The small sample size is a limitation in this investigation, and therefore further research is required to verify these findings to a larger population. In addition further work needs to be carried out into the application of this research into the coaching athlete interface.

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