OVERUSE INJURIES IN RUNNING: DO COMPLEX ANALYSES HELP OUR UNDERSTANDING?

Joseph Hamill, Jeffrey M. Haddad, Richard E. A. Van Emmerik

Biomechanics Laboratory, University of Massachusetts Amherst, USA

The purpose of this paper is to discuss the change in focus in biomechanics from relatively simple analysis techniques to more complex techniques. Overuse injuries, linked to rearfoot motion, will be used as an example. In the early development of biomechanical techniques, the angle magnitudes were presented to suggest the mechanisms of overuse injuries. Later, coupling rearfoot motion with actions of the knee became commonplace. In these analyses, the timing and ratios of the angular movements were expressed. However, none of these measures provided a sufficient explanation for injury mechanisms. New techniques, derived from dynamical systems theory, have provided a more salient explanation of the overuse injury mechanism through assessing the role of variability in movement coordination.

KEYWORDS: overuse injuries, rearfoot motion, dynamical systems, continuous relative phase, variability

INTRODUCTION: As a discipline, biomechanics has progressed significantly from both a technological and analytical point of view. Technological development has allowed biomechanists to become ever more sophisticated. In the 1970's most of the kinematic research was two-dimensional, and very few laboratories were equipped with force platforms. The published research of the day was composed of relatively simple questions with simple methods of analysis. Today, nearly all laboratories are equipped with three-dimensional systems with a variety of force and pressure platforms. The leap in technology has allowed biomechanists to ask more complicated questions with significantly more complex methods of analysis. The development in research sophistication has been apparent in research attempting to identify the basic mechanisms of cumulative trauma or overuse injuries. In this paper we will discuss the basic questions that have been asked regarding overuse injuries and assess the degree to which these questions have been answered using both simple and complex levels of data collection and analysis.

THE EARLY YEARS OF INJURY RESEARCH: In the mid-1970's, several researchers identified that shock attenuation and mediolateral control were two aspects of foot function that appeared to be linked to particular overuse injuries of the lower extremity (e.g. Nigg et al., 1985, Bates et al., 1978). In this paper, we will concentrate on mediolateral control which was identified as an important component of stability. The measure that was uniquely associated with stability was the supination/pronation angle (calcaneal inversion/eversion) or rearfoot angle. This angle was most often determined from a two-dimensional set-up with markers placed on the leg and calcaneus. The analysis was conducted in the frontal plane from which the maximum angle was extracted. It was hypothesized that, the greater the pronation (eversion) angle, the greater the possibility of incurring a lower extremity injury. Many studies then reported the magnitude of pronation angles for runners with all types of lower extremity injuries (e.g. Bates et al., 1979). The term that was coined for large pronation angles was 'excessive pronation'. Unfortunately, there is no clinical definition for an 'excessive' pronation angle. In addition, there was no consensus among the studies to determine if injuries were a cause or result of 'excessive' pronation.

A COUPLING THEORY: Until the early 1980's there was little or no epidemiological research that substantiated the claim made that a large pronation angle was the root cause of certain injuries. However, in the early 1980's, Clement et al. (1981), in a large epidemiological study, reported that the vast majority of lower extremity injuries to runners was not in the foot region but at the knee. Because the foot is loaded during contact with the ground, it was speculated that "excessive" pronation was still implicated in overuse injuries.

James et al. (1978) had suggested that the pronatory action of the foot on the ground is linked to the action of the knee via tibial internal/external rotation. James and colleagues explained that tibial internal rotation occurred with pronation and knee flexion, while tibial external rotation occurred with supination and knee extension. Delayed or prolonged pronation would cause knee pain when the knee extended during this time. Because tibial rotation could not be measured from a two-dimensional analysis, the measure of maximal internal rotation was determined from the instant when the knee of the swing leg passed by the knee of the support leg. Essentially, the timing of maximal tibial rotation was compared to maximal pronation. In many instances, researchers used angle-angle histories to illustrate the maximal angle differences but no quantitative analysis was conducted on these plots. This paradigm illustrated that a single joint action may not give the correct answer, whereas coupled motions of joints may give greater insight into the mechanism of overuse injury.

JOINT COUPLING: Attacking the same coupling problem, Hamill et al. (1992), in a two-dimensional study, attempted to show that an extrinsic factor could also influence the relationship between tibial rotation and pronation although they did not measure tibial rotation directly. They suggested that this extrinsic factor, shoe midsole density, could influence the degree of pronation and therefore disrupt the timing of internal tibial rotation (Fig. 1). The midsoles in this study ranged from very hard (Shoe 1) to very soft (Shoe 3). Shoe 3 produced the greatest discrepancy in timing and was thus thought to present the greatest potential of injury to the runner. It was assumed that increased pronation could exacerbate overuse injury.

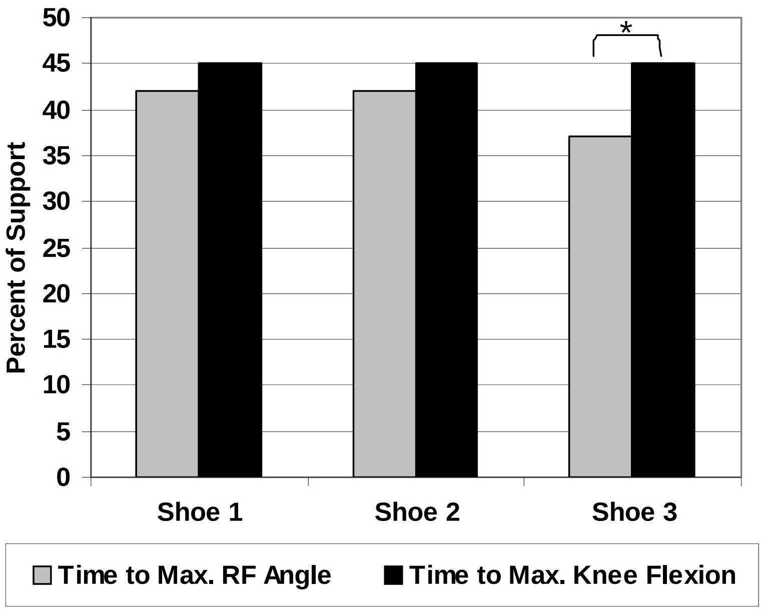

Figure 1 - Timing of knee and rearfoot angles as a function of midsole density.

The relationship between internal tibial rotation and eversion was presented in a different manner by McClay and Manal (1997). This was one of the first three-dimensional studies conducted on rear foot and tibial motion. These researchers determined maximal internal tibial rotation (TIR) and maximum calcaneal eversion (EV) and created an EV/TIR ratio. It was assumed that a ratio >1.0 may pre-dispose runners to foot-related injuries while a ratio <1.0 would pre-dispose runners to more knee-related injuries. What these investigators reported, however, was that the EV/TIR ratio was not significantly different between subjects who pronated to a "normal" degree and those who pronated "excessively".

Even with a newer model that assessed the coupling between segments and with newer 3-D analysis techniques, no definitive conclusions concerning an injury mechanism was proposed. Basically, the research was still inconclusive on the mechanism of injury.

COMPLEX COUPLING MEASURES: In recent years, researchers have further investigated joint or segment coupling using methods based on dynamical systems theory (Hamill et al., 1999; Heiderscheit et al., 2002). These methods typically incorporate multiple component variables (i.e. position and velocity information from multiple joints or segments) into the final measure. Using this approach, the typically high number of degrees of freedom involved in movements are studied together at the level of a coordinative structure from which the system may be more easily explainable (Kelso, 1995). These collective variables have been used to assess qualitative aspects of movement coordination and modal changes between coordinative patterns. Over the past 20 years, a growing body of literature has purported that these types of analytical techniques are more sensitive than basic kinematic or kinetic parameters at identifying the coordination of a multisegmental system (see Davids et al., 2006 for a recent review). This approach, therefore, allows for definite predictions of movement patterns that could be tested empirically.

While there are several methods of analysis often used in this approach (e.g. relative phase, discrete relative phase), the method that has been most used is continuous relative phase (CRP). This measure is a collective variable that employs spatial and temporal information from two joints or segments in its final measure, resulting in a more detailed analysis of the system behavior (Figure 2). One benefit of the CRP analysis is that it uses position and velocity information throughout the entire stride cycle rather than at only a specific event (as other methods previously noted). Therefore, while the basic kinetics and kinematics may not change, the higher order parameters contain much more information and this information may be the key to determining an injury mechanism.

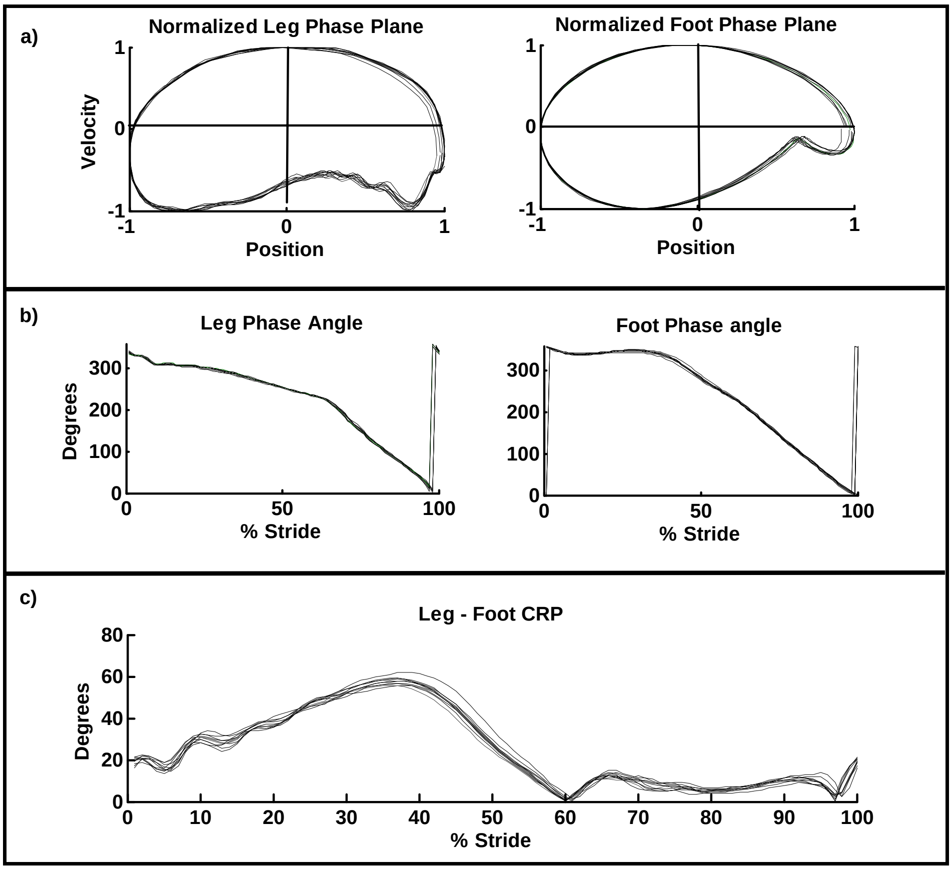

Figure 2 - a) Position - velocity phase planes of the leg (left) and foot (right) segments over 10 stride cycles normalized to a unit circle. b) Phase angles are calculated from the phase planes as the four-quadrant arctangent function of the normalized position over normalized velocity at each point in the stride cycle. c) Finally the discontinuities that arise in the phase angles from quadrant crossings are removed and CRP is obtained by simply subtracting the phase angle of the proximal segment from that of the distal segment.

One basic hypothesis of the dynamical systems approach, is that CRP variability increases at key transition points in the movement cycle (Kelso, 1995; Van Emmerik & Wagenaar, 1996). For example, it should be expected that CRP variability should increase at the transition from the swing period to the support period of running or during the transition from braking to propulsion during the stance period. It is the measure of CRP variability that has shown promise in the evaluation of overuse running injuries.

In 1999, Hamill and colleagues proposed a mechanism for overuse injuries using a dynamical systems approach. They evaluated coupling in key joint actions first in women with high (>15^o) and low (<15^o) Q-angles and second in patellofemoral pain (PFP) subjects and compared those to healthy subjects. In both cases, 'excessive' pronation has been reported as an exacerbating factor in causing pain and injury. CRP variability was determined for each of these coupling actions and was evaluated as the average variability across key intervals in the support period. Generally what was reported was that higher CRP variability was associated with the healthy state (i.e. low Q-angle and non-PFP subjects) while lower variability was associated with both the high Q-angle and PFP subjects. This finding contradicted the traditional view of variability and suggested a functional role for coupling variability.

Lower CRP variability in the involved versus uninvolved limb has also been observed in patients who have been previously diagnosed with a tibial stress fracture (Figure 3). One interesting component from this study was that lower variability was found despite the fact that the stress fracture group was asymptomatic at the time of the data collection. A second interesting finding from this study was that differences in variability were found in the proximal as well as the distal limb couplings (Hamill et al., 2005). These proximal effects show that a distal injury affect the proximal as well as distal couplings suggesting that mechanisms of injury should be examined at the level of the coordinative structures and not the individual joints or segments. It has been proposed that reduced CRP variability indicates a less flexible or adaptable movement pattern and may exacerbate or cause further injury (Hamill, et al., 1999; Van Emmerik et al., 1999).

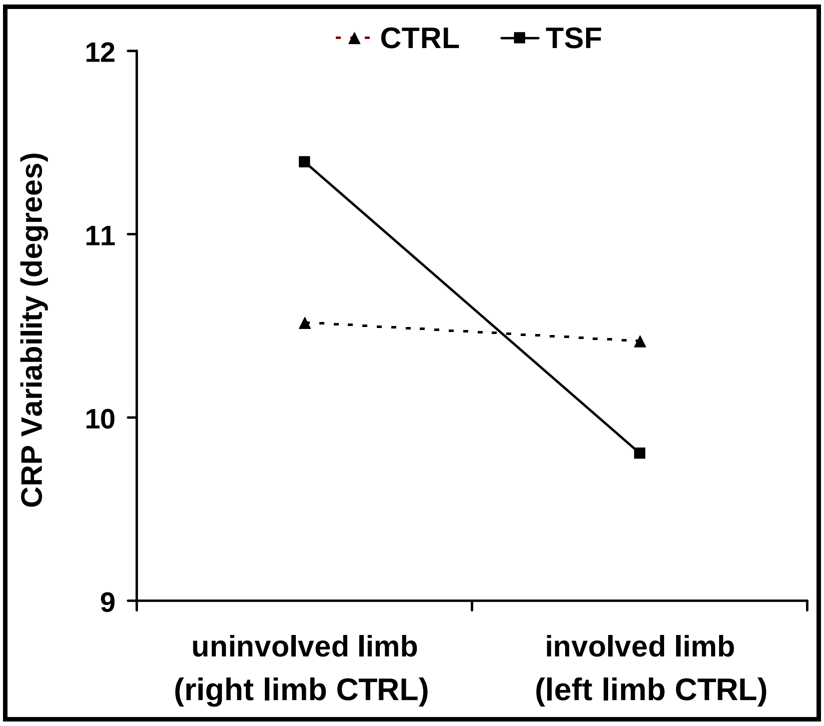

Figure 3: Mean CRP variability in the knee-ankle coupling in the involved and contralateral limbs of TSF group and right and left limbs of the CTRL group. Lower CRP variability is observed in the involved versus uninvolved limb in the patients. No differences were found between the limbs in the control group.

Further, even more complex methods of calculating CRP and CRP variability have been suggested and used for the study of rearfoot motions. These complex methods were proported to alleviate some of the limitations (such as the assumed sinusoidal nature of the input signals) and problems (such as normalization) of the CRP calculation (see Peters et al., 2003). One such method involved the construction of the CRP based on the Hilbert Transformation (Hamill et al., 2001). However, this method did not produce results that were different from the previous CRP calculations when assessing runners with PFP.
Recently some of the theories discussed above in regards to gait have been applied to human postural control, where, similar interpretations have been observed. A large degree of postural variability was found to be characteristic of a more healthy adaptable postural system. Conversely a low amount of variability was characteristic of a more diseased less adaptable system. In a manner similar to the gait research, these interpretations were only only observed using higher order measures of postural stability (Van Emmerik and Van Wegen 2002).

CONCLUSIONS: The key to the research on overuse injuries and specifically those 'caused' by rearfoot motion, is the formulation of a mechanism for the injury. This finding could then be used to prevent such injuries. What then have we found over the years of study? First, the methods of analysis of rearfoot motion have progressed from simple angle-time analysis to the recognition that joints work in concert and should be evaluated thusly. Second came the evaluation of the coupling behavior using various timing and angle ratios. Lastly, a dynamical systems approach was used to investigate the higher order dynamics of the movement. These methods have highlighted the role of movement coordination and variability in addressing the mechanisms of overuse injuries. Several recent studies in both posture and gait have demonstrated changes in coordination and variability in various pathologies (i.e. aging, PFP and tibial stress fractures), highlighting the importance of variability in understanding mechanisms of injuries and disease. The major criticism of this proposed mechanism is that we cannot determine whether the higher CRP variability is the cause of the injury or the result of the injury. A significant complication with all of these studies was that they all had an *ex post facto* design. That is, the studies were retrospective in nature in which the injury cohort being studied already had the injury.
It does appear that more complex methods of analysis can lead to a deeper understanding of the injury process. The rich dynamical interactions amongst the multiple degrees of freedom during movement may not be adequately represented using simple parameter – time plots. However, it should also be noted that if a simple analysis method results in the answer to a specific question, then there is no need for a more complex technique. When researchers introduce new analysis methods that are complex, extra care should be taken to indicate what additional knowledge these new methods provide over and above existing analysis techniques. In addition, researchers must be cognizant of the audience to which they address their results. If the audience cannot be clear about the implications then whatever analysis used is inconsequential.

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