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EXPERTISE IN THE PERFORMANCE OF MULTI- ARTICULAR SPORTS ACTIONS

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Introduction

Multi-articular, or multi-joint, actions are integral to all sports. The purpose of this chapter is to critically evaluate the literature and provide a summary of the technical features that distinguish experts from non-experts performing multi-articular sport actions, specifically throwing, kicking, and hitting actions. The biomechanics of these sport techniques, and the theoretical principles governing them, have been well documented in the scientific literature (see Atwater, 1979; Putnam, 1993; Fleisig *et al.*, 1996; Bartlett, 2000; Elliott, 2000; Kellis & Katis, 2007; Bartlett & Robins, 2008; Elliott *et al.*, 2008 for comprehensive reviews) and we draw upon this body of knowledge to focus our analysis on particular aspects of technique that are known to be linked to fast, accurate, and consistent performance outcomes. Although we limit our summary to the biomechanical aspects of expertise in throwing, kicking, and hitting actions, we recognize the important role that perception plays in the successful execution of these multi-articular actions, and that perception and movement cannot, and should not, be considered independently of one another (see Savelsbergh & Bootsma, 1994; Williams *et al.*, 1999; Davids *et al.*, 2002; Warren, 2006; Fajen *et al.*, 2008; Zelaznik, 2014). Accordingly, we recommend that this chapter be read in conjunction with others in this book, specifically Chapter 5 by van der Kamp and Renshaw and Chapter 12 by Davids, Araújo, Seifer, and Orth.

Biomechanical characteristics distinguishing experts from non-experts during the performance of multi-articular sport actions

It is somewhat self-evident that expert and non-expert throwers, kickers, and hitters differ, not only in terms of the speed, accuracy, and consistency of performance outcomes, but also the techniques they use to produce those outcomes. However, most biomechanical studies examining these multi-articular sport actions have generally not focused on establishing differences in “technique”—defined by Lees as “. . . the *relative* position and orientation of body segments as they *change* during the performance of a sport task” (2002, p. 814, our emphasis)—between performers of various skill levels. Rather, these investigations have typically attempted to identify relationships between technical characteristics and performance outcomes within groups of performers who are relatively homogenous in terms of expertise or experience (e.g., De Witt &

Hinrichs, 2012; Worthington *et al.*, 2013). Typically, these technical characteristics have been presented as time-discrete kinematic variables describing segmental motions at key moments—as prescribed, for example, by deterministic or hierarchical performance models (see Lees, 1999, for a review)—but this approach, at best, provides only snapshots of isolated aspects of “technique.” Some biomechanical analyses of multi-articular sport actions have compared kinematics, kinetics, and muscle activation characteristics across experimental conditions, such as dominant versus non-dominant limb (e.g., Sachlikidis & Salter, 2007), fatigued versus unfatigued states (e.g., Rota *et al.*, 2014), successful versus unsuccessful trials (e.g., Göktepe *et al.*, 2009), and maximal versus submaximal effort (e.g., Zhang *et al.*, 2011), and across groups, such as males versus females (e.g., Barfield *et al.*, 2002) and seniors versus juniors (e.g., Delextrat & Goss-Sampson, 2010) but skill level has rarely been included as an additional independent variable.

In the following subsections, we identify specific aspects of throwing, kicking, and hitting techniques that have either been empirically associated with, or have been theoretically linked to, the production of fast, accurate, and consistent performance outcomes, and we examine how these technical features differ between experts and non-experts. Given the remit of this book and the nature of the research area it covers, we primarily consider studies that have directly examined biomechanical differences among performers of different skill levels. We neither compare and contrast studies that have considered experts and non-experts separately, nor do we attempt to extrapolate findings from correlation studies on expert performers to non-expert performers, although it could be argued that these types of studies could legitimately fall under the “expertise” rubric.

Sequencing and timing of body segment motions

A key feature of all throwing, kicking, and hitting techniques is the sequencing and timing of body segment motions (e.g., Atwater, 1979; Putnam, 1993; Bartlett, 2000; Elliott, 2000). Although the underpinning biomechanical mechanisms and the ubiquity of this particular sequence of segmental motions are still subject to much debate (e.g., Marshall & Elliott, 2000; Fradet *et al.*, 2004), it is generally accepted that, during the performance of these multi-articular actions, energy and momentum are initially generated in the larger, heavier, more proximal body segments before being transferred sequentially to the smaller, lighter, more distal body segments through a precisely timed series of segmental accelerations and decelerations (see Figure 8.1). This proximal-to-distal transfer of energy and momentum along the upper extremity-linked segment system for throwing and hitting, and lower extremity-linked segment system for kicking, has been termed variously as the “summation of speed” (Bunn, 1955), “acceleration–deceleration” (Plagenhoef, 1971), “kinetic linking” (Kreighbaum & Barthels, 1996), “proximal-to-distal sequencing” (Putnam, 1991), and the “kinematic chain” (Bartlett, 1999), and has been demonstrated in a range of multi-articular sport actions, including batting (e.g., Stretch *et al.*, 1998) and bowling (e.g., Glazier *et al.*, 2000) in cricket, the serve (e.g., Elliott *et al.*, 1986) and forehand groundstrokes (e.g., Elliott & Marsh, 1989) in tennis, batting (e.g., Welch *et al.*, 1995) and pitching (e.g., Pappas *et al.*, 1985) in baseball, full and partial golf swings (e.g., Tinmark *et al.*, 2010), instep kicking in soccer (e.g., Nunome *et al.*, 2006) and rugby (e.g., Zhang *et al.*, 2012), javelin (e.g., Mero *et al.*, 1994) and handball throwing (e.g., Jöris *et al.*, 1985), and water polo shooting (e.g., Elliott & Armour, 1988).

According to the limited number of studies that have compared experts and non-experts performing throwing, kicking, and hitting actions, most appear to suggest that all performers, regardless of skill level, exhibit a proximal-to-distal sequence of segmental motion, but the magnitudes of segmental linear and angular velocities are greater in experts (e.g., Burden & Bartlett,

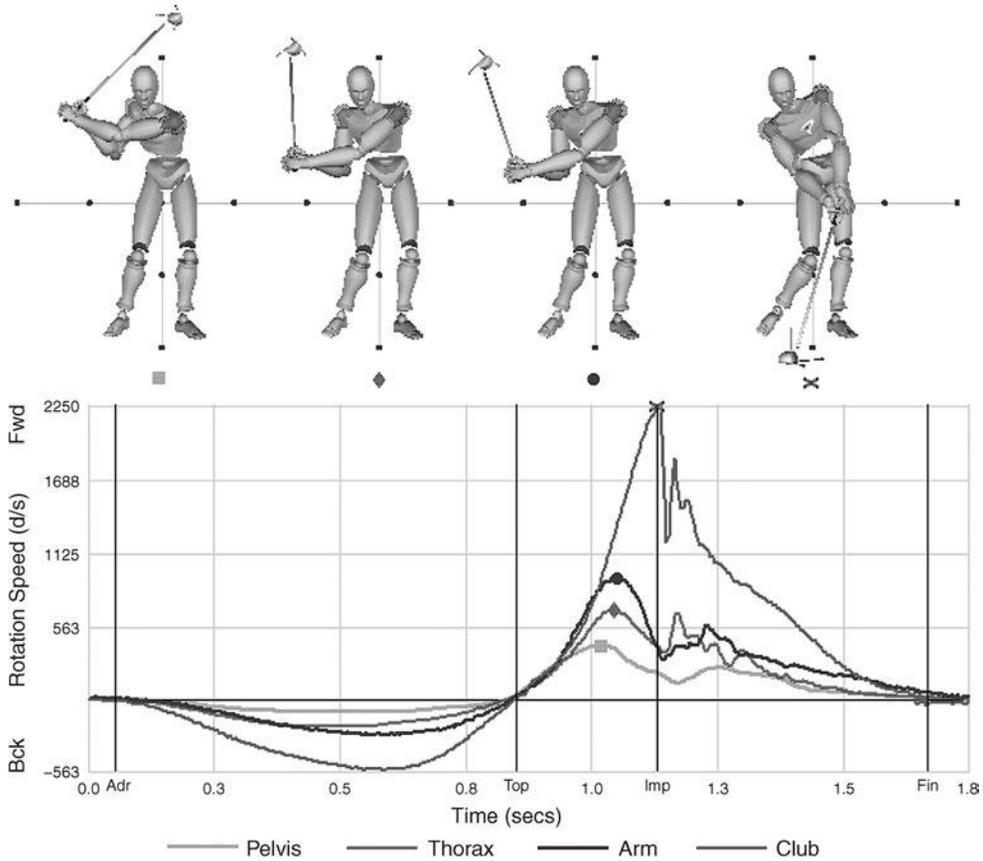


Figure 8.1 A graphical representation of proximal-to-distal sequencing of segmental motion, using the golf swing as an exemplar multi-articular action. Owing to the need to reduce time series measurements to single data points for statistical analysis purposes during group-based comparisons of experts and non-experts, it is common for proximal-to-distal sequencing to be expressed as the peak linear or angular velocities of key body segments. Here, however, entire angular velocity time series measurements for each body segment in the upper extremity-linked segment system and the golf club are presented for a professional golfer. As shown, energy and momentum generation commences with the rotation of the pelvis and is transferred sequentially to the thorax, lead arm, and club through a series of angular accelerations and decelerations. Each successive segment peaks faster and later than the preceding segment. The smooth shape and orderly nature of the curves representing each body segment are hallmark features of an efficient, fluid and well-coordinated golf swing. Used with permission from Phil Cheetham.

1990; Bartlett *et al.*, 1996). For example, in their comparison of novice, club-level, and elite javelin throwers, Bartlett *et al.* (1996) reported that all throwers produced the same temporal order of peak horizontal velocities of the shoulder, elbow, and hand of the throwing arm, but the magnitudes of these peak horizontal velocities were significantly greater in the elite group compared to the novice and club-level groups. Similar findings have also been reported by Burden and Bartlett (1990) for cricket fast bowling—a multi-articular action that has been considered biomechanically comparable to javelin throwing (Bartlett, 2000). They compared the upper extremity kinematic chain of international fast bowlers and collegiate fast-medium bowlers and found that the former not only had higher joint center velocities than the latter, but also the

differences in velocities between the two groups became more pronounced in progressively more distal joint centers. In baseball batting, Inkster, Murphy, Bower, and Watsford (2011) reported that highly skilled hitters exhibited significantly greater angular velocities of the pelvis and lead elbow compared to less-skilled hitters, which apparently contributed to the significantly higher linear bat speeds generated by the former. However, curiously, no other upper extremity segment or joint peak angular velocities or their timings were reported.

The analysis procedures and research designs used in many of the above studies have, in some respects, limited the insights that can be drawn from these investigations and potentially provided misleading information about characteristics distinguishing experts from non-experts in the performance of multi-articular sport actions. In particular, the emphasis on time-discrete kinematic variables has generally precluded insights from being made into interactions of body segments comprising the kinematic chain, and group-based research designs have tended to mask key differences among individuals within their respective skill group. A good example of these anomalies can be found in the study of Cheetham, Rose, Hinrichs, Neal, Mottram, Hur- rion, and Vint (2008), which examined differences in segmental sequencing between amateur (n = 19) and professional (n = 19) golfers. Of the 15 time-discrete kinematic variables used to describe the motion of the pelvis, thorax, arm, and club during the golf swing, 14 were shown to be significantly greater in magnitude for professionals compared to amateurs. However, no significant mean differences between the two groups in the timing of peak rotational speeds of body segments and club relative to impact existed, although amateurs were more variable in their timing. When multiple angular velocity time series measurements were examined for selected golfers, individual differences became apparent in terms of the sequencing, timing, and interaction of body segments (see Figure 8.2). Other studies have also demonstrated how group- and

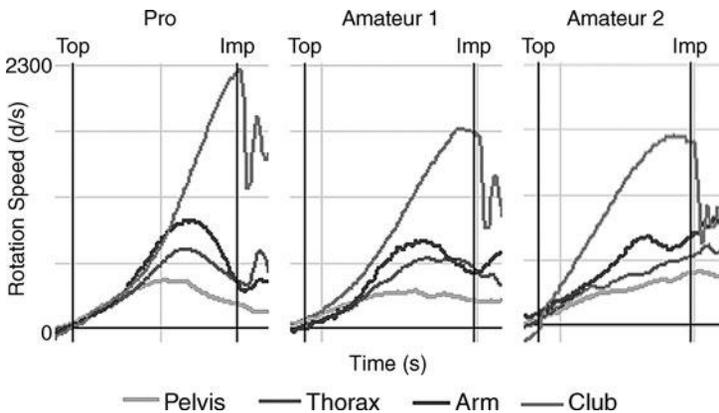


Figure 8.2 Comparisons of body segment and club motions between golfers of different skill levels. These graphs indicate differences between a professional (“Pro”) and two amateurs (“Amateur 1” and “Amateur 2”) in the sequencing, timing, and interaction of body segment and club rotations during the downswing phase of the golf swing. The “Pro” exhibited comparatively smooth accelerations and decelerations with the rotational speed of each segment peaking higher and later than the preceding segment in the kinematic chain. In contrast, “Amateur 1” exhibited lower peak rotational speeds, which are out of sequence (lead arm peaks before thorax), and poorer accelerations and decelerations. “Amateur 2” exhibited no deceleration of the pelvis and thorax before impact, and the rotational speed of the lead arm peaks well before impact before decelerating and accelerating again, leading up to, and through, impact. These graphs indicate that some of the results derived from the group-based analysis for this study (i.e., no significant difference in the order and timing of peak rotational speeds of segments between amateurs and professionals) are not demonstrable in individual golfers. Used with permission from Phil Cheetham.

individual-based analyses can produce equivocal, and often conflicting, results (e.g., Dufek *et al.*, 1995; Ball *et al.*, 2003; Ball & Best, 2012). Accordingly, caution should be applied when making generalized, “on average” statements based on the findings of group-based analyses in expertise research, especially if applying them in a talent identification context, since “. . . propositions about people cannot necessarily be derived from propositions about the mean of people because the patterns found by aggregating data across people do not necessarily apply to individuals” (Bouffard 1993, p. 371).

Inter- and intra-individual movement variability

The amount of variability in the movement patterns of throwing, kicking, and hitting actions is usually considered, often intuitively, to be a good indicator of level of expertise. Since experts generally produce more consistent performance outcomes than non-experts, it is often assumed that the movement patterns used by experts to produce those outcomes are more consistent (i.e., less variable) over repeated performance trials than those used by non-experts (e.g., Phillips, 1985). Furthermore, as the pathway to expertise in these multi-articular actions is often considered to be a progression towards a perceived “ideal” technique (e.g., Sherman *et al.*, 2001), it is typically assumed that there is less variability among the throwing, kicking, and hitting actions of experts than non-experts. A schematic describing the putative relationship between inter- and intra-individual movement variability and expertise in the performance of multi-articular sports actions is provided in Figure 8.3.

Owing to the research designs and methods habitually used by sport biomechanists, and because it has often been deemed to have negligible practical significance due to its association with unwanted system “noise” (see Glazier *et al.*, 2006), only a limited number of studies have investigated movement variability in throwing, kicking, and hitting actions, and even fewer have compared differences between experts and non-experts. Bradshaw, Keogh, Hume, Maulder, Nortje, and Marnewick (2009) and Fleisig, Chu, Weber, and Andrews (2009) confirmed that expert golfers and baseball pitchers, respectively, were less variable than non-experts, but both operationalized movement variability as simply the coefficient of variation and standard deviation of various, isolated, time-discrete variables over repeated performance

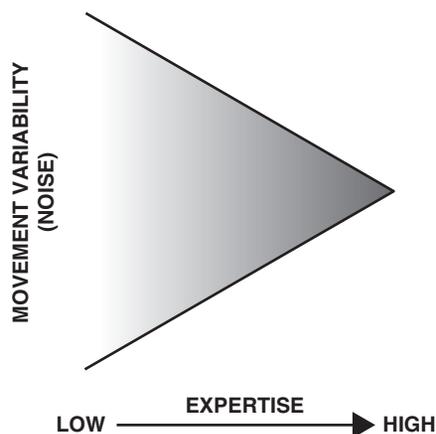


Figure 8.3 Both inter- and intra-individual movement variability, which is usually considered to be a reflection of “noise,” are commonly thought to reduce to a minimum with expertise.

trials. These analytical approaches, however, are inherently limited because, amongst other issues identified by Newell and Corcos (1993), they provide little information about variability of the underlying coordination patterns.

The problem with focusing essentially on outcome measures was nicely demonstrated in the often-cited study of Arutyunyan, Gurfinkel, and Mirskii (1968), which compared expert and novice marksmen in a simulated pistol shooting task—another type of multi-articular sport action. As could be anticipated, skilled marksmen were found to exhibit less variability in the performance outcome (radial scatter of “shots”) than unskilled marksmen. However, skilled marksmen were shown to exhibit more variability in the coupling relationships between joints of the shooting arm than unskilled marksmen. It was concluded that, whereas unskilled marksmen attempted to rigidly fix their shoulder, elbow, and wrist joints, skilled marksmen allowed them to co-vary, thus minimizing any errors in the position and orientation of the gun barrel and, therefore, reducing the radial scatter of “shots.” This study indicates the need to examine outcome variability in relation to coordination variability in throwing, kicking, and hitting actions across performers of different skill levels, particularly in light of recent research showing that stable performance outcomes are often a product of variable coordination patterns (see Newell & James, 2008 for a recent review). Indeed, preliminary insights from Button, MacLeod, Sanders, and Coleman (2003) on free throwing in basketball and Schorer, Baker, Fath, and Jaitner (2007) on penalty shooting in handball have indicated that the functionality of intra-individual movement variability may differ between experts and non-experts; i.e., skilled throwers tend to exhibit functional variability in that it enables task goals to be accomplished, whereas less-skilled throwers tend to exhibit dysfunctional variability in that it jeopardizes the successful attainment of task goals.

Although, to date, it has received only very limited coverage in the literature, the commonly held assumption that there is less inter-individual variability among the throwing, kicking and hitting actions of experts than non-experts has not been well supported in biomechanical studies. Schöllhorn and Bauer (1998) investigated differences in throwing technique among male and female national and international javelin specialists and heptathletes. They reported highly individual movement patterns, especially among the elite male specialists, who exhibited more inter-individual variability than the female throwers. It was speculated that this greater variability may be attributable to the greater variety of nationalities of the male throwers and the different sociocultural constraints (e.g., coaching ideologies, etc.) of those nations. They also found greater movement variability among the international-standard female specialists compared to the national-standard female specialists, thus contradicting the often-held view that increased expertise involves the gradual refinement of technique towards a common optimal, or template, movement pattern (see Brisson & Alain, 1996). This study is noteworthy because it represents one of the first attempts to move beyond conventional reductionist paradigms in biomechanics to truly analyze differences in “technique” between performers of various skill levels (see Schöllhorn *et al.*, 2014 for a review).

Range of motion and utilization of stored elastic energy

Two further, somewhat interrelated, technical characteristics that may distinguish experts from non-experts performing multi-articular sport actions are range of motion at key joints and the utilization of elastic energy stored in muscles crossing those joints. In principle, an increased range of motion will increase the distance over which the throwing, kicking, or hitting limb can be accelerated, resulting in greater speed of the end-effector, hitting implement or projectile at the moment of impact or release. As experts are generally able to produce more speed in more distal body segments than non-experts, it follows that the former may use a greater range of

motion at key joints than the latter. This proposal, however, has only received limited support in the literature. For example, in the aforementioned study of Bartlett *et al.* (1996), elite javelin throwers were shown to exhibit a longer acceleration path or range of motion of the throwing arm than club-level and novice javelin throwers, which the authors argued was a potentially important contributory factor in the observed differences in release speed and throwing distance among the groups. In contrast, both McTeigue, Lamb, Mottram, and Pirozzolo (1994) and Egret, Dujardin, Weber, and Chollet (2004) reported no significant differences in the pelvis-thorax separation angle at the top of the backswing (the “X-factor”) between expert and non-expert golfers, despite the magnitude of the X-factor being significantly associated with golf driving performance (Myers *et al.*, 2008). Further contributing to the ambiguity of the relationship between range of motion and expertise is that, when chip kicking in soccer, the hip and knee joints of the kicking leg have been shown to move through a smaller and larger range of motion, respectively, in more skilled kickers compared to novices (Chow *et al.*, 2007). The equivocal nature of the aforementioned findings indicates that the hypothesized unidirectional relationship between range of motion and expertise is not universal and is somewhat dependent on the prevailing task constraints.

If an increased range of motion is also accompanied by eccentric loading (pre-stretch) of the active muscle(s) spanning the joint(s)—for example, through counter-rotating the preceding proximal body segment in the linked segment system—transient elastic energy can, in principle, be used to produce a more forceful concentric contraction, leading to a greater increase in the speed of more distal body segments. This feature may be a distinguishing factor between experts and non-experts performing multi-articular sport actions since, again, the former tend to generate more speed in distal body segments than the latter. Cheetham, Martin, Mottram and St. Laurent (2001) demonstrated how both low and high handicap golfers were able to make use of stored elastic energy during the golf swing by increasing the X-factor during the early downswing. This move—termed the “X-factor stretch”—involves the rotation of the pelvis back towards the target whilst the thorax is still either completing the backswing or is stationary at the top of the backswing. Both low and high handicap golfers increased the X-factor, on average, by 19 per cent and 13 per cent, respectively, and this difference was reported to be statistically significant. Interestingly, no significant difference in the mean X-factor at the top of the backswing was reported between the two groups, thus corroborating the results of McTeigue *et al.* (1994) and Egret *et al.* (2004). In skilled soccer kickers, Shan and Westerhoff (2005) suggested that increased trunk rotation and contralateral arm extension and abduction during the preparatory phase produced a “tension arc” that provided greater muscle pre-stretching across the trunk flexors, hip flexors, and quadriceps of the kicking leg, leading to increased force production during the action phase. The pre-stretching of limb and trunk muscle groups, however, was less evident in novice soccer kickers. More effective use of stored elastic energy has also been suggested as a reason why expert tennis players performing the power serve are able to produce faster ball speeds than non-experts (Girard *et al.*, 2005).

Concluding remarks and recommendations for future research

The purpose of this chapter was to critically evaluate the literature and provide a summary of the technical features that distinguish experts from non-experts performing multi-articular sport actions. Of the comparatively few studies that have examined skill level differences in throwing, kicking, and hitting actions, most have adopted a product- rather than a process-oriented focus, which has tended to yield limited, and oftentimes trivial, findings (e.g., experts generate larger peak body segment angular velocities and produce greater release speeds and more accurate

outcomes than non-experts). Furthermore, the somewhat arbitrary and inconsistent selection of time-discrete performance parameters across studies has made making conclusive statements about skill level differences challenging, and the almost exclusive use of group-based research designs has tended to mask individual differences within groups, thus permitting only probabilistic statements to be made about technical differences between experts and non-experts. In future studies, it is recommended that greater recognition is given to the biomechanical principles of movement (see Lees, 2002) and that the selection of performance parameters be based on more rational grounds, such as a theoretical model of performance (see Lees, 1999). Although deterministic or hierarchical models do have inherent limitations (see Glazier & Robins, 2012), they at least provide sound justification for the inclusion and analysis of specific variables and could help increase coherence between studies. It is also recommended that future research on expertise in the performance multi-articular sport actions explores, and makes use of, more individual-based research designs and associated methodologies, such as coordination profiling (Button *et al.*, 2006), which can provide further insights into the consistency and variability of “technique” and how it relates to variations in speed, accuracy, and consistency of performance outcomes within and between different skill levels.

Acknowledgments

We thank Phil Cheetham for permitting the reproduction of Figures 8.1 and 8.2.

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