Physiological and Musculoskeletal Characteristics of the Modern Golfer

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Introduction

The game of golf has changed. Once a sport where successful performance was almost exclusively linked to technique, golf has evolved to include a heavy emphasis on the physicality and athleticism of the player. Rhetoric around the successful modern day ‘golf athlete’ often includes reference to Tiger Woods training with Navy Seals, Rory McIlroy performing Olympic lifts in the gym, or Jason Day using his ‘muscular physique’ to launch driver shots well over 300 yards. Professional golfers now employ not only golf coaches to work with them on their technique, but also physiotherapists and trainers to help them optimise their body for golf. In general, the modern day golfer is stronger and more athletic than his predecessor. This is probably in part due to a more concerted effort to improve their physical preparation, and in part due to advances in sports science and athletic training approaches. While corollary improvements in on-course performance are difficult to tease out due to continued advancements in equipment and changes in golf course design, there is no denying that modern day professional golfers hit the ball further and average lower scores (USGA & R&A, 2016).

Relationship Between Golf Swing Biomechanics and Physical Attributes

The biomechanics of the full golf swing has been studied extensively in recent times (e.g. Horan et al., 2010; Kwon et al., 2012). While such studies have not always led to agreement on what might be considered ‘optimal’ golf swing biomechanics, they have to some extent helped focus the areas deemed important for hitting high-quality golf shots. Even amongst skilled golfers, there is considerable variation in the kinematics, kinetics, and neuromuscular control of movement during the swing (Horan et al., 2011; Tucker et al., 2013).

The many degrees of freedom within the golfer-club system mean countless different movement control strategies can be used to achieve the same outcome of hitting the golf ball (Glazier, 2011). The strong association between hitting the ball long distances accurately and success, however, has led to the emergence of a number of well accepted principles relevant to the execution of the golf swing. Biomechanical principles commonly acknowledged as being central to a successful golf swing and the associated implications on player physical development, include:

- A proximal-to-distal pattern of movement that utilises the summation of speed principle (Putnam, 1993; Hume et al., 2005) >> *Emphasizing the importance of the larger more proximal body segments, and timing and / or coordination of movement of those segments.*
- Stretch-shorten cycles, where a muscle is lengthened prior to contracting, allowing for potentiation and thus, a more powerful contraction (Ingen Schenau et al., 1997; Hume et al., 2005) >> *Emphasizing the importance of adequate range-of-motion and flexibility particularly of the larger muscle groups of the pelvis, trunk, and shoulder, and the importance of timing and coordination of movement.*
- Utilisation of ground reaction forces to enhance the generation of torque, and consequently speed in the golf swing. The interaction of the feet and lower limbs with the ground is a fundamental component of this principle (Lynn et al., 2012; Kwon et al., 2016) >> *Emphasizing the important contribution of the lower body (legs and pelvis) and need for a strong supportive base of support.*
- Adoption of movement patterns that allow for an accurate and repeatable golf swing >> *While not strictly a principle, this notion highlights the need for simple, 'efficient', and coordinated movements, all of which are influenced by adequate range-of-motion, strength, proprioception, and neuromuscular control.*

Measuring the Physical Attributes of a Golfer

In order to determine and document the key physical attributes of golfers, clinicians and researchers have utilised and developed a range of testing protocols (Smith, 2010). While this has enabled the examination of many different physical performance domains, it is important to consider the reliability and validity of the testing protocol used, and perhaps more importantly, the relevance of the resultant outcome measure to on-course performance. For example, when assessing lung function of a golfer, the use of spirometry may be a very reliable and valid measure of total lung capacity, but the measure itself may have little or no influence on overall golf performance. Historically, the relevance of a physical attribute or skill has typically been verified by either collecting data from golfers across a range of performance levels (e.g., high vs low handicap) and investigating the relationship between that attribute and some golf performance indicator (e.g., driving distance or handicap), or implementing some intervention aimed at improving a physical attribute and examining whether there are concomitant improvements in golf performance (Hume et al., 2005; Smith, 2010). While this approach has yielded important information about the most influential physical traits of golfers, limitations in research methodologies (for example, the heavy reliance on cross-sectional designs and correlation analyses), and inconsistency of findings, has meant there is still a lack of consensus regarding which physical traits and associated testing protocols are most useful. Physical measures with an obvious link to the execution of the golf swing and some evidence to support their use are briefly outlined below.

(i) Body Composition: Golfers, and the fitness professionals they work with, have become increasingly interested in measuring and monitoring body composition (Dorado et al., 2002; Kawashima et al., 2003). Measures of interest have included total and regional areas of muscle mass, fat mass, and to a lesser extent, bone mass. While it does not directly influence

golf swing performance, muscle mass is a useful measure to examine due to its very strong positive relationship with the force output of a muscle (Lieber et al., 2000; Weeks et al., 2016). It is also frequently measured in an effort to evaluate the effectiveness of strength-based training programs elite golfers frequently engage in. Common methods used to measure body composition include skin-fold measurements, underwater weighing, and bioelectrical impedance, however owing to its established reliability and validity, Dual-Energy X-Ray Absorptiometry is considered the gold standard.

(ii) *Range of Motion (ROM) / Flexibility*: While both terms are used interchangeably, ROM is more often referred to as the amount of movement of a joint in a specific direction (e.g., hip joint internal rotation), while flexibility is typically referred to as the extensibility of a muscle, or muscle group (e.g., hamstring length) (Kendall et al., 1993). The general consensus amongst health and fitness professionals is that it is more advantageous for golfers to have greater levels of flexibility so they can perform a swing exploiting the biomechanical principles outlined previously (Hume et al., 2005). Furthermore, the joints and regions where adequate ROM and / or flexibility is deemed most critical to the golf swing varies amongst different professionals, but for most includes the lumbar, thoracic, and cervical joints of the spine; the hip and shoulder joints; the iliopsoas, gluteal, hamstring, and gastrocnemius muscle groups; and the pectoral and latissimus muscle groups (Chettle et al., 2001; Smith, 2010). Range of motion and flexibility are typically measured during a musculoskeletal or general movement screening. Goniometry is the most common measurement method, however other less common methods include electro-goniometers, tape measures, and 2D and 3D videography.

(iii) *Strength / Power*: A central focus of golf-specific training programs has been the assessment and development of strength and power. While it is beyond the scope of this chapter to detail all the different aspects of strength and the training of it, a number of important points warrant acknowledgement. Isolated strength at the single joint level is relatively simple and

reliable to measure (Lieber et al., 2000). However, its relevance needs to be considered carefully given the complexity of movement and the differing roles of muscles (e.g., eccentric vs concentric) during the golf swing. Potentially in response to these limitations, the emergence of more global or 'functional' measures of strength and power (e.g., lateral jump distance or medicine ball throw distance) relevant to the golf swing has occurred. Like ROM, the muscle groups in which strength and / or power are thought to be most critical to the golf swing are often debated. Based on electromyography studies of the golf swing (McHardy et al., 2005), however, the most common groups measured and targeted in training programs include the major muscle groups of the legs, in particular the gluteals; the abdominals and other major muscles of the lumbar spine; the major muscles of the shoulder girdle and chest such as the trapezius, rhomboids, latissimus, triceps, deltoids, and pectorals; and the muscles of the forearm and wrist (Doan et al., 2006; Lephart et al., 2007). Assessment of strength involves the measurement of force and torque, or impulse in the case of power. Isokinetic dynamometry is considered the gold standard for measuring such parameters, however, it is best suited to single joint movements and some controlled multi-joint movements. Another common method of quantifying strength includes the displacement of a given load; examples include the number of repetition maximums for a given free weight, medicine ball toss distance, vertical jump height, and number of chin ups.

(iv) Balance / Control of Centre of Mass (COM): Effectively controlling balance during the golf swing is touted as a key hallmark of skilled golfers (Adams et al., 2001; Smith, 2010). With the advent of user friendly, economical measurement tools such as portable force plates and pressure mats, the objective assessment of balance is becoming increasingly common. Researchers typically focus on the examination of parameters such as ground reaction force (GRF), COM, and centre of pressure (COP) during the swing, or alternatively use more 'clinically' oriented assessments that include functional postures such as standing with feet

together, standing on one leg or walking on unstable surfaces. Examples of clinical based tests with known reliability and validity, include the Single Leg Stance Test with eyes open or closed, the Functional Reach Test, and the Star Excursion Balance Test. While many clinical tests have been found to be predictive of adverse balance events such as falls, their relevance to the execution of the golf swing and overall performance is yet to be fully established.

(v) Posture: Golf coaches and trainers frequently advocate the importance of maintaining ‘good posture’ throughout the golf swing (Adams et al., 2001; Chettle et al., 2001). Static posture is typically referred to as the position of the body at rest (typically in sitting or standing), and is generally attributed to the habitual positions individuals adopt throughout everyday life (Chek, 2001). Assessing and measuring posture is more challenging than one might expect. In elite golfers, static posture is most often assessed as part of a musculoskeletal screening conducted by a physiotherapist, and is typically measured according to some subjective, checklist type format (Chek, 2001; Chettle et al., 2001). Common postural traits assessed include head position relative to the trunk, shoulder symmetry, primary spinal curvature (cervical, thoracic, lumbar), scapulae position, pelvis rotation and tilt, and lower limb and feet alignment (Chettle et al., 2001).

(vi) Neuromuscular Control of Movement: The precision and speed at which skilled golfers are able to perform the full swing is a remarkable motor control feat. To achieve this, golfers need to be able to coordinate the movement of a large number of body segments with accuracy, timing, and speed (Glazier, 2011; Horan et al., 2011; Horan et al., 2012). Accordingly, there is interest in assessing a golfers’ ability to control movement during not only the golf swing, but other functionally relevant tasks, with the overarching aim of identifying regions or patterns of movement where control issues exist. Neuromuscular control of movement has not always been clearly defined, with other terms being used interchangeably to represent the same, or a similar concept such as dynamic postural control, movement

patterning, and movement quality. Like posture, the objective measurement of neuromuscular control is a difficult undertaking. During the golf swing, objective measurement using 3D motion analysis and electromyography can be illuminating, although their cost and unwieldiness negate their uptake more widely. A more convenient approach is to examine movement control during other functionally relevant tasks such as the overhead squat, the lateral hop, and trunk and pelvis rotational movement tasks. The obvious limitation of this approach, however, is the subjective and qualitative nature of the assessment. Attempts have been made to minimise these limitations, namely the use of video and criterion based reference scales (Dalglish et al., 2011; Olivier et al., 2016).

Physiological and Musculoskeletal Characteristics of the Modern Day Golfer

Other than a number of strength based studies, there are relatively few methodologically robust studies that have clearly documented the physiological and musculoskeletal characteristics of the successful modern day golfer. The following section provides a review of the most pertinent studies, with a particular emphasis on studies that have utilised sufficiently valid and reliable measurement methods in accordance with the discussion in the previous section.

(i) *Body Composition*: To date, only a modicum of scientific attention has focussed on the physical makeup of the modern day golfer. A group of Japanese researchers compared the somatotypes and body composition of six different groups of males, including four golfer groups (n=63) and two control groups (n=65) (Kawashima et al., 2003). The well accepted 'Health-Carter' anthropometric method was utilised, where skin-fold and anthropometric measurements were used in conjunction with standardised equations to calculate body composition. Results revealed that professional and collegiate golfer groups were more mesomorphic (i.e., muscular or athletic) in appearance than their respective non-golfer control

groups, and that professional golfers had larger biceps and calf girths, greater body mass index (BMI) percentages, and greater fat free mass than the non-golfer control group. In a similar cross-sectional type investigation of Caucasian individuals (Dorado et al., 2002), professional golfers (n=15) were found to have a similar overall body mass and body fat percentage compared to age matched sedentary controls (n=18), although dominant arm muscle mass was significantly greater in the professional golfers (9%, $p < 0.05$). Likewise, Keogh and colleagues (2009), found no difference in BMI, body fat percentage, and fat-free mass in a group of high handicap (20.3 ± 2.4) and low handicap (0.3 ± 0.5) golfers who were matched for age and height.

(ii) ROM / Flexibility: Possessing or attaining adequate ROM and flexibility has long been promoted as important for golf success. Professionals frequently incorporate ‘stretching’ into their fitness regimes. Even coaching vernacular references the importance of flexibility, with common instructional cues such as ‘create a good turn’, ‘develop separation at the top’, and ‘stay loose and relaxed during the backswing’ (Adams et al., 2001). Despite the importance bestowed upon flexibility, there is a dearth of high quality evidence supporting such assertions. Of the investigations undertaken to date, Sell and colleagues (2007) conducted one of the largest and most methodologically sound investigations of the physical characteristics (including flexibility) of skilled golfers. The golfers examined (n=257) were separated into one of three groups based on playing ability (handicap < 0 ; handicap = 1 - 9; handicap = 10 - 20), with a range of flexibility, strength and balance measures investigated. Hip and shoulder joint ROM, as well as general trunk ROM, and hamstring muscle flexibility were assessed using standard goniometry techniques. Overall the handicap < 0 group possessed the greatest ROM, followed by the 1 - 9 handicap group, and finally the 10-20 handicap group. The most highly skilled golfers (handicap < 0) displayed the greatest shoulder extension and external rotation ROM, greatest hip extension and flexion ROM, and greatest torso rotation ROM in the

backswing direction. It is important to acknowledge, however, that absolute differences in degrees between groups ranged on average between 2-6 degrees, and that the average age of the groups was significantly different (handicap < 0: 39 years; handicap = 1 - 9: 44 years; and handicap = 10 - 20: 51 years; $p < 0.001$). This inverse relationship between age and ability, may in part explain the observed differences in ROM between the groups.

Others have in part corroborated the findings of Sell and colleagues (2007), with a modestly sized cohort study ($n=20$) reporting low handicap golfers ($n=10$; handicap = 0) tending to have greater trunk rotation ROM, but conversely lesser hip internal and external rotation ROM than high handicap golfers ($n=10$; handicap = 20) (Keogh et al., 2009). Interestingly, absolute values for hip internal and external rotation ROM reported by Sell et al., (2007) were very similar to those reported for a group of elite tennis players ($n=147$) and professional baseball pitchers ($n=101$) (Ellenbecker et al., 2007). Golfers, baseball pitchers, and tennis players all undertake loaded hip rotation on a planted foot, and consequently are likely to require similar amounts of hip ROM in their respective sports. Moreover, in a correlational investigation by Gordon and colleagues (2009), trunk rotation ROM was found not to be related to clubhead speed (a surrogate measure of skill level) in a small group of low handicap male golfers ($n=15$; handicap = 5). These findings were not unexpected given the low subject numbers, and the homogeneity (from a skill perspective) of the group examined. Sex comparisons in ROM and flexibility have also been conducted in collegiate level golfers (Doan et al., 2006). Although the premise of the study was to examine the effect of a golf conditioning program, baseline data revealed that males ($n=10$; handicap = 0) and females ($n=6$; handicap = 5 - 10) had comparable amounts of trunk rotation ROM in both directions ($72-76^\circ$), which compared favourably to other investigations of similar level golfers (Sell et al., 2007; Gordon et al., 2009; Keogh et al., 2009).

(iii) *Strength / Power*: Of all the physical characteristics examined in golfers, strength and power has received the most attention. Most studies have either been modestly powered cross-sectional investigations, or uncontrolled training interventions that incorporate some form of strength training. Parameters evaluated in both skilled and unskilled golfers have included single joint expressions of strength or power, or functional, multi-joint expressions of strength or power (e.g., medicine ball toss distance). For the upper body, both bench press strength (i.e., one repetition maximum – 1RM) and shoulder internal and external rotation strength (% body weight) have been reported to be greater in lower handicap golfers than higher handicap golfers (Sell et al., 2007; Keogh et al., 2009). Doan and colleagues (2006) examined sex differences in upper body strength in collegiate golfers, and predictably, found shoulder overhead press strength (1RM) and lat pull down strength (1RM) to be greater in males (handicap = 0) compared to females (handicap = 5 - 10).

Another key area of focus has been trunk strength and power in golfers. The trunk is often considered the hub or focal point of the golf swing, and is frequently examined by researchers. An investigation by Bae and colleagues (2012), examined isokinetic trunk rotation strength (30, 60, and 120 deg/s) using a gold standard Biodex isokinetic dynamometer in a large group of Korean male professional golfers (n=51). The study was strengthened by the addition of a closely matched (age, height, and body mass) non-golfing control group (n=50). Results demonstrated that professionals were significantly stronger (i.e., peak torque at 60 deg/s) than controls when rotating toward the target side (Professionals = 140.6 ± 30.9 Nm; Controls = 132 ± 28.7 Nm; $p=0.012$), however no differences were evident when rotating toward the non-target side. Interestingly, professionals exhibited asymmetry in trunk rotation strength (i.e., toward target side was stronger) at all three speeds of movement, while the control group was symmetrical for two of the three speeds tested. The observed asymmetry in trunk rotation strength in professionals was very likely an adaptive response to hitting many

thousands of shots toward the target side, and although potentially advantageous from a performance perspective, may increase the risk of injury if excessively large. Others have found similar positive relationships between trunk rotation strength and golf playing ability. Using the same method of assessment (Biodex III, 60 deg/s), Sell and colleagues (2007) found trunk rotation strength in both directions to be significantly greater in < 0 handicap players, when compared to both 0 - 9 and 10 - 20 handicap players (handicap < 0 : Right = $157.3 \pm 31.3\%$ Left = $154.9 \pm 31.5\%$; handicap 0 - 9: Right = $136.9 \pm 36.7\%$ Left = $138.8 \pm 34.9\%$; handicap 10 - 20: Right = $122.7 \pm 33.4\%$ Left = $125.2 \pm 34.1\%$; $p < 0.05$). Furthermore, trunk rotation strength was significantly greater in the 0 - 9 handicap players compared to the 10 - 20 handicap players ($p < 0.05$).

Lower limb strength has been examined in low and high handicap golfers by a number of different research groups. Sell et al., (2007) found significantly greater isometric hip abduction and adduction strength (% body weight; $p < 0.001$ - $p = 0.014$) in low handicap golfers (handicap < 0) compared to high handicap golfers (handicap = 0 - 9 and 10 - 20), while Keogh et al., (2009) reported a tendency toward greater lower limb strength (1RM) in low handicap players (low handicap = 96 ± 26 kg; high handicap = 83 ± 13 kg) based on hack squat performance. In the same cohort of golfers, hack squat performance was positively correlated ($r = 0.533$, $p < 0.05$) with clubhead speed. Others have confirmed similar positive relationships, with Lewis (2016) reporting a strong positive relationship between squat jump performance (jump height) and clubhead speed in a modest sized group of PGA professionals ($n = 20$; age = 32 ± 7 years).

The golf swing is a dynamic, powerful, multi-planar movement. Consequently, a large focus of modern training methods has been on functional, or 'golf specific' movements. This has been verified in part by a number of cross-sectional and training studies that have demonstrated positive relationships between golf performance and functional measures of

strength. For example, Keogh et al., (2009) reported a significant between group difference ($p < 0.01$, effect size=1.88) in cable woodchop rotational strength in a group of low and high handicap golfers (low handicap = 69 ± 9 kg; high handicap = 54 ± 7 kg). When grouped together ($n=20$), there was a significant and strong positive relationship ($r=0.706$, $p < 0.001$) between cable woodchop rotational strength and clubhead speed. Lewis and colleagues (2016) also reported a positive relationship ($r=0.706$, $p < 0.01$) between sitting medicine ball throw distance and clubhead speed in professional golfers, further verifying the importance of ‘golf specific’ strength to the modern day golfer.

(v) Balance / Control of COM: Somewhat surprisingly, only a handful of investigations have examined the balance of golfers. This is despite many anecdotal claims that golfers have better balance than the general population. Using a rigorous methodological approach, Stemm and colleagues (2006) examined measures of static stability and dynamic weight shift in a relatively large group of golfers ($n=51$) varying in skill level. For the assessment of static balance, postural sway velocity (using a force plate) was examined during bilateral stance and unilateral stance on the right and left legs, while the assessment of dynamic balance included examination of the speed and accuracy at which golfers could displace their COP by leaning forward and backward and side to side (without losing their balance or stepping). Analysis of static and dynamic data grouped by skill level (low handicap = 0 - 9, $n=17$; medium handicap = 10 - 16, $n=16$; and high handicap > 17 , $n=19$), revealed no significant differences, indicating similar levels of balance between all three groups. Contrasting these findings, Sell et al., (2007) reported lower handicap golfers (handicap < 0) had greater balance during right single leg standing with their eyes open in both the anterior-posterior and medial-lateral direction compared to higher handicap golfers (handicap = 10 - 20). In light of the contrasting findings and the scarcity of balance related research, it is obvious that further examination of the balance

of golfers is required, particularly given the rapid and multiple weight shifts encountered during the swing.

(iv) Posture: Posture is perhaps the most difficult of all physical characteristics to examine in golfers owing to a lack of consensus on what is 'good' and what is 'poor' posture, as well as the difficulty in measuring it. Formal investigations of posture in golfers is almost non-existent, with only a few anecdotal accounts of postural observations in golfers. Chettle and Neal (2001) and Booth (2005), have both described a number of common postural abnormalities in golfers including excessive thoracic spine kyphosis, asymmetry in shoulder height, and spinal scoliosis (resulting in asymmetry of trunk rotation). These descriptions however, are based on experiential accounts of working with golfers, rather than formal scientific investigation.

The relationship between spinal posture and trunk rotation is particularly important to golfers given the motion that occurs during the swing. Montgomery and colleagues (2011) examined how different spinal postures affected trunk rotation in a group of non-golfing adult males ($n=20$, age = 31 ± 8 years). Using gold standard 3D motion analysis technology, Montgomery et al., (2011) revealed that when standing in 45° of trunk inclination there was a significant reduction in trunk rotation when subjects adopted a flexed (i.e., kyphotic; 5% decrease, $p<0.01$) and extended (i.e., lordotic; 4% decrease, $p<0.05$) spinal posture compared to a neutral spinal posture. While the results are not representative of a golfing population, they do highlight the importance of examining spinal posture in golfers during physical assessments and screenings.

(vi) Neuromuscular Control of Movement: Like posture, the examination of neuromuscular control of movement in golfers is a difficult undertaking. The general approach by previous researchers has been to investigate movement control during the golf swing rather than during some other functional task performed during a physical assessment. A recent study

by Olivier and colleagues (2016), however, investigated movement control during a number of functional movement tasks in a group of collegiate level golfers before and after a 2-month training intervention ($n=43$, age = 24 ± 9 years; handicap = 8.6 ± 8.3). Specific functional movements examined included the overhead squat (i.e., hands overhead), single-leg squat, and single-leg bridging. Each movement was scored using a 1-5 criterion based reference scale, with different qualitative descriptions of movement control provided for each of the possible scores. Although no comparisons were made between golfers of different skill levels, pre / post-intervention comparisons revealed significant improvements in movement control for the single-leg squat (pre = $2.4 / 5$; post = $3.0 / 5$; $p<0.001$) and single-leg bridge (pre = $4.5 / 5$; post = $4.8 / 5$; $p=0.024$) movements.

Using a different approach, Gulgin and colleagues (2014) examined the relationship between movement control assessed using a range of commonly prescribed functional movement tests (based on the Titleist Performance Institute protocol) and golf swing faults in a group of mid-level handicap golfers ($n=36$; handicap = 14 ± 10). Of the movement control tests performed (i.e., isolated pelvic rotation and tilt, isolated trunk rotation, overhead squat, and single-leg bridge), a deficit or limitation in single leg bridging was found to be significantly associated with 'early hip extension' ($p=0.050$) and 'loss of posture' ($p=0.028$) swing faults. Although the testing procedures and scoring criteria were not fully described, the preliminary findings of Gulgin et al., (2014) support further examination of the relationship between movement control and golf swing technique and / or performance.

Implications for the Game of Golf

There is no denying that being physically fit and athletically competent is strongly correlated with improved golf performance (Lephart et al., 2007; Sell et al., 2007; Smith, 2010). While the musculoskeletal, biomechanical, and overall task-related requirements of the swing

dictate that certain attributes will always be more influential, individual variation amongst golfers is inevitable. Like a deterministic model, golfers likely utilise unique combinations of physical attributes, each 'weighted' differently to achieve the end outcome of hitting the golf ball. It is essential, therefore, that golfers have truly individualised training programs.

Not all physical attributes are easily modifiable, with some considered non-modifiable such as height and limb length. Furthermore, some attributes are challenging to objectively measure, making it difficult to accurately assess their change over time, and if they are truly related to golf performance. Such challenges have also led to ambiguity in defining different physical characteristics by not only researchers, but also health and fitness professionals. To overcome this issue, consensus must be reached on what the key physical characteristics (physiological and musculoskeletal) for the modern golfer are, and what the most practical and scientifically valid and reliable methods of measuring such characteristics include.

Importantly, the consequences of the increasing physicality of professional golf should not be overlooked. Golfers who choose not to improve physical performance are likely to find it progressively more difficult to compete on the major tours around the world. Conversely, for golfers who do choose to engage in physical training, the development of individually relevant and targeted training programs will become more important in their quest for success. While the human body is incredibly adaptable and resilient, there is also a physical limit for all individuals. Consequently, golfers and health and fitness professionals need to be cognizant of the risks of overtraining, and the potential of suffering a career ending injury when training and playing too close to one's physical capacity.

Summary and Future Directions

The modern day golfer has evolved in a way that places great importance on hitting the ball long distances. Data supports this, with analysis of PGA Tour results demonstrating that

the long game is a crucial determinant of success on tour (Broadie, 2012, 2014). It is therefore unsurprising that empirical data from investigations of physical characteristics of golfers has included predominantly measures of strength and power, and to a lesser extent ROM, body composition, and balance. Critical review of those investigations suggests that trunk strength and ROM have the greatest influence on golf performance. While some evidence exists to support other physical characteristics, the lack of consensus between researchers, and the preliminary nature of many of the investigations, makes it difficult to draw any firm conclusions on the value of other characteristics. Researchers and health and fitness professionals must attempt to reach agreement on the fundamental physical characteristics of the modern golfer, and how to best measure them if the field of physical performance and golf is to continue to evolve.

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