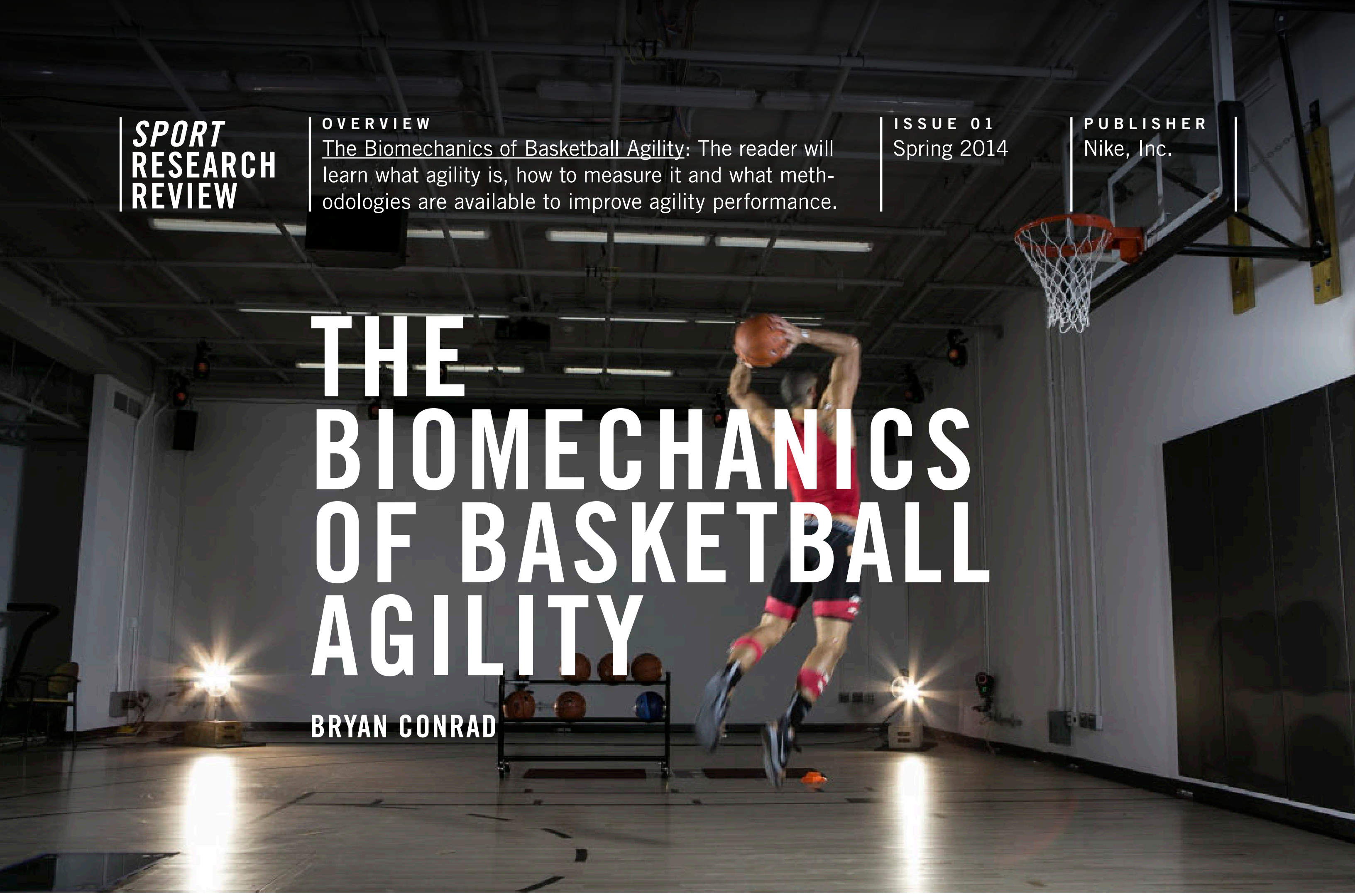

SPORT RESEARCH REVIEW

OVERVIEW
The Biomechanics of Basketball Agility: The reader will learn what agility is, how to measure it and what methodologies are available to improve agility performance.

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THE BIOMECHANICS OF BASKETBALL AGILITY

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WHAT IS AGILITY?

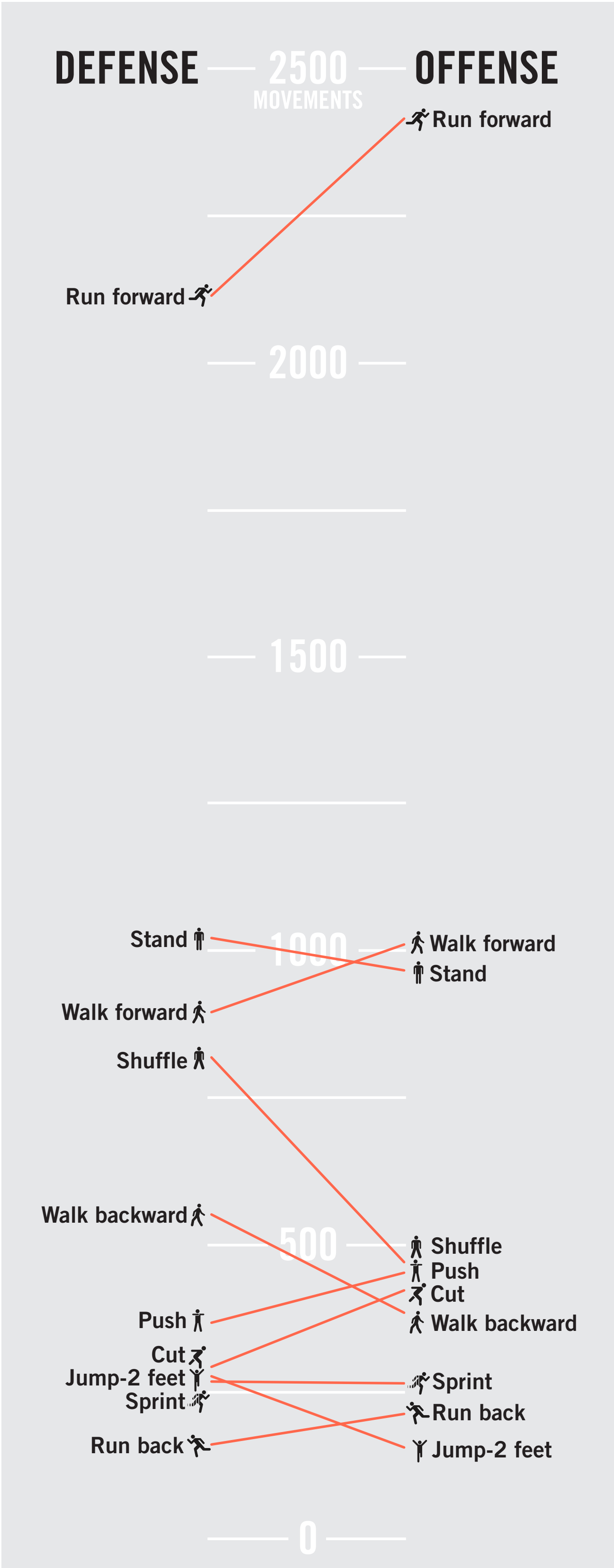
Athletes aspire to perform with agility across a variety of athletic settings: getting out of the blocks during a sprint, returning a serve on the tennis court, throwing a shot-put, evading a defender on the soccer pitch, or juking a player on the basketball court. The ability to perform movements with agility is not even limited to the human species: for example, canine agility courses are common for recreation and competition. The range of different activities that emphasize agility speak to the importance of the trait, but it also suggests that there are many different definitions for what agility truly is. Is it speed, quickness, changing direction of the limbs, changing direction of the whole body, reactivity? In one literature review, agility has been defined as "a rapid whole body change of velocity or direction in response to a stimulus" (Sheppard & Young, 2006). This definition highlights some of the most important aspects of agility as it relates to sport performance in that it acknowledges that agility is required to accelerate and decelerate even in straight line sprints in addition to change of direction tasks. During athletic competition, agility is an open ended task, meaning that it is performed in response to a stimulus and not pre-planned. However, during many training evaluations and research studies, agility is treated as a closed task, consisting of a controlled anticipated change of direction movement. During this review we will discuss both the reactivity element of agility as well as the change of direction component.

HOW IMPORTANT IS AGILITY TO SUCCESS ON THE BASKETBALL COURT?

The game of basketball demands multi-directional speed during both offensive and defensive gameplay. An offensive player can gain an advantage on a defender by outmaneuvering them to achieve an uncontested shot, path to the basket, or passing lane. Agility is a particularly prized trait in guards who frequently advance the ball up the court. The ability to create space between the ball handler and the defender presents advantageous offensive options. During drives to the basket, offensive

TOP 10 PLAYER MOVEMENTS PER GAME

FIGURE 1



players that can produce explosive movements will be more likely to outmaneuver the defense. According to player tracking data from the NBA, the top players in the league average more than 10 drives to the basket per game (Player Tracking Data. stats.nba.com 2014), which can put them in position to take a high percentage shot or make a pass to an open teammate. The ability to accelerate rapidly from a stop, or first step quickness, is particularly important in initiating a drive. If an offensive player can gain a step on the defense, it will minimize the chances that the defensive player will be able to recover to an effective position.

A defensive player who is able to rapidly change his position to impede the path of the offensive player or ball will be more effective at challenging the shot or pass. Defenders frequently utilize side to side shuffling movements to maintain a position between the offensive player and the basket. In addition to moving quickly to the right and left, the defender must be prepared to step forward and backpedal to maintain a defensive posture on an offensive player, even when they do not have the ball.

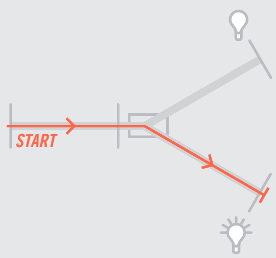
During a game, players perform a number of distinct movements. Previous studies have attempted to quantify the number and type of movements performed by basketball players, which have been estimated to be 1000 movements per game, most of which last 3 seconds or less (McInnes *et al.*, 1995; Ben Abdelkrim *et al.*, 2007). Over 40% of the movements are forward-backward and about 20% are sideways movements (McInnes *et al.*, 1995). Multi-directional movement is clearly an important aspect of basketball agility. The type of motions performed during a game differs depending on the position of the player, with guards executing more high and moderate intensity basketball specific movements (shuffling, cutting, etc.) and centers performing more jumps (Ben Abdelkrim *et al.*, 2007).

The frequency of movements performed by basketball players depends on whether they are on offense or defense. In particular during defense, the player is shuffling from side to side more and running forward less.

HOW IS AGILITY MEASURED?

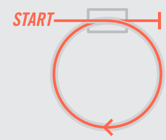
Based on our working definition of agility we can begin to explore different methods for measuring agility performance (Figure 2). A wide range of drills have been described to evaluate agility and at this time there is almost no standardization across sports and very little within sports. Despite our earlier definition of agility as comprising a reaction to a stimulus, many of the agility drills employed in research and training do not include a reactionary component. This could be due to the increased difficulty and equipment required to administer

Y-DRILL



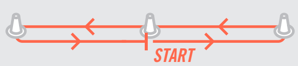
LENGTH:	10M
CoDS:	1
DIRECTION:	30°
STRAIGHTS:	2
REACTION:	YES

CIRCLE DRILL



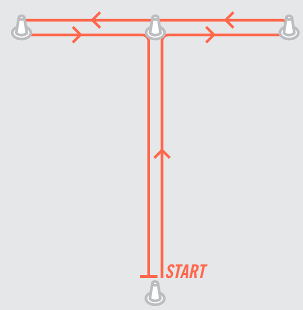
LENGTH:	12.5M
CoDS:	INFINITE ∞
DIRECTION:	360°
STRAIGHTS:	0
REACTION:	NO

5-10-5 DRILL



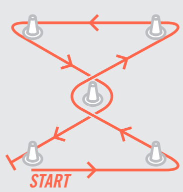
LENGTH:	20M
CoDS:	2
DIRECTION:	180°
STRAIGHTS:	3
REACTION:	NO

T-AGILITY DRILL



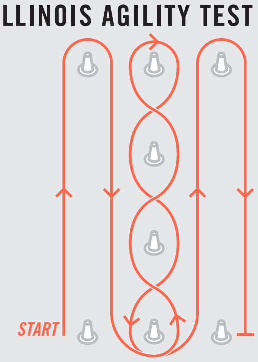
LENGTH:	40M
CoDS:	4
DIRECTION:	90° 180°
STRAIGHTS:	5
REACTION:	NO

HOURGLASS



LENGTH:	40M
CoDS:	4
DIRECTION:	135° 90°
STRAIGHTS:	6
REACTION:	NO

ILLINOIS AGILITY TEST



LENGTH:	60M
CoDS:	8
DIRECTION:	180° 225° 45°
STRAIGHTS:	4
REACTION:	NO

BOX

LENGTH:	8M
CoDS:	4
DIRECTION:	90°
STRAIGHTS:	0
REACTION:	NO

AGILITY DRILL COMPARISON
FIGURE 2
Seven common drills used to evaluate agility. The drills are compared based on total length of drill, number of changes of direction, type of direction change, number of straights, and whether it is reactive.

reactionary drills. Nevertheless, tools to measure reactionary agility are becoming increasingly available. In the context of a sprint start, instrumented starting blocks can measure the reaction time from when the starter's gun fires to when push off force is initiated. In fact this technology is utilized in elite sprinting competitions to detect false starts, which are defined as a movement that begins less than 100 ms after the firing of the starting gun (2014 IAAF Rule Book). Some commercially available timing gates can also be used to administer and measure reactionary agility drills. New features such as electronically controlled lights can be used to construct drills with unanticipated changes of direction. By linking together several timing gates to a central control unit, lighting sequences can be randomized so that the direction of a cut is not known before an athlete begins the drill (See Y-Drill, Figure 2).

Almost all agility drills are quantified based on the time required to complete the task. Additional information can be captured by taking split times during the drill. For example, separating straight sprint speed from time taken to change direction can be useful for determining which component to focus on for training. Although traditionally, many agility drills were measured manually with a stopwatch, the use of electronic devices is becoming widespread in research and training in situations where accuracy and repeatability are paramount.

THE BIOMECHANICS OF CHANGING DIRECTION

The mechanical process of changing the direction of a body in motion is based on Newton's classical laws of motion.

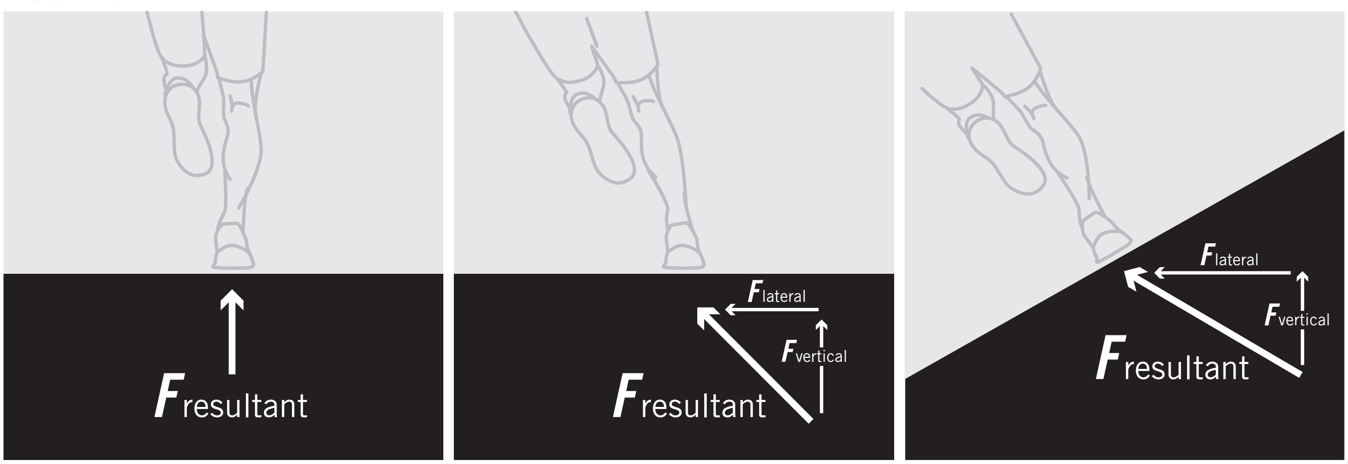
> "To every action there is always opposed an equal reaction." NEWTON'S 3RD LAW

To make a change in direction, the athlete must apply a force to the ground, and the force must be in the opposite direction of the cut (Figure 3). The greater the force that is generated, the more effectively an athlete can accelerate after making a change of direction maneuver. Therefore to increase change of agility speed, an athlete will want to maximize their ability to generate lateral forces opposite to the direction of cutting.

There are at least two characteristics of the foot-ground interaction that can affect the amount of lateral forces generated: traction and banking. If the contact surface between the athlete and the ground is flat, then all lateral forces will produced by friction between the foot and the ground (Figure 3b). Appropriate traction between the foot and ground will prevent slipping and maximize the amount of lateral frictional forces.

FREE BODY DIAGRAM

FIGURE 3



A. During straight ahead running, the majority of impact forces are vertical.

B. When changing direction on a flat surface, vertical and lateral forces are generated. Lateral forces are transferred to the ground through traction between the footwear and ground.

C. When changing direction on a banked surface, greater lateral forces can be generated due to the angle of the resultant to the ground.

Another method to increase lateral forces is to alter the angle of the foot ground contact surface (Figure 3c). The concept of lateral banking of contact surface has been employed in various settings to improve cornering speed. For instance in velodrome design, the track is typically banked 30-45 degrees so that cyclist can keep bikes perpendicular to the track during turns and maintain speed through the curves. Typical NASCAR tracks are banked at 36 degrees in the corners to allow cars to go faster than they could if turning on a flat track. Applying a 10-20 degree bank to either footwear or the ground surface (Wannop *et al.*, 2013) has been shown to increase performance in cutting drills.

WHAT IS THE RELATIONSHIP BETWEEN STRAIGHT AHEAD SPEED AND CHANGE OF DIRECTION SPEED?

Straight sprint speed does not necessarily translate to change of direction speed. In a study of Australian rules football players, Young and colleagues found low correlations between straight sprinting and change of direction speed (Young *et al.*, 1996). Similar results were documented in elite and developmental rugby players (Baker & Nance, 1999) and soccer players (Buttifant *et al.*, 2002). Agility is a distinct trait that is characterized by unique attributes beyond those associated with straight acceleration and velocity. In a study of elite basketball players, there was only a small to moderate relationship between linear sprint speed and reactive agility (Scanlan *et al.*, 2014a). The strongest predictor of reactive agility is response time and decision making time. Based on these findings, rather than focusing on faster linear speed, athletes may be more effective at improving agility by training cognitive processing skills.

One potential reason why straight sprint speed does not strongly correlate with agility is that straight sprints do not require deceleration or lateral force. Techniques for efficient deceleration utilize powerful eccentric contractions of the lower extremity extensors. Generating lateral forces requires significant contributions from hip abductors, which may not be as prominent during straight sprinting. Straight sprint speed is strongly correlated with lower body strength and power (Young *et al.*, 1995, 1996; Baker & Nance, 1999), however at least one study has shown that lower extremity power and strength are not correlated with change of direction speed. (Young *et al.*, 1996)

These previous studies suggest that linear speed and change of direction speed can be developed independently, which implies that each skill might be selected for based on the requirements of the sport or even position within the team. In elite basketball players, positions on the court were related to different skill sets in terms of linear and change of direction speed (Scanlan *et al.*, 2014b). Backcourt players (guards) had greater linear sprint speed while frontcourt (forwards and centers) players had superior change of direction speed. It is unclear whether players were selected for their position based on their inherent athletic abilities or if they developed specialized skills after they began playing a certain position.

AGILITY DIFFERENTIATES SKILL LEVELS

More so than straight-ahead speed, the ability to rapidly change direction is a key differentiator between skill levels of athletes. Studies have shown that elite athletes consistently score higher than sub-elite athletes in measures of agility. For soccer players, agility has been shown to be the most powerful metric to differentiate skill levels (Reilly *et al.*, 2000; Kaplan *et al.*, 2009). Agility performance during the National Football League combine is able to differentiate between players that are drafted versus those that go undrafted, regardless of specific position (Sierer *et al.*, 2008). A video based reactive agility test was able to discriminate between different levels of Australian footballers (Henry *et al.*, 2011).

Some studies have not found a correlation between change of direction speed and skill levels. For example, in a study of rugby players, there was not a significant correlation between L-drill agility and level of play (Gabbett *et al.*, 2007). One reason for this finding may be explained through a follow-up study by the same group in which they evaluated reactive agility as well as change of direction speed (Gabbett *et al.*, 2008). They discovered that while preplanned change of direction activities were not related to skill level, reactive agility was a good predictor of skill level in rugby league players.

CAN AGILITY BE IMPROVED THROUGH STRENGTH TRAINING?

Since we have established that agility is related to superior performance in sport, many athletes will seek training to improve agility skills. Of the many aspects that comprise agility performance, which provide opportunities that can be optimized through training? There is some conflicting evidence regarding the relationship between change of direction speed and strength.

Some studies have demonstrated a link between strength and agility. Change of direction speed in the non-dominant direction was strongly correlated with speed in elite female softball athletes. Relative strength was also strongly correlated with straight line speed and change of direction speed (Nimphius *et al*., 2010). Body mass adjusted, Lower-body muscular strength is strongly correlated to speed and agility in both male and female collegiate athletes (Peterson *et al*., 2006). This suggests that increasing strength can be transferred into increased sport specific performance.

On the other hand, a number of studies have not shown a correlation between agility and strength. In elite female basketball players, change of direction speed was strongly correlated to eccentric strength, however reactive agility was not related to any measure of strength (Spiteri *et al*., 2014). This is perhaps because of the strong roles reaction time and decision making make in reactive agility performance. Leg extensor strength is weakly correlated to agility performance in physically active males (Marcovic, 2007). Muscle power is not associated with change of direction speed, however, reactive strength (drop jump) has a moderate correlation with agility (Young *et al*., 2002). Change of direction speed may be more closely related to reactive strength due to the similarity of the movements compared to isokinetic strength measures.

Plyometric training has been shown to improve agility performance in the T-test and Illinois Agility Test (Miller *et al*., 2006). The basis of plyometric training is to enhance the eccentric muscular contraction combined with a rapid concentric contraction. The focus on eccentric action may contribute to the ability to improve deceleration during a change of direction movement. Also training contraction speed may be more relevant to agility than peak contraction strength.

Overall, there seems to be a trend that more than pure strength and the ability to generate force quickly (increased muscular power) is related to change of direction performance. However, since cognitive processing plays such a large role in success during reactive agility drills, the influence of strength may be masked.

CAN AGILITY BE IMPROVED THROUGH NEUROMUSCULAR TRAINING?

Although the scientific literature is unclear regarding the contributions of strength training to agility performance, there seems to be clear trends that higher level cognitive processing abilities are key to performance (Gabbett *et al*., 2008; Scanlan *et al*., 2014a). There may be benefits to training the neuromuscular control of movements in improving agility. These training benefits may be actualized through improved muscular coordination, improved neural drive, improved decision making or changes to the mechanics of the muscle-tendon complex.

A recent study by Lyle *et al.* at USC found that Lower Extremity Dexterity is associated with agility in soccer players (Lyle *et al*., 2014a, 2014b). Their study defined lower extremity dexterity as the ability to dynamically control the foot-ground interaction in multiple planes. The foot ground interaction can be controlled by modifying the magnitude and direction of foot force. In this study, the evaluation of agility focused only on quick change of directions accomplished through a cross-shaped hopping sequence, and did not include any periods of straight ahead running or sprinting. This highlights an important aspect of how the definition of agility can affect study design and the generalizability of results. Is the skill of quick hopping transferable to the soccer pitch? Does it relate to improved sport specific performance?

In other studies of neuromuscular control and agility, the combination of plyometric and balance training was effective at improving agility in children following an 8 week intervention (Chaouachi *et al*., 2014). A neuromuscular training program designed to reduce risk of ACL injuries in female high school soccer players was also effective in improving agility performance, demonstrating a potential link between improved neuromuscular control and performance (Noyes *et al*., 2013). Subjects that underwent balance training program improved in their change of direction speed. Interestingly, an agility training program is effective at improving muscle reaction time, whereas strength training was not (Wojtys *et al*., 1996).

WHAT ATTRIBUTES OF FOOTWEAR CAN AFFECT AGILITY?

In addition to the effects that can be achieved through training the athlete, it is possible to change agility performance through footwear. Footwear that puts the body in a biomechanically efficient alignment for applying force to the ground will optimize the ability to change direction. Furthermore, footwear is critical for maintaining appropriate traction with the ground so that lateral forces can be generated. In a study of the effects of traction on agility, a clear threshold was identified for optimal performance, shoes with coefficient of friction values below 0.5 producing significantly worse results to shoes with greater traction (Pedroza *et al.*, 2010). In a similar study evaluating curved running, performance increased with increasing traction up to a value of 0.8, at which point performance plateaued (Luo & Stefanyshyn, 2011).

Other attributes of footwear may affect agility. Increasing the vertical offset between the heel and toe (a negative heel offset, or placing the toe higher than heel) can cause increased stretch of the ankle plantarflexors, which has been hypothesized to produce performance benefits in agility. However, research on this topic has been inconclusive, with studies showing no correlation between a negative heel-toe offset and agility performance (Salinero *et al.*, 2014).

One of the more promising findings in the relationship between footwear and agility is using banked shoes to improve cutting performance. By incorporating wedges into footwear, ankle plantarflexor moment and maximum curved sprinting speed can be increased (Luo & Stefanyshyn, 2012). Wedged footwear significantly decreases the ankle inversion angle during stance, moving the ankle into a more neutral alignment. Achieving a more neutral alignment allows the ankle plantarflexors to generate greater moments during the propulsive phase of the running cycle, while decreasing the frontal plane moment at the ankle. While the use of banked footwear offers a great opportunity to improve agility performance, the technology is currently limited to using fixed angle shoes, which only facilitate cutting in one direction.

SUMMARY

Agility is an important skill for athletes in many sports. It is comprised of both physical prowess (strength and power generation) as well as cognitive processing (reaction time, decision making). An area of great need in the field of agility is standardized tests to evaluate agility skills. Large variation in agility evaluations makes it difficult to determine what attributes of agility are being measured in each drill. It is also challenging to compare across studies that utilize widely varying definition and measurements of agility. Regardless, a number of sports have demonstrated a strong link between agility and optimal performance in sport. Agility can be improved through training, but because of the multifactorial nature of the skill, training regimens can be quite varied, and it is likely that there is room to improve sport specific agility training programs. In addition to improving agility through training, it has been shown that footwear can have a significant impact on agility performance.

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