EFFECTS OF AGILITY, CHANGE OF DIRECTION AND COMBINATION TRAINING ON AGILITY IN ADOLESCENT FOOTBALL PLAYERS

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ABSTRACT

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Agility is defined as a rapid whole-body movement with change of direction or velocity in response to a stimulus. Only a few studies have investigated the influence of different training interventions on agility in adolescent athletes. The aim of the study was to investigate the effects of three training interventions on agility in adolescent football players.

Thirty male adolescent football players (age 13.6±0.5 years), from three different teams, participated in the study. Teams were randomly divided into one of the three training groups; an agility training group (AG, n=14), a change of direction group (CODG, n=8), and a combination group (COMB, n=8). Each group participated into two intervention sessions a week, on top of their normal football training. The testing included isometric leg press, reactive strength index test, 20m sprint, change of direction (Y-test) and football specific reactive agility test.

The AG and CODG groups improved their agility performance significantly during the intervention. The improved agility performance may be partly due to improved stretch shortening cycle utilization, and improved reaction time during the agility task. Both of these were likely increased by the pre-activation of leg muscles and leg stiffness, which shortened contact time and the propulsive impulse produced during the agility task.

In conclusion, it is important to train both the movement and reaction aspects of agility when the aim is to improve agility performance. Muscle strength also plays a crucial role in agility, especially in adolescent athletes. Therefore coaches should also aim to improve the strength of their athletes.

Key words: agility, training, adolescent, small sided games, change of direction

ABREVIATIONS

ACL	anterior cruciate ligament
AG	agility training group
APHV	age at peak height velocity
BT	braking time in agility test
COD	change of direction
CODG	change of direction training group
COM	centre of mass
COMG	combination training group
COP	centre of pressure
CT	contact time in agility test
PHV	peak height velocity
PT	propulsive time in agility test
RAT	reactive agility test
RSI	reactive strength index
DT	decision making time
SSC	stretch shortening cycle
SSG	small sided games

CONTENT

1 INTRODUCTION

Agility has been defined as “a rapid whole body movement with change of direction or velocity in response to a stimulus” (Sheppard & Young 2006). Therefore, agility is considered to be an important factor in invasion and court sports. According to Sheppard & Young (2006), agility has two major components, cognition and change of direction (COD) speed. The cognitive aspects include perception and decision making, and COD is affected by both technical and physical factors. Current research has shown that agility is one of the major factors separating higher skill level athletes from lower skill level athletes (Scanlan et al. 2014, Young, Dawson & Henry 2015). Young et al. (2015) showed that lower skill level athletes performed better in linear speed and COD tests, where there was no stimulus involved, than higher skill level athletes, whereas higher skill level athletes performed better in the agility test (Young, Dawson & Henry 2015). This suggests the importance of developing agility in team and court sports (Veale, Pearce & Carlson 2010, Young & Willey 2010).

Although more research is emerging on the influence of agility in sport performance and agility training, there is still a limited amount of research on improving agility in adolescent athletes (Lloyd et al. 2013). For decades, it was thought that agility and change of direction were the same skill, and developers of long-term athletic development models did not include agility (Lloyd et al. 2013). Recently, Sheppard and Young (2006) proposed that agility and change of direction are separate skills and since that several research groups have investigated the differences between agility and change of direction. Recently, Lloyd et al. (2013) suggested a framework for agility training in adolescent athletes in their article. This framework has been supported by other researchers, who have investigated the influence of different agility training methods on youth athletes’ agility performance (Chaalali et al. 2016, Chaouachi et al. 2014, Trecroci et al. 2016).

Previous research has shown that the biomechanics between pre-planned COD tasks and agility tasks differ from each other (Wheeler & Sayers 2010, Ford et al. 2005). When COD tasks involve reacting to a stimulus, athletes change their speed of approach, foot placement, and trunk lean. Even though current research has shown that agility can be improved, there is currently limited research on how agility training influences biomechanical factors during an agility task. Since reacting to a stimulus compromises an athlete's biomechanics and increases risk of injuries, more studies are needed to investigate how to optimally improve kinetics and kinematics during agility tasks.

With this in mind, combined with the limited studies investigating agility improvement in adolescent athletes, the aim of this study was to investigate the influence of three agility training methods on agility performance and biomechanics in adolescent football players.

2 AGILITY

2.1 What is agility?

In their review, Sheppard & Young (2006) define agility as ‘a rapid whole body movement with change of velocity or direction in response to a stimulus’. As agility involves reacting to a stimulus, agility is a skill that utilizes the information-processing model (Gabbett & Abernathy 2013). Before athletes can execute a movement, they need to find relevant environmental information and process it in relation to previous knowledge. After the athlete has processed the information, they can execute the correct movement. (Broadbent et al. 2015.) The more sport-specific experience an athlete has, the better anticipation skill they have (Gabbett & Abernathy 2013). In their study, Gabbett & Abernathy (2013) showed that higher-level athletes were better at anticipating movement than lower-level athletes. Higher-level players also made a greater number of correct decisions than lower-level players did. They argued that this difference was due the ability of higher-level rugby players to recognized rugby specific cues better compared to lower-level rugby players. This finding demonstrates the importance of developing sport-specific experiences, in order to improve sport specific information processing. (Gabbett & Abernathy 2013.)

Based on Sheppard’s & Young’s (2006) definition, several research groups started to investigate the differences between agility and change of direction (Paul, Gabbett & Nassis 2016). Young et al. (2015) found that there was only a trivial correlation between agility and COD tests. This supports Sheppard and Young’s (2006) definition of agility and the importance of the cognitive process needed in agility tasks. Since then, many authors have investigated agility and the factors influencing agility (Young, Miller & Talpey 2015, Paul, Gabbett & Nassis 2016, Young & Farrow 2013, Serpell, Young & Ford 2011). In 2015, Young et al. proposed a universal concept for agility and included three factors that influence agility (figure 1). These three factors include cognitive, physical, and technical aspects (Young, Miller & Talpey 2015).

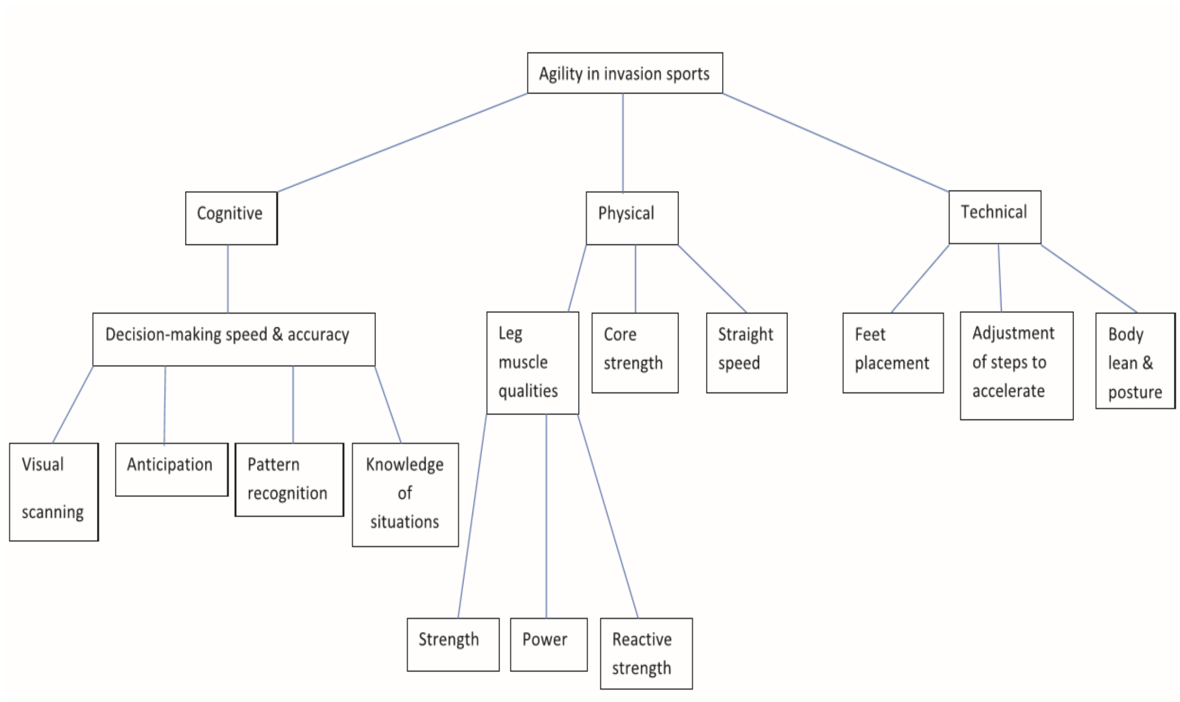


Figure 1. Universal concept of agility proposed by Young et al. (2015).

Sprinting speed was thought to be the most important factor separating different levels of invasion sport athletes (Sheppard & Young 2006). Until a decade ago, some researchers thought that the faster an athlete's linear sprint is, the better their multidirectional movement would be. One of the first to investigate the differences between change of direction and linear speed was Young et al. (2001). In their study, Young et al. (2001) investigated whether there was a correlation between linear sprint speed and change of direction (COD) tasks, with different COD angles and number of COD's during a task. They found that linear speed did not correlate with sprints involving COD, and the larger the angle and the more COD tasks during the sprint, the smaller the correlation between linear sprint speed and COD tasks. After the Young et al. (2001) study, research has continued to investigate the COD ability of athletes and its relationship to agility (Sheppard & Young 2006).

Considering invasion sports involve several changes of direction, the ability to change direction is important for these athletes (Young, Dawson & Henry 2015). Most of these COD movements include responses to stimuli, either movement of an opponent, teammate or a ball, and these movements are different to pre-planned COD tasks. Chelladurai (1976, from (Young & Farrow 2013) was likely the first to describe the presence of perceptual and cognitive aspects in an agility task. Chelladurai, Whasz and Sipura (1977) were probably the first to suggest the need for sport specific stimuli for agility testing. Until Young et al's (2001) and Besier et al. (2001) studies, there was no research found investigating the effect of anticipation on COD. After Sheppard and Young (2006)'s review, more studies have introduced sport specific stimuli to investigate agility.

Research has shown that COD speed only explains a small aspect of agility performance (Young, Dawson & Henry 2015). In their study, Young et al. (2015) found that higher-level athletes had faster agility task time when compared to lower-level athletes, but both groups had similar COD time. This and other studies support the finding that agility is only partly explained by COD speed, and the cognitive part of agility is the main factor that separates higher- and lower-level athletes (Young, Dawson & Henry 2015, Young & Farrow 2013, Young et al. 2011, Veale, Pearce & Carlson 2010).

For the purpose of this study, Sheppard and Young's (2006) definition of agility is used. When referring to agility in this review, all COD movements or changes in velocity that include reactions to stimuli are considered to be agility. If the task is pre-planned and does not involve a reaction to a stimulus, this is considered to be COD.

2.2 Factors affecting agility

There are three major aspects of agility 1) cognitive; 2) physical; and 3) technical (Young, Dawson & Henry 2015) (figure 1). This literature review concentrates mainly on the technical and physical aspects affecting agility, but also briefly discusses the cognitive aspect. In the definition of agility, cognition is important, and the cognitive aspect has been shown to be the primary differentiating factor between higher and lower skill level athletes (Sheppard et al.

2006, Young et al. 2011). These cognitive aspects include visual scanning, anticipation of movement, pattern recognition, and knowledge of situation (figure 1). Visual scanning refers to an athlete's ability to scan the environment, concentrate, and detect important cues to help anticipate what happens next (Williams & Davids 1998).

Previous research has shown that anticipation and pattern recognition are important to reach a high level of skilled performance (Young, Dawson & Henry 2015, Sheppard & Young 2006). Anticipation is an athlete's ability to predict the movements of the opponent, teammate, and ball. Pattern recognition is the athlete's ability to find and recognise patterns during game play. This includes detecting movement or tactical patterns from their opponent or teammates on the field. Recognising patterns during game play helps the athlete to anticipate their next movements. Knowledge of the situation refers to the athlete's familiarity with the situation they are in. This also helps the athlete to anticipate an opponent's movements. (Mann et al. 2007.) All these factors go hand in hand during agility tasks. Improving visual scanning, pattern recognition, and knowledge of situation can improve an athlete's ability to anticipate the game, movements of opponents and teammates. Improving all of these aspects helps the athlete to improve their agility. (Scanlan et al. 2014, Serpell, Young & Ford 2011.)

Previous research has recognized three technical factors influencing agility performance. The first is foot placement. This refers to where the athlete must place their centre of pressure (COP) in relation to their centre of mass (COM) (figure 2). To perform the COD movement optimally, the athlete's COP must be on the opposite side of their COM in relation to the direction they are intending to move. (Wheeler & Sayers 2010.) This allows the athlete to produce optimal force towards the new direction and increase their exiting velocity. The second technical factor affecting agility is the ability to adjust steps to accelerate. The third factor is trunk lean, which relates to directing the trunk more towards the new direction of movement. This optimizes COM separation from COP, and when combined with foot placement, this also improves the athletes' force production ability towards the new direction. (Hewit, Cronin & Hume 2012, Marshall et al. 2014.) These technical factors, and their influence on agility, are discussed in more detail later in this review.

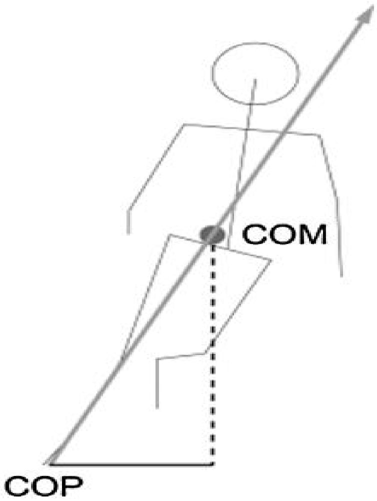


Figure 2. Medial-lateral relationship between centre of pressure (COP) and centre of mass (COM) during change of direction task to optimize performance (Havens & Sigward 2015b).

In their model, Young and Farrow (2006) proposed that there are three physical factors that influence agility. These factors are 1) leg muscle qualities, including strength, power and reactive strength; 2) core strength; and 3) linear sprint speed (Young & Farrow 2006). These physical factors are discussed in more detail later during this review.

2.3 Agility testing

Many tests have been developed to evaluate an athlete's level of agility. These tests include the 5-0-5, Illinois agility test, and the T-test agility test. (Sporis et al. 2010, Thomas, French & Hayes 2009, Cavaco et al. 2014, Jullien et al. 2008.) As all these tests lack a cognitive aspect, they actually measure COD ability rather than agility. Due to the importance of the cognitive aspect of agility, the agility test should include reaction to an external stimulus. As a result of this, recent research has concentrated on developing new agility tests that includes reaction to an external stimulus. It has also been shown that ability to react to an external stimulus is an effective method of differentiating the skill level of athletes (Young, Dawson & Henry 2015). Previous research has shown that higher skill level athletes perform better in agility tests than lower skill level athletes. What was interesting in these studies, however, was that lower skill level athletes performed better in linear sprinting and COD tests compared to higher skill level athletes. (Young, Miller & Talpey 2015.)

There are several different external stimuli used in the research. These stimuli include a light stimulus (Oliver & Meyers 2009, Green, Blake & Caulfield 2011, Spasic et al. 2015), a directional indicator stimulus (Young et al. 2011), a human stimulus (Gabbett & Benton 2009, Sheppard et al. 2006, Young & Murray 2016, Scanlan et al. 2014, Young & Willey 2010) and a video stimulus (Henry et al. 2011, Farrow, Young & Bruce 2005, Serpell, Ford & Young 2010, Young et al. 2011). These tests range from general external stimuli, such as light and voice stimuli, to sport-specific external stimuli, including human and video stimuli. It has been shown that the more sport-specific the external stimulus is, the more effective it is at separating athletes by their sport ability. (Paul, Gabbett & Nassis 2016.) In their study with Australian rules football players, Henry et al. (2011), showed that higher-level athletes performed better in sport-specific agility tasks than lower-level athletes. The same study also showed that a general external stimulus (light) was not a specific enough stimulus to separate different skill levels of athletes (Henry et al. 2011).

During agility testing, the stimulus should be as sport-specific as possible to be able to separate higher-level athletes from lower-level athletes. Spiteri et al. (2012) suggested that a 3-dimensional human stimulus is more specific than a 2-dimensional video stimulus. They argued that the 3-dimensional stimulus provided by a human allows athletes to better anticipate specific cues from a person’s body, when compared to a more generic 2-dimensional video stimulus (Spiteri, Nimphius & Cochrane 2012). So far, there are no studies comparing a human stimulus to video stimulus, so this argument requires further research.

3 EFFECTS OF GROWTH AND MATURATION ON AGILITY

3.1 Growth and maturation

During adolescence, athletes mature and develop at different rates (Malina et al. 2015). Children who have same chronological age (calendar age) might have several years difference in their biological age, based on biological maturation (Lloyd et al. 2014). Adolescence also shows individual variation in onset, tempo and duration of maturation (Philippaerts et al. 2006). Due to a difference in age at the onset of maturation, athletes can be divided into early developers (biological age ahead of chronological age), average developers (biological age on-time with chronological age), or late developers (biological age is behind chronological age). At the onset of puberty, there is significant improvement in neurological and muscular development, which is due to increased hormonal production. (Malina et al. 2015.) This causes great variation in skills and physical qualities between adolescents during puberty (Philippaerts et al. 2006).

Due to the significant difference within athletes of the same chronological age, it has been suggested to group athletes by biological age, using peak height velocity (PHV) as an indicator of biological age, during puberty (Philippaerts et al. 2006). There are several techniques to estimate PHV of athlete. These calculations differ according to the measurements used to calculate PHV (Moore et al. 2015). One of the methods was developed by Mirwald and colleagues (2002). To use this method, the practitioner needs to measure weight, standing and sitting height of the subject, and also use date of measurement, date of birth and the gender of subject to estimate the onset of PHV (Mirwald et al. 2002). Moore et al. (2015) developed a regression equation to estimate maturity offset, when the sitting height of the subject cannot be measured. To use this equation, the practitioner only needs the age of the subject and height. This equation has been shown to be as accurate as Mirwalds original equation to estimate maturation offset and is a great option when calculating maturity offset with limited time and equipment. (Moore et al. 2015.)

3.2 Effect of neural development on sport performance

Two factors that affect sport performance during growth and maturation are neural and muscular development. The development of these two systems leads to improvement in sprinting, muscular strength, and power of the athlete. These two systems develop in a non-linear fashion, and have been shown to have sensitive periods for development. (Lloyd et al. 2014.) Previous research has shown that neural development, myelination of motor nerves, is completed when sexual maturity has been reached (De Ste Croix et al. 2002). Maturation of neural systems happens through myelination of axons. Increased myelination leads to improved coordination, and this improved coordination results from faster recruitment and synchronisation of motor units and faster contraction-relaxation cycles. (Viru et al. 1999.)

Previous research has shown that there are two sensitive periods for neural development. The first period is during preadolescent, which is characterised by improvement in speed, strength, endurance, and explosive strength without development in the muscular system. The second sensitive period is around the APHV, where improvements in physical qualities are linked to development in both neural and muscular systems. (Lloyd & Oliver 2012, Viru et al. 1999.) These sensitive periods of neural development should be used to improve skill and coordination of movement (Rumpf et al. 2012, Viru et al. 1999). Even though there is a sensitive period for neural development, it does not mean that these qualities cannot be improved outside of these sensitive periods (Ford et al. 2011).

3.3 Effect of muscular development on sport performance

Previous research has shown that there is only a limited amount of development in the muscular system during childhood. Between the ages of 7 and 13.5 years, there is only a 0.6% increase in muscle mass per year. After the start of the puberty, there is a significant improvement in muscle cross-sectional area. Previous literature has shown that after the start of puberty, there is a 29% increase in muscle mass per year. (Viru et al. 1999.) This significant improvement in muscle mass after puberty is linked to increased hormonal production associated with this age. At this age, differences in strength between the sexes start to increase. Girls still continue to increase muscle mass, however the rate is much slower than in boys. This is due to a greater amount of androgen production in boys than in girls. (Rumpf et al. 2012.)

Current research has shown that young athletes can improve speed, power and strength throughout their career (Lloyd & Oliver 2012, Ford et al. 2011, Rumpf et al. 2012). Before the onset of puberty, development in physical qualities is more neural. After puberty, developments are both neural and muscular. Due to the differences in neural and muscular development, training during the preadolescent period should focus on improving neural factors. After the onset of puberty, training should be aimed more towards improving both muscular qualities and neural factors. (Ford et al. 2011.)

3.4 Long-term athletic development

National sporting organisations and sports club have practised long-term athletic development for decades (Barker-Ruchti et al. 2017). The scientific community has developed several different frameworks for long-term athletic development. One of the first published, and most widely utilized, is Way's and Balyi's Long Term Athletic Development Model (Way & Balyi 2000). Way and Balyi (2000) divided sports into early and late specialization sports. Early specialization sports include for example gymnastics, figure skating, and diving, whereas late specialization sports include all team sports and track and field. This model suggests that there are five separate stages for a late specialization sport that need to be completed to reach elite performance level. These stages are 1) FUNdamental stage, 2) Learning to train, 3) Training to train, 4) Training to compete, and 5) Training to win. The sixth stage is Retirement/retainment, and is considered as lifelong participation in sport. The model also proposes that there is a so called 'window of optimal trainability' for speed, strength, suppleness, skills, and stamina. (Way & Balyi 2000.)

More recent scientific literature has challenged the Long Term Athletic Development model, and especially the concept of windows of opportunity as an optimal way to develop talented athletes (Lloyd & Oliver 2012). Researchers criticized mostly the argument that if a child or adolescent does not take part in specific training during the windows of opportunity, they may not reach their maximum potential later in their athletic career. They argue that there is no scientific literature to support windows of opportunity. (Lloyd & Oliver 2012, Ford et al. 2011.) The findings of Lloyd & Oliver (2012) are supported by other studies that have showed the ability to improve strength (De Ste Croix 2007), sprint performance (Rumpf et al. 2012), and aerobic fitness (Baquet, Van Praagh & Berthoin 2003) outside of the window of opportunity. Lloyd & Oliver (2012) also criticized the Long Term Athletic Development model for not including guidelines for hypertrophy, power, and agility training. These three qualities have been shown to be important in athletic performance (Lloyd & Oliver, 2012).

Several other models have been developed, due to the holistic shortcomings of the Long Term Athletic Development model. These new athletic developmental models include the youth physical development model (Lloyd & Oliver, 2012), FTEM – athlete development pathway (Gulbin et al. 2013), the developmental Model for Sport Participation (Cote & Vierimaa 2014), and Athletic Talent Development Environment model (Henriksen, Stambulova & Roessler 2010). Several national sporting organizations and national governments have used these models as they are, or modified them to develop their own long-term athletic development plan (Barker-Ruchti et al. 2017). Several of these models also propose the importance of developing fundamental movement skills before starting more sport specific training (Cote & Vierimaa 2014, Gulbin et al. 2013, Lloyd & Oliver 2012). All of these models propose that when planning for long-term athletic development, early specialization in one sport should be avoided. The models also propose that holistic development, and a diversified approach, is important in developing athletes. (Barker-Ruchti et al. 2017, Cote & Vierimaa 2014, Gulbin et al. 2013, Henriksen, Stambulova & Roessler 2010, Lloyd & Oliver 2012.) According to scientific literature, long-term athletic development should be based on a holistic approach, including to see youth athletes as adolescents and children, not as adults; and sampling multiple sports before specializing in one sport.

4 BIOMECHANICS AND PHYSICAL ASPECTS OF AGILITY

4.1 Biomechanics of change of direction

An important aspect of agility performance is technique (figure 1). Within technique there are three main factors to consider 1) foot placement; 2) body lean and posture adjustment; and 3) adjustment of the steps to accelerate (Young, Dawson & Henry 2015, Mornieux et al. 2014). Previous research has shown that the influence of each of these technical factors depends on the velocity of the movement prior to COD and the angle of COD (Dos'Santos et al. 2017, Havens & Sigward 2015b). An important factor during COD movements are the athlete's kinetics, force characteristics, kinematics, and motion characteristics, which describes the athlete's ability to decelerate, and reaccelerate their body towards a new direction (Sasaki et al. 2011). Athletes also adjust their COD technique according to their individual anthropometrics, which also influence their kinetics and kinematics (Dos'Santos et al. 2017).

The change of direction skill can be divided into three phases. These phases include 1) braking phase (eccentric phase), when the athlete decelerates their body and adjusts their posture to prepare for COD. Following this is 2) the plant phase (isometric phase), where the athlete plants their foot to the ground. The final phase is 3) the propulsive phase (concentric phase). During this phase, the athlete produces force to reaccelerate their body towards the new direction of movement. (Dos'Santos et al. 2017, Spiteri et al. 2015.) These three phases of COD are similar to the phases of the stretch shortening cycle (SSC). SSC also includes three phases which are 1) pre-activation; 2) active stretching (eccentric); and 3) shortening (concentric) phase (Komi 2000). Due to the fact that eccentric contraction is followed by concentric contraction, COD can be classified as a SSC activity (Komi 2000, Ishikawa & Komi 2004).

As mentioned previously, when athletes are approaching COD they decelerate their body and adjust their posture to prepare themselves for reaccelerating towards a new direction of movement (Green, Blake & Caulfield 2011). This reacceleration is achieved by redirecting the athlete's COM towards the new direction, opposite to the athlete's COP (Havens & Sigward 2015a). One of the ways athletes' can achieve this is to plant their foot on the opposite side of their COM, in relation to their reacceleration direction (Mornieux et al. 2014). Placement of the foot plays a crucial role during the COD task. Planting of the foot determines the position of the athletes COP. Orientation of the COP from COM, determines the direction where COM can be reaccelerated. (Mornieux et al. 2014.) This placement of the foot also determines the medial-lateral separation of their COM and COP (figure 2). The greater the medial-lateral separation is, the greater the ground reaction force towards the new direction that can be produced by the athlete. Another postural adjustment that affects medial-lateral separation of COM and COP is trunk lean. When the athlete leans more towards the direction of movement, this moves the athlete's COM further away from COP. (Havens & Sigward 2015a, Mornieux et al. 2014.)

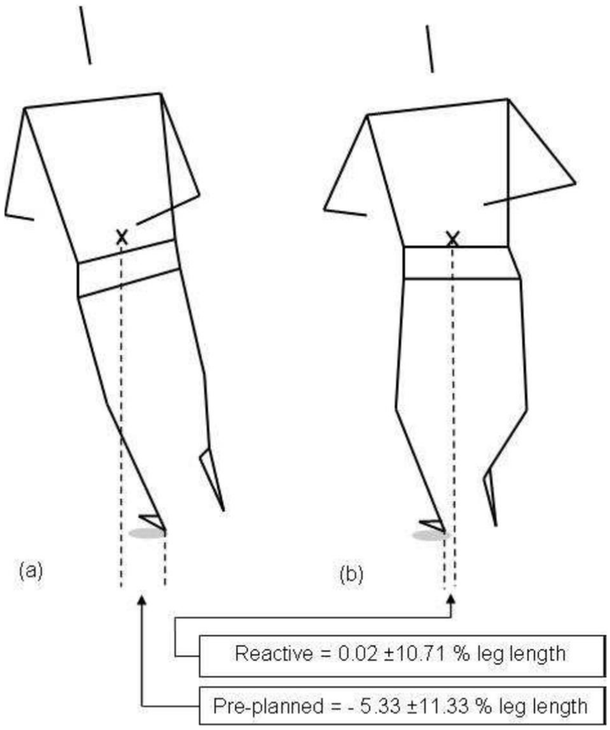


Figure 2. Demonstration of medial-lateral separation of centre of pressure (COP) (foot strike) and centre of mass (COM), and difference between foot placement and trunk lean during a) change of direction and b) agility (Wheeler & Sayers 2010).

Previous research has shown that when the velocity of movement before COD and the angle of COD increase, athletes must increase medial-lateral separation to be able to reaccelerate their body towards the new direction of movement (Havens & Sigward 2015b, Mornieux et al. 2014).

This increased medial-lateral separation results in greater braking needed prior to COD (Havens & Sigward 2015b). Havens and Sigward (2015a) showed in their study, that when hip abduction was decreased, trunk lean was increased. They proposed that when the cutting angle is high (90°), hip muscles may act more as a stabiliser in the frontal plane, rather than a force producer, which leads to increased trunk lean (Havens & Sigward 2015a).

When studying kinetic variables during different change of direction drills, Spiteri et al. (2014) showed that faster athletes produced a smaller braking impulse and a greater propulsive impulse when compared to slower athletes. Their findings contradicted previous research (Green, Blake & Caulfield 2011, Spiteri, Newton & Nimphius 2015). In previous studies, it was found that athletes that can produce a greater braking impulse, produce higher exiting velocity from COD tasks (Green, Blake & Caulfield 2011, Spiteri, Newton & Nimphius 2015). Spiteri et al. (2015) argued that because the greater braking impulse was due to longer contact time, both groups had a similar braking force, leading to decreased propulsive impulse, slower exiting velocity and slower COD time in the slower athletes. As the slower athletes had longer contact time, they might have lost more stored elastic energy than faster athletes (Spiteri et al. 2015). It has been shown that longer contact time decreases the amount of stored elastic energy during SSC (Ishikawa & Komi 2004, Flanagan & Comyns 2008).

4.2 Biomechanical differences of agility and change of direction

As previously mentioned, higher-level athletes perform better during sport-specific agility tasks as lower-level athletes. Until recently there has been limited research on the biomechanical differences during COD and agility (Besier, Lloyd, Ackland et al. 2001, Wheeler & Sayers 2010, Ford et al. 2005, Mornieux et al. 2014, Houck, Duncan & Haven 2006). These studies have found three major biomechanical differences between anticipated (COD) and unanticipated (agility) COD tasks (Besier et al. 2001, Wheeler & Sayers 2010, Houck et al 2006, Mournieux et al. 2014, Ford et al. 2005).

The first biomechanical difference between anticipated and unanticipated COD tasks is foot placement. In their study, Wheeler and Sayers (2010) found that when athletes must react to a defensive player before changing direction, the athlete place their foot closer to COM than when a COD task is planned. As mentioned earlier, one way to maximize exiting velocity is to place the foot further away from COM, to maximize ground reaction force production towards the new direction of movement (Mournieux et al. 2014). Houck et al. (2006) found that when performing an anticipated cutting task, lateral foot placement was greater than when performing an unanticipated cutting task. This finding is supported by Wheeler and Sayers (2010). They found that athletes positioned their foot closer to COM when the athlete had to perform a reactive COD. They argued that positioning the foot closer to COM allows the athlete to better execute the movement away from the defensive player. (Wheeler & Sayers 2010.) In contrast to these findings, Mournieux et al. (2014) found no difference in foot placement when comparing between different times available to perform COD tasks. These findings suggest that when there is limited time to plan a COD task (agility), athletes must rely on other strategies to optimally reaccelerate their body towards the new direction of movement (Mournieux et al. 2014, Wheeler & Sayers 2010).

The second biomechanical difference between COD and agility tasks is the use of trunk lean. When an athlete has to react to an opponent, they have less time to plan the movement than when the movement is pre-planned. Therefore, the athlete has to use more trunk lean to position COM towards the new direction compared to COP. (Mournieux et al. 2014, Houck, Duncan & Haven 2006.) As the foot is placed closer to COM to better react to the opponent's movement, trunk lean is the most relevant strategy to orientate COM towards the new direction of movement (Mournieux et al. 2014, Wheeler& Sayers 2010, Houck, Duncan & Haven 2006). Mournieux et al. (2014) showed that when athletes have enough time (more than 600ms) to plan their movement, the athlete orientates their trunk towards the new direction of movement. On the other hand, when the decision time is short, athletes tend to have a more erect trunk, or lean their trunk in the opposite direction than the new direction of movement. These finding suggest, that to produce maximum exit velocity, athletes should orientate their trunk towards the new direction. (Mournieux et al. 2014, Houck, Duncan & Haven 2006.)

The third, and final, difference between COD and agility tasks is the amount of knee valgus during change of direction (Mournieux et al. 2014, Ford et al. 2005, Houck, Duncan & Haven 2006, Besier et al. 2001b). Studies have shown, that when there is limited time to plan a COD task, this increases the amount of knee abduction (valgus) and knee abduction moment (valgus moment) (Besier, Lloyd, Cochrane et al. 2001, Mornieux et al. 2014, Ford et al. 2005, Houck, Duncan & Haven 2006). When an athlete has to react to an opponent, and has limited time to plan their movement, more medial foot placement and trunk lean (opposite direction) increases knee valgus angle and moment (Besier, Lloyd, Ackland et al. 2001, Mornieux et al. 2014). This increased knee valgus may be a risk factor for non-contact ACL injuries, which are discussed in more detail in the next section (Besier, Lloyd, Cochrane et al. 2001, Ford et al. 2005, Houck, Duncan & Haven 2006, Mornieux et al. 2014).

Mournieux et al. (2014) found, that if athletes have enough time to plan their movement during agility task, not knowing which direction to go after the signal did not change their technique, when compared to a pre-planned COD task. If athletes have enough time to plan their movement after a stimulus, they do not change their movement strategy. According to Mournieux et al. (2014), it can be argued that if athletes can improve their perceptual skills and decision making, this increases their time to plan the movement. This increased planning time allows athletes to use optimal COD strategies and might decrease risk of non-contact knee and ankle injuries (Mournieux et al. 2014).

4.3 Risk of injuries during agility and change of direction movements

Invasion sports are characterised by frequent COD actions and constant change in velocity by acceleration and deceleration of the body (Faude, Rößler & Junge 2013). Unfortunately, COD is also one of the most common causes of non-contact injuries in invasion sports. Previous research has shown that the two most often injured body parts, during COD, are the ankle and knee. The most common ankle and knee injury is a ligament sprain. In the knee, the anterior cruciate ligament (ACL) is the most common ligament injury (Faude et al. 2005), whereas the most common ankle sprain is a talofibular or calcaneal fibular ligament injury, caused by inversion of the ankle (Valderrabano et al. 2014). It is important to try to prevent these injuries, because ligament sprains could lead to greater ligament laxity and increased joint instability (Faude et al. 2005).

It has been shown that ankle kinematics effect both the ankle joint (Valderrabano et al. 2014) and knee joint kinematics and loading (Alentron-Geli et al. 2009). If the athlete places their foot on the ground with excessive ankle eversion, the ankle turns out, causing increased internal tibial rotation, knee valgus and anterior tibial slide. All these actions are associated with increased ACL injury risk. (Alentron-Geli et al. 2009.) On the other hand, if the athlete places their foot on the ground with excessive inversion, the ankle turns in, and the risk of ankle sprain increases. Excessive inversion of the ankle increases loading on the lateral side of the ankle, which causes excessive stress on the talofibular ligament. (Valderrabano et al. 2014.) Research has also shown that because the foot is the first, and only, body part to contact the ground during sporting movements, ankle biomechanics are an important factor when evaluating non-contact injury risk factors (Alentron-Geli et al. 2009). Only a few studies have been conducted for ankle frontal plane actions during COD tasks.

To minimize ACL injuries, previous research has concentrated on analysing risk factors during COD and the effect of ACL prevention programs on COD ability (Alentorn-Geli et al. 2009). One factor increasing ACL injury risk during COD is increased trunk lean to the opposite direction of movement (Zazulak 2007). This action causes increased loading on the knee while in a vulnerable position (Zazulak 2007, Hewett & Myer 2011). This can be prevented by increasing trunk stabiliser strength, and by improving athletes COD technique by teaching them to lean their trunk towards the direction of movement (Alentron-Geli et al. 2009, Zazulak 2007).

A lack of pre-activation of the lower extremity muscles prior to foot contact during unanticipated COD tasks, has been shown to increase the risk of injuries. Increased pre-activation of the muscles increases joint stiffness, which helps to stabilize the joints during agility tasks. Agility tasks require a higher attentional effort, where the athlete needs to read and react to a stimulus. (Spiteri, Newton & Nimphius 2015.) This action increases processing time and affects the pre-activation level of the lower extremity muscles (Spiteri, Newton & Nimphius 2015, Bencke & Zebis 2011). In their study, Spiteri et al. (2015) found that athletes with a faster agility time had greater muscle pre-activation than slower athletes. Faster athletes also had a faster decision-making time. These results show that when athletes have faster decision time, they have more time to pre-activate their muscles. This increases the stability of the knee and ankle joint and potentially helps to decrease the athlete's risk of non-contact injuries. (Spiteri, Newton & Nimphius 2015.)

4.4 Physical factors influencing agility

Previous research has identified three separate physical factors that influence agility. These qualities include 1) leg muscle qualities, which include strength, power and reactive strength; 2) core strength; and 3) linear speed. Much of the research so far has concentrated on the influence of physical aspects on COD tasks. Although there are limited studies on the physical factors of agility performance, there is significant research concentrating on the physical factors of COD. Physical factors in COD are thought to be the same during agility. (Paul, Gabbett & Nassis 2016.)

The three leg muscle qualities considered to influence agility and COD are strength, power and reactive strength. Previous studies have shown that there is only a moderate to small correlation between COD performance and typical strength tests (Young & Farrow 2006, Young, Miller & Talpey 2015). Some researchers consider power to be a more important leg muscle quality in agility and COD than strength (Young, James & Montgomery 2002). This is supported by the fact that there is limited time to produce force during athletic movements, so power could be the more important factor influencing COD speed than strength. Previous research has demonstrated that there is low-to-moderate correlation between COD and leg power tests. (Young, James & Montgomery 2002.)

The final leg muscle quality influencing COD speed is reactive strength, which is an athlete's ability to change quickly from eccentric to concentric contraction (Young & Farrow 2006). Plyometric training has been shown to be an effective method for improving reactive strength (Asadi et al. 2016, Sáez de Villarreal, Requena & Cronin 2012). Research has shown a moderate correlation between COD and reactive strength, when using drop jump protocols to measure reactive strength (Young, Miller & Talpey 2015). Some studies have shown no improvement of COD performance after plyometric training. This might be due to the use of vertically orientated plyometric exercises, and the fact that COD movements are typically more laterally and horizontally orientated. (Asadi et al. 2016, Henry et al. 2016.) Previous research supports this force vector direction theory (McCormick et al. 2016). McCormick et al. (2016) showed that frontal plane plyometrics improved COD performance more than sagittal plane plyometrics. They argued that this was a result of the laterally orientated exercises which were used in the frontal plane group. These lateral exercises improved athletes lateral force production, which lead to improved COD speed, because training was more specific to COD movements. (McCormick et al. 2016.) This finding is supported by the specificity principle. The principle of specificity means that training has to stress the specific system the athlete wants to improve. (Reilly, Morris & Whyte 2009.)

Many studies have shown that improved core strength can improve athletic performance (Young & Farrow 2006, Kibler, Press & Sciascia 2006). If athletes do not possess enough core stability, their trunk absorbs the force produced by the lower limbs, instead of keeping the trunk stable and orienting the trunk towards the new direction of movement (Young & Farrow 2006). If the trunk is not stable during COD movements, this directs trunk lean away from the direction of movement, and increases risk of injuries (Alentorn-Geli et al. 2009). This also reduces COD speed and its effect on athletic performance (Young & Farrow 2006). Due to these factors, core stability is an important factor to consider in an athletic population.

The final physical factor influencing COD performance is linear speed (Young & Farrow 2006). Young et al. (2001) showed that there was a high correlation between linear speed and COD, when only small COD angles and a small number of COD tasks were performed. They also found that when COD angle increased and/or the amount of COD tasks increased, the correlation between COD and linear speed decreased (Young, McDowell & Scarlett 2001). These findings have been supported by further research (Paul, Gabbett & Nassis 2016). These findings suggest that linear speed influences the COD task more when the angle is small, so when aiming to improve COD, coaches should concentrate on developing other aspects more than just linear speed.

5 AGILITY TRAINING

5.1 Principles of agility training

When the aim of the training program is to improve agility, it is important that the training program involves some aspect of technical, physical, and cognitive factors of agility (Young & Farrow 2006). Recent research has focused on the importance of training the cognitive aspect of agility and forgets the technical and physical aspects (Serpell, Young & Ford 2011). At the same time, some studies have considered only the technical and/or physical aspect of agility and forget the cognitive aspect (Milanović et al. 2013, Milanovic et al. 2014).

There have been four main interventions used to improve agility. These include 1) speed, agility, and quickness training; 2) strength training; 3) plyometric training; and 4) small sided games (SSG) and evasion drills. Commonly speed, agility and quickness training is used to improve the technical aspect of agility, whereas plyometric and strength training is aimed at the physical aspect (Milanović et al. 2013). To improve the cognitive aspect of agility, researchers have used SSG training and evasion drills (Young & Rogers 2014, Chaouachi et al. 2014, Trecroci et al. 2016) All these methods are discussed in more detail in the next section of this review.

A common limitation in studies aiming to improve agility has been the lack of agility test in the study design (Milanović et al. 2013). Instead, many of the studies investigating the effect of training intervention on agility have used pre-planned COD drills as a measure of agility. As discussed earlier, perceptual and cognitive aspect are also important factors affecting agility, and using a pre-planned COD test misses this part of agility. (Young, Dawson & Henry 2015.) Therefore, only studies that included agility tests are discussed in the next section, unless mentioned otherwise.

5.2 Methods used to train agility

5.2.1 Speed, agility, and quickness

Speed, agility and quickness training is defined as training that combines high intensity and fast movements performed with limited time (quickness), including both linear speed and multidirectional movement, and with or without cognitive stimulus (Trecroci et al. 2016). This type of training has become popular in football and is rather well studied (Milanović et al. 2013, Jovanovic et al. 2011, Milanovic et al. 2014). During the literature search, however, only one study was found that investigated the effect of speed, agility and quickness training on agility (Trecroci et al. 2016).

In their study, Trecroci et al. (2016) found that 12 weeks of speed, agility and quickness training improved reactive agility significantly more than football training alone, in pre-pubertal football players. Their training involved foot work exercises, speed ladder exercises, and linear and multidirectional sprint training with and without reaction to stimulus (Trecroci et al. 2016). Their findings showed that agility is highly trainable in pre-pubertal football players with speed, agility and quickness training, but more research is needed to find out more about agility training.

5.2.2 Strength training

There were no studies found investigating the effects of strength training on agility. This was surprising as physical qualities are one of three main factors influencing agility performance (figure 1). A review of the literature found some studies investigating the effect of strength training on pre-planned COD tests (García-Pinillos et al. 2014, Negra et al. 2016, Jullien et al. 2008). As COD performance influences agility, the findings of these studies are discussed here.

In their study, Negra et al. (2016) investigated the effects of 12 weeks of a high-velocity resistance training protocol on U-13 football players, with no previous experience in resistance training. The experimental group performed three football training sessions and two high-velocity resistance training sessions per week, whereas the control group performed five football training sessions per week. The research used the Illinois agility test and the T-test as a measure of pre-planned COD ability. They found that the high-velocity resistance training group improved in the Illinois and T-test significantly more than the control group, even with less football specific training sessions per week. (Negra et al. 2016.)

In another study, Jullien et al. (2008) investigated the effects of two different training protocols on a COD circuit test in young adult football players. One group, the squat group, performed squats at 3 sets of 3 reps of 90% 1RM followed by 12 minutes of a coordination circuit designed by the researchers. Another group, the coordination group, performed a 30m sprint followed by 12 minutes of a coordination circuit. The coordination circuit included runs in various directions with and without the ball. Both groups participated in training once a day, five times a week, for three weeks. The study found that the squat group training group did not improve time during the test, while the coordination group did. (Jullien et al. 2008.) They concluded that sprint training and coordination training is more beneficial for football players than strength training. This finding is in contrast with Keiner et al. (2014). They found that a long term periodised strength program improved COD performance significantly when compared to the control group (Keiner et al. 2014). As the intervention was only three weeks, it is likely that the strength training group did not have enough time to benefit from training.

A third study investigated the effect of contrast training, performed twice a week for 12 weeks, on physical performance in U-16 football players (García-Pinillos et al. 2014). The program involved one isometric exercise followed by one or two plyometric exercises. None of the exercises included an external load. The experimental group performed three football trainings and one match per week, on top of the experimental intervention. They found that the contrast training group improved the Balsom agility test significantly when compared to the control group, performing only football training and one match per week. They concluded that 12 weeks of contrast training is beneficial for young football players to improve power, agility, and speed. (García-Pinillos et al. 2014.)

Although none of these investigations specifically tested the effect of strength training on agility, these findings support the importance of improving lower limb strength levels, especially in football players with no previous experience in resistance training. Improving lower limb strength means athletes are better able to produce force during COD tasks, and this likely improves their time. (Negra et al. 2016, Keiner et al. 2014, García-Pinillos et al. 2014.)

5.2.3 Plyometrics

Plyometric training is considered to enhance the muscle's ability to utilize SSC. SSC is an eccentric contraction (where the muscle and tendon lengthens under contraction) which is immediately followed by a concentric contraction. (Komi 2000, Asadi et al. 2016.) Use of SSC during plyometric exercises enables the muscle-tendon unit to produce the maximum amount of force in the shortest time possible (Asadi et al. 2016, Sáez de Villarreal, Requena & Cronin 2012). Due to this, and the fact that SSC is an integral part of athletic actions, it is important to include plyometric exercises into an athlete's training plan (Asadi et al. 2016, Sáez de Villarreal, Requena & Cronin 2012, Sáez de Villarreal et al. 2015).

No research investigating the effect of plyometric training on agility were found during the literature review. All studies investigating plyometric training effect on athletic performance have used a pre-planned COD test as a measure of plyometric training effect. Due to this, the effects of plyometric training on COD performance in football players are discussed in this section.

There are several studies investigating the effects of plyometric training on football performance in different age and skill level athletes. All studies included in this review showed that plyometric training was an effective method for improving COD in football players (Hammami et al. 2016, Meylan & Malatesta 2009, Thomas, French & Hayes 2009, Ramírez-Campillo et al. 2014, Ramírez-Campillo et al. 2015, Ramírez-Campillo et al. 2016, Vaczi et al. 2013). Ramirez-Campillo et al. (2015) found that a combination of both unilateral and bilateral plyometric exercises improved COD performance more than just bilateral or unilateral training alone. Another interesting finding from their study was that unilateral plyometric training was as effective as a combination of unilateral and bilateral plyometric training in improving linear sprint and COD. They found that unilateral training was significantly better when unilateral performance was measured (vertical and horizontal bounds) and bilateral training was more beneficial when performance was measured using a bilateral test (vertical counter movement jump and horizontal jump). Combining both unilateral and bilateral plyometric training resulted in similar improvements in the unilateral test when compared to the unilateral plyometric group, and the results for the bilateral test was also comparable to the bilateral group. Their finding supports the specificity of training principle. This suggests that when improving running or COD performance, a combination of unilateral and bilateral plyometric training is more advantageous than just unilateral or bilateral plyometric training, or football training alone. (Ramírez-Campillo et al. 2015.)

Yanci et al. (2016) found that performing a high volume of horizontal plyometric training was no more beneficial than lower volume plyometric training. In their study, one group performed 180 foot contacts and another group performed 360 foot contacts per session during a 6-week period. They found that there was no difference in football performance and COD performance between the groups. (Yanci et al. 2016.) This is in line with the recommendations from Saez de Villareal et al. (2012), who concluded in their meta-analysis that around 80 foot contacts per session is sufficient to provide enough stimulus to improve performance. To optimally apply plyometric training, training should follow the progressive overload principle, starting with lower intensity and less complex exercises, and progressing to higher intensity and more complex exercises over time (Sáez de Villarreal, Requena & Cronin 2012). Also, when the intensity of training is increasing, training volume should be decreased (Lloyd, Meyers & Oliver 2011). According to these findings, plyometric training could be used as an effective method of improving agility performance, but more research is needed to find the optimal volume and intensity of plyometric training.

5.2.4 Small sided games

The effect of SSG training on the physiological aspect of athletic performance is well known, but research has only recently started focusing on the effects of SSG training on agility (Paul, Gabbett & Nassis 2016). In theory, SSG training could be an excellent training method to improve agility performance in athletes. Small sided games include sport specific stimuli, and the athlete must make decisions according to the stimuli, before COD. Due to this, research has started to investigate the effect of SSG on agility performance. (Chaalali et al. 2016, Chaouachi et al. 2014, Young & Rogers 2014.)

In their study, Young and Rogers (2014) found that SSG's, specifically planned for Australian rules football, produced significantly better results in an Australian rules football specific reactive agility test (RAT) test than COD training. Rules for the SSG games were modified so that they encouraged players to evade their opponent and to improve agility. They showed that the SSG group improved their total and decision time significantly more when compared to the COD group. (Young & Rogers 2014.) In another study, Chaouchi et al. (2014) showed that SSG improved RAT time more in U-15 football players than the COD sprint group. Interestingly, their study found that the COD sprint group improved linear sprinting speed and COD speed more than the SSG group as could be expected based on the specificity principle (Chaouachi et al. 2014).

The Chaalali et al. (2016) study demonstrated similar results to Chaouchi et al. (2014). In their study, the agility training group improved RAT, and RAT with ball, time more than the COD group. Similar to Chaouchi et al. (2014), Chaalali et al. (2016) showed that COD training improved linear sprint and COD speed more than the agility training group. This brings up the question of if a combination of SSG/agility training and COD speed training, could improve agility performance even more than just SSG/agility training. These two studies showed that SSG and COD training methods improve different aspects of physical performance, so in theory combining these two methods could improve RAT time and agility more than SSG/agility training alone. There is currently no research investigating this hypothesis, so further research is needed.

5.2.5 Agility training in adolescent populations

Although previous studies have highlighted the importance of agility in athletics, and the connection between agility performance and the skill level of the athlete, there is still limited research on how to improve agility during the developmental years (Lloyd et al. 2013, Lloyd & Oliver 2012). Lloyd and Oliver (2012) were the first, to this author's knowledge, to publish specific framework for the development of agility in children and adolescents. Interestingly, some of the long-term athletic developmental models do not even discuss the development of agility during athletic progression (Lloyd et al. 2013, R. Lloyd & Oliver 2012). Current research has shown that agility can be developed during the developmental years, and the new athletic development model has included agility as a foundation athletic skill (Lloyd & Oliver 2012).

There has been limited research on agility training in adolescent populations (Lloyd et al. 2013). Much of the research has concentrated on improving the physical and technical aspects of agility (Lloyd et al. 2013, Milanovic et al. 2014, Milanović et al. 2013, Jovanovic et al. 2011). Most of the research on how to improve cognitive skills has been completed in fields outside of sport. These findings can be applied to athletic training, but more research is needed to determine how to optimally improve agility during childhood and adolescent years. (Lloyd et al. 2013, Lloyd & Oliver 2012.) Lloyd et al. (2013) suggested in their review on agility training during childhood and adolescence, that there are three major components of agility training during this period of development that coaches should focus on improving. These components are fundamental movement skills, COD speed, and the reactive component of agility (Lloyd et al. 2013). Current research recommends that all components should be trained during each developmental stage, but the amount of time dedicated to each component differs according the age of the athlete (figure 3) (Lloyd & Oliver 2012, Lloyd et al. 2013).

Figure 3. Percentage of time dedicated to each component of agility during each developmental stage (Lloyd et al. 2013).

Lloyd et al. (2013) based the amount of time spend in each component of the agility development model on previous research. During the pre-pubertal phase, the majority of time is spent on fundamental movement skills. They proposed this is important, because previous studies have shown that improving fundamental movement skills is important for long-term athletic development and life-long physical activity (Lloyd et al. 2013). The amount of COD speed training is increased during the circumpubertal phase to teach adolescent athletes to accelerate, deaccelerate and reaccelerate rapidly in a controlled environment. It is also important to include fundamental movement skills and the reactive component of agility during this phase, because there is increased neural development during puberty. During the post-pubertal phase, the amount of the reactive component of agility is the greatest. This is due to the fact that more sport-specific stimulus is needed at this stage of development. Including more reactive training at this stage allows athlete to increase sport-specific movement practise. (Lloyd et al. 2013.)

6 PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

The purpose of this study was to investigate the effects of three different training interventions on agility performance in adolescent football players. Furthermore, the purpose was to compare the effects of maturation on agility performance, and to investigate the differences between faster and slower agility performers.

Research Question 1: Will a combination of AG and COD training improve RAT performance similar to AG or COD training alone in adolescent football players?

Hypothesis: Yes. Both Chaouchi et al. (2014) and Chaalali et al. (2016) found that SSG training was more advantageous in developing RAT when compared to COD training. Both groups also showed that COD training was more beneficial in improving COD speed when compared to SSG training (Chaouchi et al. 2014, Chaalali et al. 2016). This supports the fact that agility and COD are separate skills and different training methods are needed to improve these skills. If these training methods are combined, athletes should improve the cognitive, technical, and physical aspects of agility at the same time. This combination should improve the athletes' agility performance more than either of these methods separately.

Research Question 2: Does 6 weeks of agility, change of direction and combination training change the kinetics of an agility task in adolescent football players?

Hypothesis: Yes. Previous studies have shown that athletes who have better agility ability, produce greater braking and propulsive force during COD tests (Spiteri et al. 2013). Furthermore, it has been shown that faster athletes produce greater braking and propulsive impulses during COD tests (T-test and 505) and during agility tests (Spiteri et al. 2015). More recent studies also support these findings. Jones et al. (2017) found in their study that stronger and faster athletes produced greater vertical and horizontal ground reaction forces during a 180° COD task. Improving an athletes' agility improves the kinetics of an agility task. No studies were found that investigates the effects of training on kinetics of agility.

Research Question 3: Does maturation effect agility in adolescent football players?

Hypothesis: Yes. Adolescents vary greatly in timing and offset of maturation, which can lead to a large difference in body size and strength (Philippaerts et al. 2006). Previous studies have shown more mature athletes are stronger and faster than less mature athletes. During growth and development, both hormonal and neural development leads to improved strength and linear speed. (Viru et al. 1999.) Furthermore, strength and linear speed have been shown to be part of agility performance (Young, Dawson & Henry 2015). Therefore, more mature athletes performs better in agility tasks.

7 METHODS

7.1 Study design

The study was completed during the latter part of the teams' competitive season. The study included three one-day testing sessions. A familiarization session was carried out one week prior to the pre-intervention tests. The intervention lasted six (6) weeks, followed by a one-day post-intervention test (figure 4). The study was conducted according to the Declaration of Helsinki, and the study was fully approved by the Ethics Committee of the University of Jyväskylä. One group did not complete familiarisation session due to unexpected changes to the schedule.

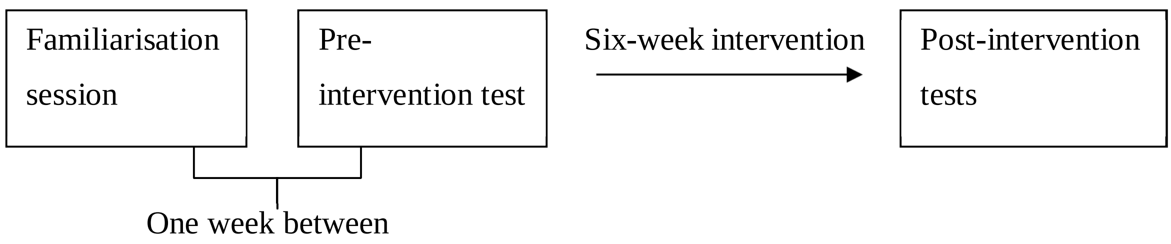


Figure 4. Design of the study.

7.2 Subjects

Three youth football teams from Central Finland were recruited to participate in the study. From these teams, 35 junior football players (age 13.6±0.5 years; body mass 53.7±6.1 kg; height 167.4±6.7 cm; maturation 0.24±0.53 years) volunteered to participate in the 6-week training study. There were no significant differences between the groups in age, height, weight or maturation. Teams were randomly assigned to one of the three training groups, where all players participated in the same training program; agility training (AG) group (n=17), change of direction (CODG) group (n=8), or combination (COMG) group (n=10). Five subjects withdrew from the study due to various reasons, so thirty subjects completed the whole study, AG (n=14), CODG (n=8), and COMG (n=8) (table 1). There were no significant differences between the groups in age, height, weight or maturation. Written informed consent was obtained from all the subjects and their guardians. Maturation of the subjects, i.e. years from maturity offset, was estimated by using the equation developed by Moore et al. (2015):

Maturation=-7.99994+(0.0036124*(age*height)).

Table 1. Age, height, and maturation of participants within each group, COD = change of direction, AG = agility, and COMG = combination group, attendance = percentage of training sessions attended.

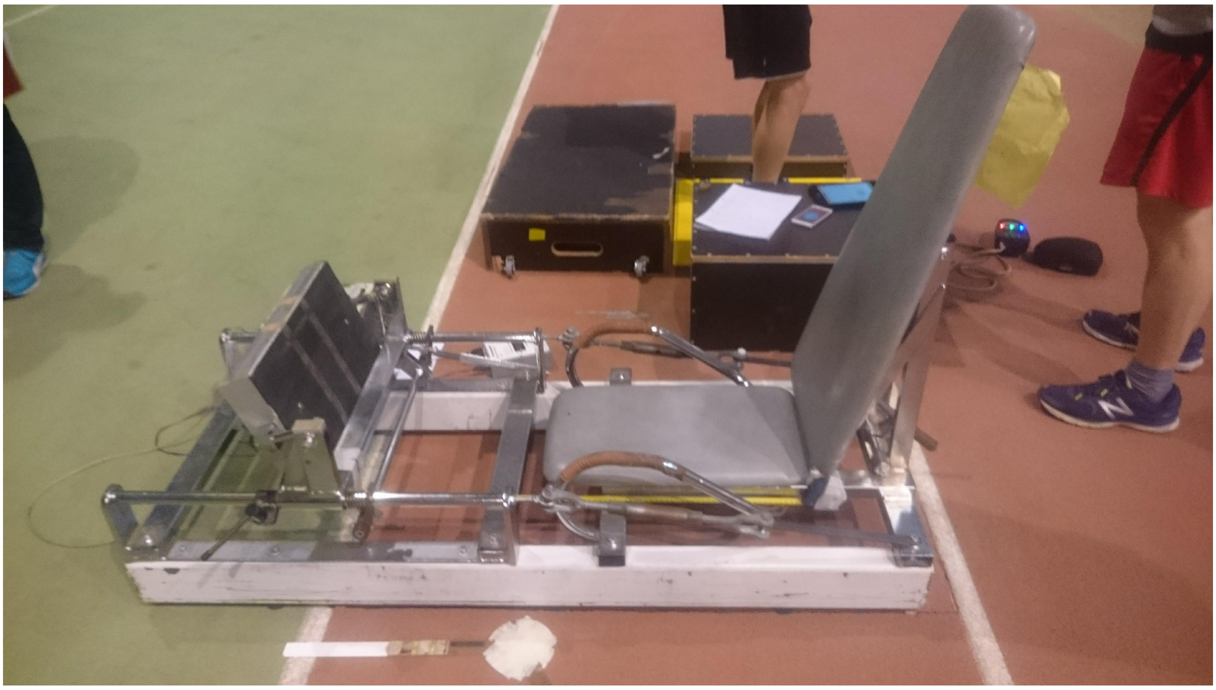
Group	Age	Height (cm)	Body mass (kg)	Maturation (years)	Attendance (%)
CODG (n=8)	13.4±0.7	164.4±7.7	51.6±6.8	-0.05±0.70	78
AG (n=14)	13.8±0.4	167.9±5.8	52.7±5.5	0.36±0.35	66
COMG (n=8)	13.8±0.5	170.3±6.4	57.3±5.1	0.46±0.53	44

7.3 Testing procedures

All tests were carried out in an indoor track and field facility. There were three testing sessions. The testing days for each team were always the same day of the week and same time of the day. Before starting the warm-up, height and weight were measured. Each testing session started with the same 10 minute dynamic warm up, which included running, skipping, lateral movements, squats and jumps (Appendix 1).

7.3.1 Isometric leg press

Leg strength was assessed using an isometric leg press (picture 1), which was purpose built at the University of Jyväskylä. The subject was instructed to sit firmly on the seat and was asked to place their feet on the edge of the force plate, to ensure the same foot placement was used during every testing session. The leg press was adjusted to a 120° knee angle (180° is equivalent to a full knee extension) (Marcora & Miller 2000). Subjects were instructed to push as hard as possible for three seconds, and the peak value was recorded in Newtons. Subjects performed one warm-up test, and two actual measurements. The best result from the two attempts was used to analyse the data. Relative strength was calculated by dividing subject's best result with subject's body weight.



Picture 1. Isometric leg press used.

7.3.2 Reactive strength index

The subjects' ability to absorb and produce force quickly, was measured using a reactive strength test. During the test, the subjects performed two drop jumps from different heights (10-50cm) to determine their optimal drop height (picture 2). A contact mat, Smartjump (Fusion Sport, Brisbane, Australia), was used to measure contact time, jump height and reactive strength index (RSI). The formula to calculate RSI was: RSI=jump height (m)/contact time (s) (Flanagan & Comyns 2008). Previous research has showed that RSI is a reliable and valid measurement of reactive strength in athletes (Markwick et al. 2015).The test ended when the reactive strength index was lower than from the previous drop height.

The subjects were instructed to hold their hands on their hip, step off the box, and "jump as high as they could and as fast as they could". If contact time was longer than 250ms (Flanagan & Comyns 2008), the attempt was considered to be failed and the athlete was asked to try again at the same height. If the contact time for the second attempt was still longer than 250ms, the test was ended. The result used to analyse the data was highest RSI from the highest drop height when contact time was less than 250ms.

Picture 2. Set up for reactive strength index test.

7.3.3 20m sprint

Each participant performed three 20m full speed sprints (picture 3). Sprints were measured with Smartspeed timing gates (Fusion Sport, Brisbane, Australia). The timing gates were set up 20m apart and 0.6m above the ground. The subjects started the test with three warm-up sprints at 70, 80 and 90% of their max speed, with a walk back rest between warm-ups. After the three warm-up sprints, subjects were instructed to perform three all out sprints. The participants started behind the first gate and were instructed to run as fast as possible for 20m. There was a two-minute rest between the attempts. The fastest time was used to analyse the data.

Picture 3. Set up for the 20m sprint test.

7.3.4 Change of direction Y-test

The subjects' change of direction ability was measured using a Y-test (figure 4). The total time was measured using beam sensors (Sunx ltd, Japan). The starting gate was placed 5m behind the change of direction spot. The spot where subjects were instructed to perform the change of direction was marked by a force plate (AMTI, Massachusetts, USA) sampling at 1000Hz. The force plate was used to collect ground reaction forces, contact time, and impulse. The finish gates were placed 5m from the force plate at a 45º angle. (Lockie et al. 2014.)

The subjects were instructed to sprint as fast as they could forward and perform a quick change of direction on top of the force plate, and finish sprinting through the timing gate. The subjects were informed which direction they should run before each attempt. Subjects performed one warm-up run for each direction, followed by two trials to each direction. The fastest time for each direction was used for analysing the data.

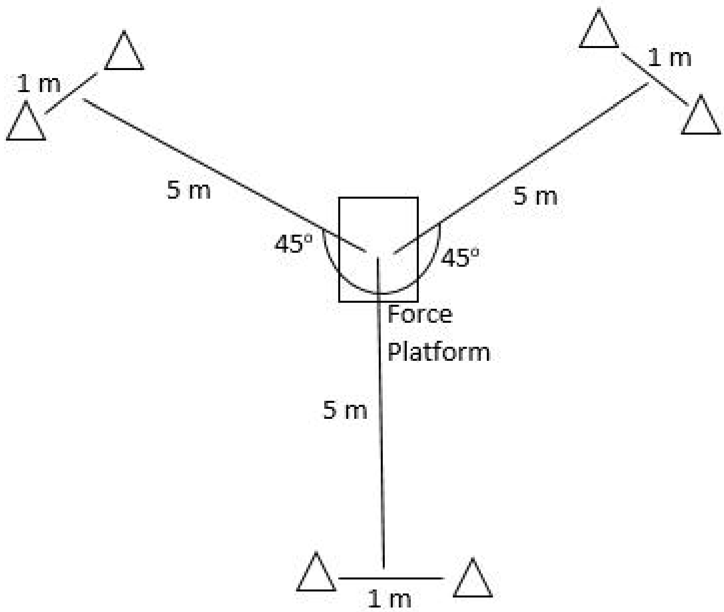


Figure 4. Set up for the change of direction Y-test.

7.3.5 Reactive agility test

The subjects' agility performance was measured using a RAT (Young et al. 2011, Henry et al. 2011). The set up for the RAT test can be seen in Figure 5. The subject started 30cm behind the first timing gates (Panasonic SUNX beam sensor VF2-RM5, Japan). When the subject crossed the first timing gate, a video started on the computer (ASUS E403S, Taiwan), which was projected on to a screen with a projector (Viewsonic, California, USA). On the video, there was one attacker (subject's teammate) and a defender (opponent). At the start of the video, the attacker was standing in front of the defender. The attacker started to move either to the right or left depending on the video, and the defender followed him. On the video, the attacker received the ball and passed it into the free space, where the subject was supposed to run. Trials were timed using a Digitest 2000 watch (Muurame, Finland), which was connected to the timing gates. All attempts were recorded using a video camera (Sony Handycam HD, 50 fps, Japan). Ground reaction forces, contact time and impulses were collected using force platforms (AMTI, Massachusetts, USA) sampling at 1000Hz at the point where the athletes changed direction (Spiteri, Hart & Nimphius 2014). Force platform data was analysed using Signal 4.10 software (Cambridge Electronic Desing Ltd, Cambridge, UK).

Subjects were instructed to run as fast as they could through the timing gate either on the right or left, depending which side attacker on the video plays the ball. If the subject realised they made the wrong decision, they were instructed to correct if possible. Before starting the test, the subjects performed four practise trials. After four practise trials, the subjects performed eight test trials, four to the right and four to the left. During the test and practice, trial videos played in randomised, predetermined order. There was a 30s break between test trials. The number of correct and incorrect decisions were collected during the test. The average of all eight tests and fastest time to left and right, was used to analyse the data.

From the videos recorded during each agility test, decision making time and movement time were analysed using Dartfish software (Dartfish 9 Team pro, Fribourg Switzerland). Decision making was the time from the first frame of the video until the first foot strike that initiates change of direction movement. Movement time was the time from the initiation of change of direction until the subject ran through the timing gates. (Spiteri, Newton & Nimphius 2015.)

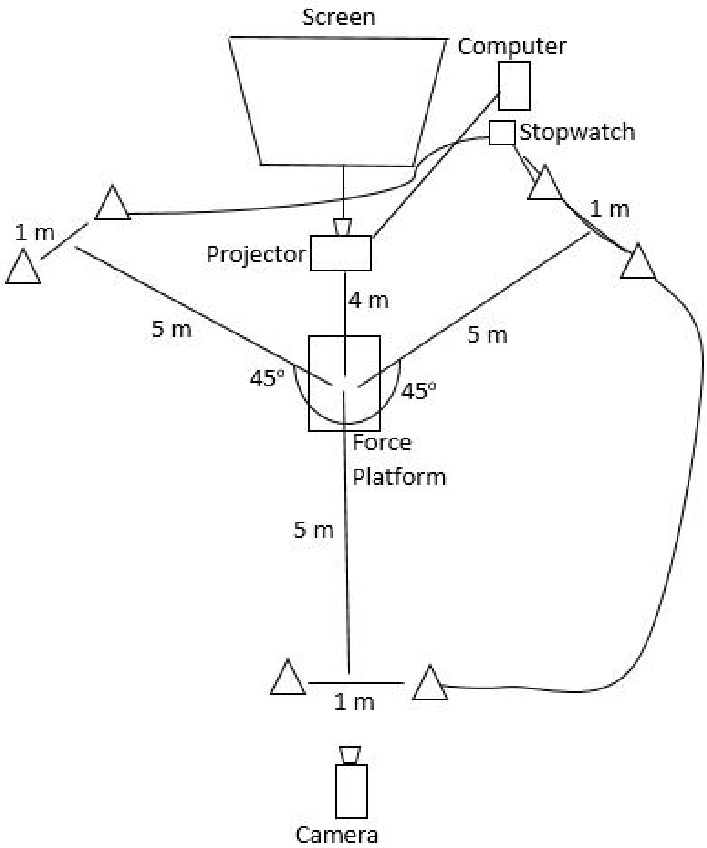


Figure 5. Testing set up for the reactive agility test.

7.4 Training programs

Each group trained twice a week (appendix 3-5). Each program was divided into three two-week blocks. The first block was a low intensity and higher volume training program, and the exercises were simple. Complexity and intensity were progressively increased in all blocks, and volume was reduced as intensity and complexity increased. The first training of each week was planned to improve horizontal and vertical movement. The second training program was designed to improve lateral movements. The intervention was scheduled to start 30 minutes before the teams' football training session. All the training groups performed the same 10-minute dynamic warm up (appendix 2) followed by the 20 minute intervention program.

After the warm up, the COD group performed plyometric exercises. During the first two weeks, the plyometric exercises included exercises to improve the subjects' landing mechanics and force absorption. Each training session included unilateral and bilateral plyometric exercises. During the first training session of the week, the subjects performed linear sprinting and change of direction exercises after finishing the plyometric exercises. On the second day, the subjects' performed lateral shuffle and lateral change of direction exercises. (Appendix 3.)

The agility-training group also performed two training sessions each week. Similar to the COD group, the first day of the week was aimed at improving horizontal movement, and the second day to improve lateral movement. During the training sessions, all exercises included a reaction to stimulus from one to three opponents. The subject had to react according to the movement of the other subject, either by moving in the same or opposite direction, depending on the drill. (Appendix 4.)

The training for COMG group included half of the daily volume of AG and COD training. Each training started with plyometric exercises, followed by speed and COD exercises. The sessions finished with agility exercises. (Appendix 5.)

7.5 Statistical analysis

Data is presented as mean±SD. The data was analysed using SPSS software. As three separate groups were included in the study, the post hoc two-way analysis of variance (ANOVA) was used to analyse differences between the groups. A paired samples t-test was used to analyse the differences between pre- and post-intervention results within the groups.

To compare the effects of maturation on performance, the subjects were divided into two groups, based on their pre-test maturation. The older group consisted of subjects whose maturation was greater than the median, and the younger group consisted of subjects whose maturation was less than the median (Spiteri, Newton & Nimphius 2015). An independent-samples T-test and a Pearson correlation test were used to compare the groups.

In order to analyse possible differences between faster and slower subjects based on agility performance, the subjects were divided into a faster and slower group, the same way as with maturation, based on their pre-intervention agility time. The faster subjects were those whose agility time was faster than the median, and slower subjects were those whose agility time was slower than the median (Spiteri, Newton & Nimphius 2015). An independent-samples T-test and a Pearson correlation test were used to compare groups.

8 RESULTS

8.1 Physical tests

Isometric leg press results have been presented in table 2. The agility group had a significantly higher maximum isometric leg strength compared to the other two groups in pre-test ($p=0.019$). Both COMG and CODG group improved the isometric leg press significantly in the post-test, when compared to pre-test results ($p<0.01$). Only the agility group significantly decreased isometric leg strength during the intervention ($p<0.01$). There were no significant difference between the groups in post-test results.

Reactive Strength Index results are presented in table 2. There was significant improvement in contact time and optimal drop height in the agility group ($p<0.01$). The CODG group also had significant improvement in contact time and optimal drop height, $p=0.04$ and $p<0.01$ respectively. No other significant differences were found. All groups improved their test results during the intervention, but there was no significant difference between the groups in post-test scores.

20m sprint results are presented in table 2. Only the AG group improved 20m sprint time significantly between pre and post measurements. No other significant differences within the groups were found. There were no significant differences between the groups.

Change of direction test results are presented in table 2. There were no significant differences between the groups in any measurements. Only the agility group significantly improved both COD left and right tests. No significant differences were found in either the CODG or COMG groups.

Table 2. Isometric leg press, 20m sprint, change of direction (COD) tests and reactive strength index (RSI) test results, and maturation in each group pre- and post-measurement. Data is presented as mean±SD. Maturation is presented in years from the offset of puberty. AG = agility group, CODG = change of direction group, COMG = combination group, R=right, L=left.

	AG		CODG		COMG	
	Pre	Post	Pre	Post	Pre	Post
Isom LP (N)	4690±965†	3896±881*	3284±1059†	3957±1239*	4090±841†	4563±734*
20m sprint (s)	3.48±0.16	3.40±0.15*	3.32±0.15	3.40±0.16	3.32±0.21	3.35±0.17
COD R (s)	2.12±0.07	2.05±0.08*	2.12±0.10	2.06±0.09	2.16±0.12	2.09±0.09
COD L (s)	2.15±0.11	2.08±0.09*	2.07±0.07	2.04±0.09	2.19±0.14	2.07±0.10
RSI	1.7±0.3	1.8±0.4	1.3±0.3	1.5±0.4	1.6±0.3	1.8±0.4
Contact Time (s)	172.2±32.6	150.9±24.7*	182.4±20.1	165.9±14.0*	168.0±15.2	158.4±17.3
Optimal Drop Height (cm)	16.4±6.3	27.9±11.2*	13.8±5.2	30.0±10.7*	25.0±5.3	27.5±8.9
Maturation (years)	0.36±0.35	0.35±0.35	-0.05±0.71	0.03±0.76	0.46±0.53	0.50±0.50

* indicates a significant difference within the group between pre- and post-measurements ($p<0.05$). † indicates a significant difference between the groups ($p<0.05$).

Agility test results can be seen in figure 6 and 7. Only the CODG group significantly improved mean agility time between pre and post measurements, 2.34±0.09s and 2.26±0.06s respectively ($p<0.05$). The only group that significantly improved their fastest agility times to the right between pre and post measurements was the AG group, 2.18±0.11s and 2.12±0.09s respectively ($p<0.05$). Both the AG (2.22±0.12s, 2.15±0.12s) and CODG (2.29±0.11s, 2.15±0.10s) groups significantly improved fastest agility time to the left. There were no significant differences between the groups.

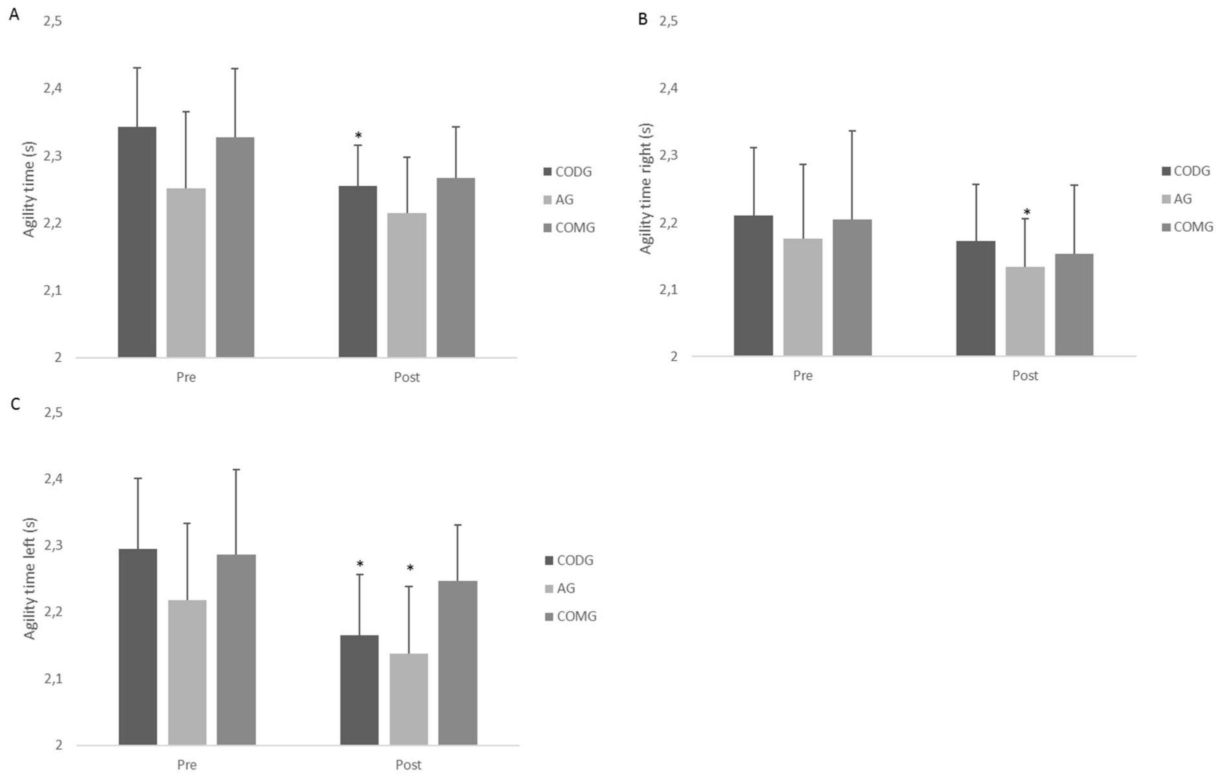


Figure 6. Results from the agility test. A) Mean time from all agility trials, B) mean of the fastest agility time to the right, C) mean of the fastest agility time to the left. CODG = change of direction group, AG = agility group, and COMG = combination group. * significant difference with-in the group between pre and post measurements (p<0.05).

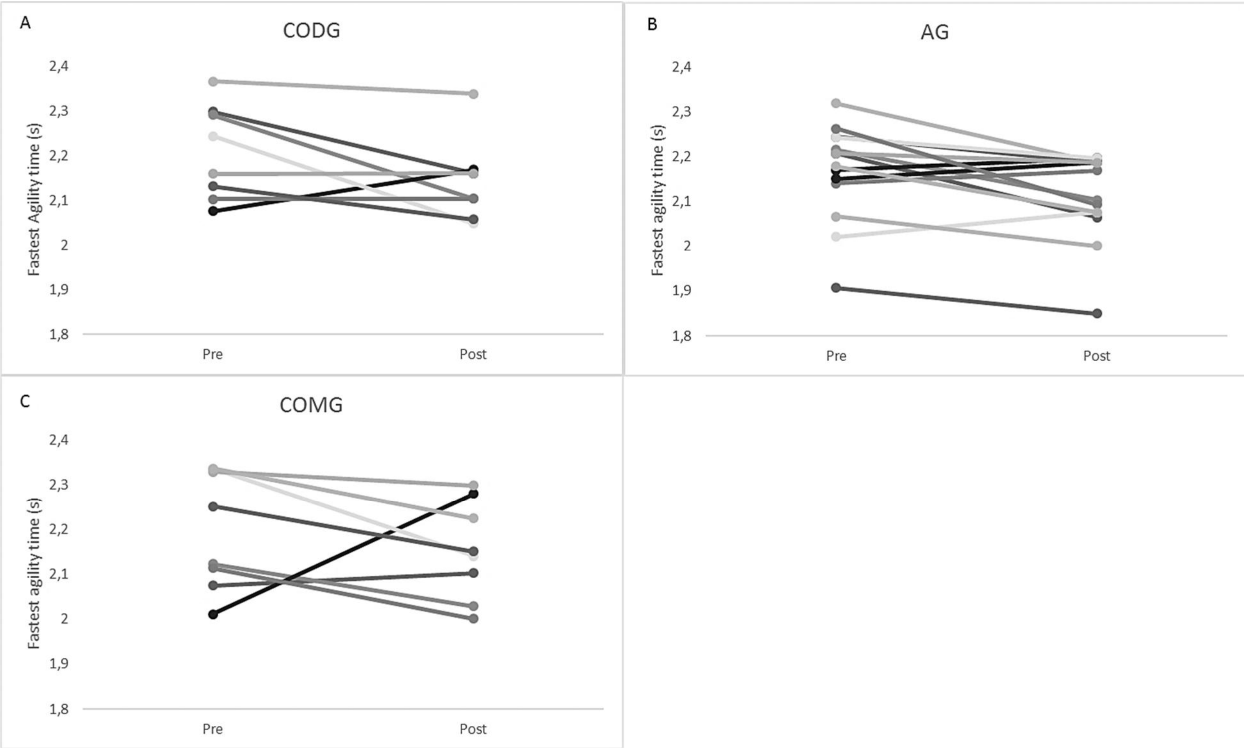


Figure 7. Individual development of fastest agility time between pre- and post-measurements in each group. CODG = change of direction group, AG = agility group, and COMG = combination group.

Maturation data are presented in table 2. There were no significant differences with-in the group between pre- and post-measurements. Although there was a difference between the groups, this difference was not statistically significant.

8.2 Kinetics

In the COD test performed to the left, the AG and COMG groups had significantly greater vertical impulse during the COD left test than the CODG group, 981±133N·s, 940±157N·s and 815±122N·s respectively (p=0.04) in pre-test. The AG group also had significantly greater braking impulse than the COMG and CODG groups, 383±145N·s, 272±109N·s and 201±90N·s (p<0.01), respectively. No other between group differences between the groups were found. In the COD test performed to the right, the COMG group significantly increased the total propulsive impulse from pre-measurement to post-measurement, 377±104N·s and 490±73N·s (p=0.02), respectively. The COMG group also had significantly greater braking impulse in post-measurements (326±109N·s) than in pre-measurements (189±24N·s) p=0.01. No other significant differences were found.

Agility test results have been presented in figure 8. When comparing impulses produced during the agility test, the AG group significantly increased total propulsive impulse in the agility test to the right between pre- and post-measurements, 363±88N·s and 416±91N·s (p=0.03), respectively. CODG significantly decreased braking time between pre- and post-measurements, 0.11±0.01s and 0.10±0.01s (p=0.048), respectively, when the mean of all agility tests were considered. In the agility test performed to the left, CODG also significantly decreased braking time, 0.11±0.01s and 0.09±0.01s (p=0.027), respectively, and propulsive time, 0.10±0.02s and 0.11±0.02s (p=0.028), respectively. In the agility tests performed to the right, the AG group significantly decreased contact time between pre- and post-measurements, 0.17±0.03s and 0.20±0.03s (p<0.01), respectively. The COMG group significantly decreased braking time between pre- and post-measurements, 0.12±0.01s and 0.11±0.01s (p=0.04), respectively, when the agility test was performed to the right. No other significant differences within the groups were found.

In the agility test, AG had significantly faster contact time (p=0.03) and propulsive time (p>0.01) than the CODG and COMG groups in the pre-test. Post-test, the AG group had significantly faster propulsive time (p=0.03) than the CODG and COMG groups. In the agility test performed to the right, the AG group had significantly faster contact time (p<0.01), braking time (p=0.02), and propulsive time (p<0.01) than the CODG and COMG groups in the pre-test. When the agility test was performed to the left, the AG group had significantly faster contact time (p=0.03) than the CODG and COMG groups in the post-intervention test. The COMG group had significantly longer braking time (p=0.03) than the AG and CODG groups, and the CODG group had significantly longer propulsive time (p=0.03) than the AG and COMG groups in the post-intervention test. No other significant differences were found between the groups. (Figure 8.)

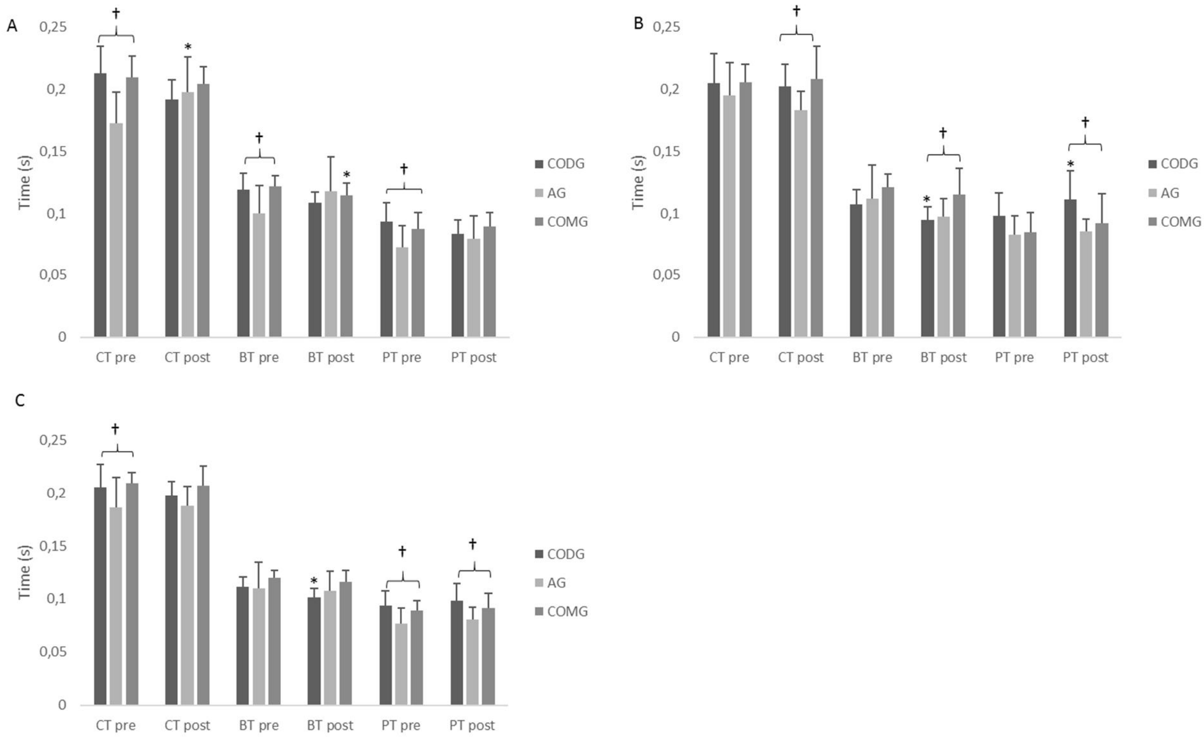


Figure 8. Contact time, braking time, and propulsive time from the agility tests. A) agility test performed to the right, B) agility test performed to the left, and C) mean of all agility tests. CODG = change of direction group, AG = agility group, and COMG = combination group, CT = contact time, BT = braking time, PT = propulsive time. * indicates significant difference within the group between pre- and post-measurements. † indicates significant difference between the groups.

8.3 Video

The AG group had significantly faster decision making times during the pre-test when compared to CODG and COMG groups, 0.89±0.09s, 0.98±0.08s and 0.97±0.07s (p=0.043), respectively. Only the COMG group significantly improved their decision making time between the pre- and post-tests, 0.98±0.08s and 0.89±0.04s (p=0.01), respectively. (Figure 9.) No other significant differences were found.

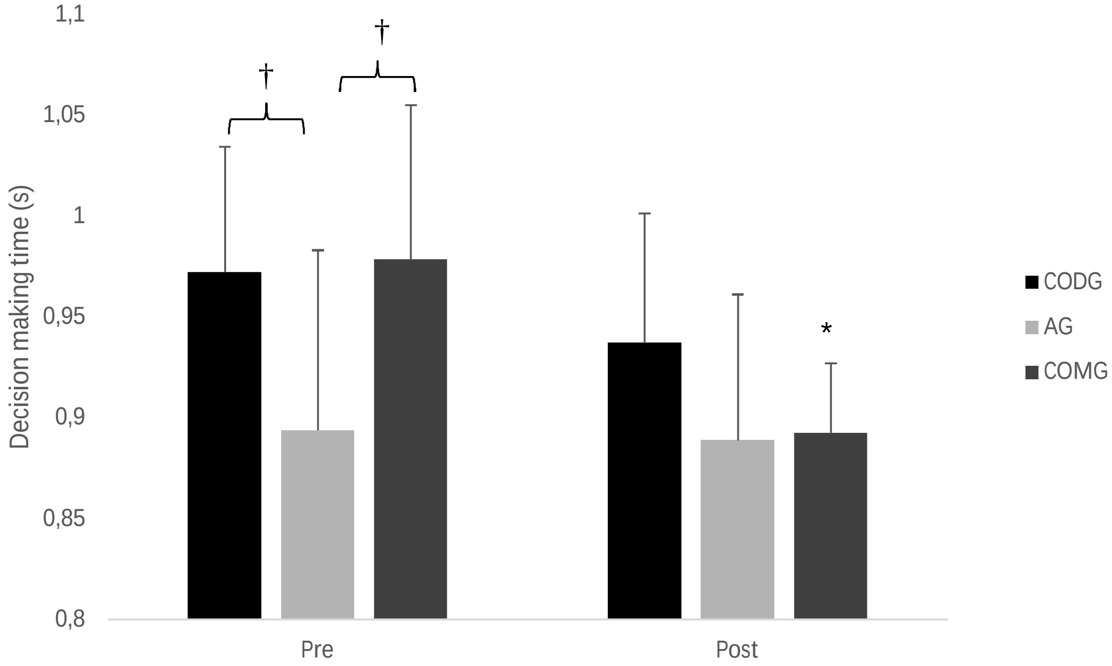


Figure 9. Decision making time from the agility test in pre- and post-measurements. CODG= change of direction group, AG= agility group, and COMG= combination group. * Significant difference within the group ($p<0.05$). † Significant difference between the groups ($p<0.05$).

8.4 Maturation and agility

There was a trend towards older subjects performing better in the isometric leg press, COD test right and left, agility test, and in RSI. The only significant difference between the older and younger subjects was 20m sprint, 3.33±0.17s and 3.47±0.18s, respectively. The differences in kinetic variables during the agility test can be seen in table 3. The older subjects had significantly greater total propulsive impulse and braking impulse during agility to the right compared to younger subjects.

Table 3. Kinetic variables during agility and COD test older and younger group based on their biological age. Data is presented in mean±SD. COD = change of direction, R = right, L = left.

	Older	Younger
Total propulsive impulse agility (N·s)	405±39*	372±47*
Braking impulse agility R (N·s)	201±66*	183±90*
Total propulsive impulse COD R (N·s)	451±73*	386±75*
Total propulsive impulse COD L (N·s)	477±91*	388±136*
Vertical Impulse COD L (N·s)	986±147*	852±120*

* indicates a significant difference between the groups ($p<0.05$).

During the COD test, the older subjects produced significantly greater total propulsive force to the right, and during COD left. The older subjects also produced significantly greater vertical impulse during the COD test to the left than the younger subjects. (Table 3.) No other significant differences between the groups were found.

8.5 Faster and slower agility

When the subjects were divided into faster and slower groups based on their pre-measurement agility time, the faster subjects had significantly greater isometric leg strength than the slower subjects, 4660±956N and 3713±1046N ($p=0.016$), respectively, and relative leg strength, 8.8±1.7 and 7.1±1.6 ($p<0.01$), respectively. The faster subjects also had significantly better RSI than the slower subjects, 1.7±0.3 and 1.4±0.3 ($p<0.01$), respectively, and jump height, 28.3±4.3cm and 24.3±3.1cm ($p<0.01$), respectively.

The faster subjects also had a significantly faster braking time during agility than the slower athletes, 0.11±0.02s and 0.12±0.02s ($p=0.03$), respectively. Movement time during agility was also significantly faster in faster subjects than in slower subjects, 1.32±0.07s and 1.40±0.07s ($p=0.01$), respectively. Decision making time was significantly better in the faster subjects compared to the slower subjects, 0.88±0.09s and 0.99±0.06s ($p<0.01$), respectively. No other significant differences were found.

8.6 Associations between variables

All significant correlations can be found in tables 4-6. Maturation had a positive, moderate, significant correlation with isometric leg press ($r=0.543$, $p=0.005$), and a negative, moderate correlation with 20m sprint ($r=-0.436$, $p=0.02$). Maturation also had a significant negative, moderate correlation with mean agility time ($r=-0.439$, $p=0.023$). (Table 4.) Mean agility time had a strong, moderate, negative correlation with maximum and relative isometric leg press, $p<0.001$ for both (table 4).

Mean agility time had a strong, significant correlation with agility decision making and movement time. Mean agility time also had a strong and moderate, negative correlation with jump height and RSI. (Table 5.)

In younger subjects, agility time had a strong significant correlation with agility decision making time ($r= 0.811$, $p<0.01$). Agility time also had a strong significant negative correlation relative to leg press ($r= -0.577$, $P<0.05$), and jump height ($r= -0.554$, $p<0.05$). The older subjects had a strong significant correlation between agility time and agility decision making time ($r= 0.809$, $p<0.01$), agility movement time ($r= 0.669$, $p<0.05$), and vertical impulse during agility test ($r= 0.518$, $p<0.05$). In the same group, there was a strong significant, negative, correlation between agility time and isometric leg press ($r= -0.687$, $p<0.01$), jump height ($r= -0.633$, $p<0.01$), and relative leg press ($r= -0.547$, $p<0.05$).

Table 4. Correlations of maturation, isometric and relative leg press, 20m sprint and agility time.

	Maturation	Isometric leg press	20m sprint	Mean agility time	Relative leg press
Maturation	1	0.543**	-0.436*	-0.439*	0.339
Isometric leg press	0.543**	1	-0.193	-0.570**	0.904**
20m sprint	-0.436*	-0.193	1	-0.316	0.008
Mean agility time	-0.439*	-0.438*	0.316	1	-0.571**
Relative leg press	0.339	0.904**	0.008	-0.571**	1

* Correlation is significant p<0.05. ** Correlation is significant p<0.01.

Table 5. Correlations between mean agility time, agility movement and decision making time, reactive strength index, and jump height. RSI= reactive strength index. MT = movement time, DT = decision making time.

	Mean agility	Agility MT	Agility DT	RSI	Jump Height
Mean agility	1	0.603**	0.781**	-0.465**	-0.610**
Agility MT	0.603**	1	0.008	-0.179	-0.231
Agility DT	0.781**	0.008	1	-0.434*	-0.524**
RSI	-0.465**	-0.179	-0.434*	1	0.663**
Jump height	-0.610**	-0.231	-0.524**	0.663**	1

* Correlation is significant p<0.05. ** Correlation is significant p<0.01.

The faster subjects had a strong, significant correlation between mean agility time and agility decision making time (r=0.667, p<0.01), agility contact time (r=0.544, p=0.04), and jump height (r=-0.667, p=0.02). The slower subjects had a strong, significant correlation between mean agility time and agility decision making time (r=0.525, p=0.04). The slower subjects also had a strong significant, but negative, correlation between mean agility time and maturation (r=-0.504, p=0.046). (Table 6.)

Table 6. Correlations between mean agility time, agility decision making time, maturation, agility contact time, and jump height when athletes are divided into faster and slower groups according to pre-test results. DT = decision making time, CT = contact time.

		Mean agility	Agility DT	Maturation	Agility CT	Jump height
Faster (n=14)	Mean agility	1	0.667**	-0.171	0.544*	-0.667**
	Agility DT	0.667**	1	0.255	0.709**	-0.493
	Maturation	-0.171	0.255	1	0.255	0.046
	Agility CT	0.544*	0.709**	0.255	1	-0.319
	Jump height	-0.667**	-0.493	0.046	-0.319	1
Slower (n=16)	Mean agility	1	0.525*	-0.504*	-0.206	-0.071
	Agility DT	0.525*	1	-0.170	0.323	-0.031
	Maturation	-0.504*	-0.170	1	0.458	0.542*
	Agility CT	-0.206	0.323	0.458	1	0.131
	Jump Height	-0.071	-0.031	0.542*	0.131	1

* Correlation is significant p<0.05. ** Correlation is significant p<0.01.

9 DISCUSSION

Main findings of the study was that only the CODG group significantly improved mean agility time, and the AG and CODG groups improved fastest agility times during the intervention (figure 6). Furthermore, there was a great variety in individual response to training intervention (figure 7). Both the CODG and AG groups improved contact time and optimal drop height during RSI test. The subjects were able to produce greater impulse during ground contact because the contact time was shorter and the drop height higher. Improved impulse shows improved ability to absorb force and utilize elastic energy stored in the tendon during eccentric contraction. Because contact times during the agility task were around 200ms (figure 8), agility could be considered as a fast SSC activity. Previous literature has defined fast SSC as activities which have contact time less than 250ms (Markwick et al. 2015, Flanagan & Comyns 2008). This improved fast SSC can explain improvements in agility time in both AG and CODG groups.

9.1 Effects of interventions on agility, kinetics and cognitive performance

Another finding was that during the agility test, the AG group showed significantly faster propulsive time and contact time compared to the CODG and COMG groups. The AG group also showed significantly faster braking time, and propulsive time during the agility left test. (Figure 8.) The subjects in the AG group were better able to utilize stored elastic energy that was stored in the tendon during the eccentric phase. Since there were no differences in braking and total propulsive impulses between groups, subjects in the AG group produced more force during a shorter contact time. This finding suggests that athletes in the AG group were better able to utilize elastic energy during the agility test. This shorter braking time and contact time has been shown to improve the ability to store elastic energy in the tendon (Spiteri et al. 2015). Previous research has shown that faster sprinters can utilize elastic energy better than slower athletes (Spiteri et al. 2015). It has been shown that faster athletes in COD and agility tasks can produce greater impulse (Spiteri et al. 2015) and maintain higher velocity during a COD task (Wheeler & Sayers 2010). Wheeler & Sayer (2010) showed in their study that one important factor in faster COD and agility performance was the ability to maintain velocity throughout the change of direction task. Having shorter braking time could mean higher velocity, because there is smaller deceleration, during the change of direction task in the AG group. Less deceleration allowed subjects in the AG group to maintain their velocity and have a higher exit velocity, therefore showing better agility performance than in the other groups (Spiteri et al. 2015, Wheeler & Sayers 2010). Even though there was no significant difference between the groups in agility performance, there was a trend towards the AG group performing better in the agility test. Exit velocity was not measured during this study, which means more studies need to be conducted to confirm this finding.

Agility had a moderate, negative correlation with RSI and jump height from the optimal drop height during the RSI test. The results also showed that agility had a strong, negative correlation with relative leg press and a moderate, negative correlation with maximum isometric leg press. These finding suggests that strength has a role in agility. This finding is in contrast with previous research (Young, Miller & Talpey 2015, Spiteri et al. 2014). In their study Young et al. (2015) found that agility did not correlate with relative or reactive strength. They also showed that COD speed had a strong, negative correlation with reactive strength. Spiteri et al. (2014) also found that there was no correlation between agility and strength measurements (dynamic, eccentric, concentric and isometric), but found a strong, negative correlation between strength measurements and COD ability. The differences between these studies can be partly explained by the subject groups. The Young et al. (2015) study investigated male Australian Rules football players and Spiteri et al. (2014) investigated female basketball players, whereas the current study investigated adolescent football players. It has been showed that maturation influences physical qualities in an adolescent population (Malina et al. 2015). This difference in physical qualities is due to development of neural and muscular systems (Viru et al. 1999). The wide range of maturity in the present study could explain the importance of strength qualities in agility performance.

Although there were faster contact times in the AG group, there were no significant differences between the groups in forces produced during agility and COD in the pre- or post-tests. As there were no significant differences between the impulses produced, the athletes were able to produce more force in a shorter time, which could have led to faster agility time. Even though there were no significant differences between the groups in agility time, there was a trend towards faster time in the AG group during the agility test. Previous studies have shown importance of braking time and contact time in agility performance (Spiteri et al. 2015). Greater braking impulse was shown to increase exit velocity, by enhancing elastic energy storage and utilization in active muscles and tendons (Spiteri et al. 2013, Spiteri et al. 2015).

9.2 Effect of biological age on agility

When the athletes were divided according to their biological age into young and old age groups, the results showed a significant difference in the 20m sprint and a trend towards older athletes performing better in the COD test, leg press, and RSI. Previous research has shown maturation to have an influence on sprinting, explosive power, and COD performance in adolescent athletes (Lloyd et al. 2014). Mendez-Villanueva et al. (2011) found that high speed running is highly related to biological maturation, particularly due to muscular development that occurs throughout maturation. Around the APHV, hormonal production increases in adolescents. This leads to an increase in muscle mass. This improved muscle mass increases strength, which improves sprinting ability and COD performance. (Lloyd et al. 2013, Lloyd & Oliver 2012.) Previous research has also shown the importance of reactive strength on change of direction performance (Young, James & Montgomery 2002). Young and Montgomery (2002) showed a moderate, negative correlation between reactive strength and change of direction performance. This finding is supported by Spiteri et al. (2015) who found that the ability to apply more force and greater impulse led to improved change of direction performance. Comfort et al. (2014) showed increased relative strength to be an important factor in 20m sprint performance. As a result of increased strength during maturation, older athletes performed better in physical tests.

Older athletes were able to produce a greater total propulsive impulse during the agility task and during both COD left and right. This could explain the trend towards older subjects performing better in agility and COD tests. Previous literature has highlighted the importance of greater total propulsive impulse in agility and COD (Spiteri, Newton & Nimphius 2015). In their study, faster athletes also had a significantly greater relative peak force and rate of force development than slower athletes. The greater relative peak force and rate force development resulted in faster muscle activation and increased muscle activity before heel strike. The authors suggested that this pre-activation improves braking and propulsive impulse, which leads to faster agility time. (Spiteri, Newton & Nimphius 2015.) This finding supports the notion that a greater total propulsive impulse in older subjects explains the trend towards a faster agility time.

9.3 Differences between fast and slow agility performance

Faster athletes produced a significantly greater relative and maximum leg press, RSI, and jump height. This significantly greater strength could result in a greater ability to control the body during agility and COD tasks. Spiteri et al. (2015) showed that isometric strength was an important factor in agility performance. This improved isometric strength allows athlete to maintain their athletic position during an agility task. The ability to maintain an athletic position allows the athlete to extend their hip, knee and ankle, and produce greater propulsive force when changing direction. They also found that athletes who performed better in agility tests had greater muscle mass and lower body mass, i.e. better functional mass. Having a greater non-functional body mass slows the athlete down during agility and change of direction tasks. (Spiteri et al. 2015.) In the current study, stronger athletes were able to produce more force relative to body weight during the agility test and this allowed them to perform better in the test. This finding is supported by another finding of the study, which showed a strong, negative correlation between agility time and maturation in slower subjects. This finding suggests that as athletes mature, agility improves. During puberty, athletes become stronger due to maturation and this improves their agility (Comfort et al. 2014).

When comparing all athletes as one group, the results showed a significant negative, moderate correlation between agility, and maximum and relative leg press. When athletes, however, were divided into faster and slower athletes based on their time in the pre-intervention agility test, the faster athletes showed a significant correlation between agility time and decision making time, not between strength and agility. This shows the importance of strength in agility performance, when comparing all athletes together. The results from this study show that when an athlete has reached a certain level in agility performance, strength might not play an important role in agility performance anymore. After reaching a higher agility level, the ability to react to stimuli influence agility performance more than strength. Previous research has found conflicting evidence to the current research. In their study, Young et al. (2015) found no correlation between strength measurements and defensive agility performance in Australian Rules football players. The subjects in their study were adult community level players. As this study investigated adolescent football players, and Young et al. (2015) investigated adult players, this might explain the conflicting results. A wide range in biological age between the subjects in the current study might explain the moderate negative correlation between leg strength and agility performance. Future studies should further investigate the effect of strength on agility performance in adolescent athletes.

In faster athletes, contact time during agility had a strong correlation with agility time. Even though RSI did not correlate with agility in faster athletes, these findings suggest that athletes who possess greater reactive strength perform better in the agility test. Athletes who have better reactive strength are better able to store and utilize elastic energy in tendons during the eccentric (braking) phase of an agility task (Spiteri et al. 2013, Spiteri et al. 2015). This improved storage of elastic energy is due to the faster activation of the neuromuscular system and pre-activation of muscles. This allows the athlete to produce more force faster when compared to an athlete with lesser reactive strength. Greater impulse during the eccentric phase increases the athlete's exit velocity. (Spiteri et al. 2015.) Having a greater exit velocity has been shown to be an important factor in change of direction and agility performance (Wheeler & Sayers 2010). In this study, athletes with faster agility time produced significantly faster braking time, with no differences between propulsive impulses, meaning the athletes were able to produce more force in a shorter time. When braking time is too long, stored elastic energy is lost as heat, and not transferred into concentric energy (Spiteri et al. 2013).

The faster subjects showed a strong association between agility time and decision making time. Faster athletes had significantly faster decision making time when compared to slower athletes. This high association, combined with significantly faster decision making time, means that faster athletes are better at anticipating an opponent's movement. Having better anticipation skills provides faster athletes with more time to "plan" their movement compared to slower athletes (Spiteri et al. 2015). This leads to faster overall agility time. Having faster decision making time allows the athlete to utilize pre-activation of the neuromuscular system to enhance agility performance (Spiteri et al. 2015). This improved pre-activation increases leg stiffness and prepares the lower body for ground contact. A stiffer leg has been shown to be better at storing elastic energy during the eccentric phase, which improves force production during the concentric phase. (Spiteri et al. 2015.) This finding suggests the importance of agility training to improve an athlete's ability to read and react to relevant cues.

Both slow and fast subjects produced a strong association between agility decision making time and agility time. As discussed earlier, reaction to stimulus is an important aspect of agility performance, and the findings from this study suggest that decision making time plays an important role in agility regardless of agility level.

9.4 Strengths and limitations of the study

This study has several strengths and weaknesses. This was the first study, to this author's knowledge, to study the effects of maturation and puberty on agility in adolescent football players. Previous studies have investigated the effects of different training interventions on agility in adolescent football players, without reporting the biological age of the subjects (Chaalali et al. 2016, Chaouachi et al. 2014, Trecroci et al. 2016). This was also the first study, to this author's knowledge, to investigate the differences between faster and slower agility performance during growth and maturation. Previous studies have investigated differences in physical qualities between faster and slower agility performers in adult athletes (Spiteri, Newton & Nimphius 2015, Young, Miller & Talpey 2015), but no studies were found to investigate this in an adolescent population. To improve agility optimally during adolescence, it is important to investigate and understand the effect of growth and maturation on agility. The findings from the current study show that growth and maturation influences agility performance during adolescence, but more studies are needed to determine what physical and cognitive abilities influence agility the most in adolescent athletes.

Furthermore, this study was the first, to this author's knowledge, to investigate kinetic abilities during agility in an adolescent population. Investigating kinetics during agility improves understanding of agility performance. The results from the current study can be used to improve understanding of agility performance, and to understand what characterizes agility performance in adolescent football players.

This study had some limitations that should be considered when interpreting the findings of the study. The first limitation was the small number of participants in the COMG and CODG groups, and the uneven distribution of participants in the intervention groups. The uneven number of participants in the intervention groups was a result of assigning teams randomly into groups, rather than athletes. This led to one team have a higher number of participants than the other two. Assigning teams into groups, rather than individuals, was done because there was only one researcher running the training interventions. The interventions were delivered before each team's training session, and dividing athletes into three groups and running three separate sessions at the same time by one researcher was impossible to organise.

There was also low participation in training in two groups (table 1). As a result of this low participation percentage, the effect of the interventions might have been smaller than with a higher participation percentage. Some athletes only participated in four training sessions. As the intervention was only 6 weeks (12 sessions) missing several sessions would have a major effect on training outcome. In particular, the COMG group had a low participation percentage, which might have influenced the outcomes of the intervention.

The final limitation was the training program. The program may have progressed too quickly and included too many training blocks (three two week blocks). As a result of only having two sessions for each progression, one linear and one lateral session per week, the athletes may not have mastered the exercises before moving to the next phase. This fast progression could have also made the third stage exercises too advanced for the athletes. This program was designed based on previous studies. These studies were mostly done with adult athletes with a higher training age than the subjects in the current study. The training interventions used in the current program should have been adjusted more for adolescent athletes than it was. A better progression could have been two three week blocks, giving the athletes more time to master the movements before moving to the next phase.

9.5 Conclusions

The findings from the present study suggest that relative and reactive strength plays a more significant role during agility tasks in an adolescent population than in an adult population. A greater relative and maximum leg strength was exhibited in faster athletes compared to slower athletes. Strength also produced a strong to moderate correlation with agility. Ability to anticipate opponents and teammates movements also plays an integral role in agility performance. When there is more time to ‘plan’ the movement during an unanticipated task, athletes can better utilize pre-activation strategies and improve leg stiffness at foot contact. This decreased contact time during agility tasks and increased exit velocity, which improved agility.

During adolescence, maturation influences physical performance significantly. Older athletes are stronger, faster, and move faster on the field. This greater physical performance is due to neural and muscular maturation that is happening during puberty. After the onset of puberty, the amount of hormones in the body are increased, which increases muscle mass and strength. This difference in maturation should be considered when prescribing physical training and comparing athletes to each other.

9.6 Practical recommendations

When aiming to improve agility in adolescent athletes, coaches should concentrate on improving an athlete’s decision making time, movement time and relative and reactive strength. This could be done by introducing stimuli to training. The best stimulus option is another player, where the player needs to read and react to the other athlete’s movements correctly. Coaches should not just do agility training, they should also include COD and plyometric training to improve the athlete’s movement time and overall agility performance. In this age group, agility, and other physical qualities are influenced by relative strength and reactive strength. This means training should include interventions that aim to improve both relative and reactive strength. Training to improve relative strength could include strength training and plyometric training.

Because maturation plays an important factor in the development of physical qualities, coaches should avoid placing too much emphasis on physical qualities during growth and maturation. Coaches should follow the physical maturation of athletes, to be able to prescribe training and track development of athletes. As both growth and maturation play crucial roles in developing physical qualities, coaches should avoid dividing athletes into teams young based on their physical qualities.

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APPENDIX 1. Dynamic warm up used during testing sessions

- Do the following warm up with each athlete
  - two cones 20m apart
  - Jogging forward up and backwards back x2
  - Side shuffle up and down
  - Walk and sweep up and down
  - Knee hug run up and down
  - High knees back and forth
  - Butt kicks back and forth
  - Sideways two up, one back facing both ways
  - Leg swings x10 each leg
  - Body weight squat x8

APPENDIX 2. Dynamic warm up used during the training sessions

Movement	Reps	Comments
Jog	2x20m	
Butt kicks	2x20m	
Walking lunges	2x10m	
Skipping	2x20m	
Lateral Shuffle	4x10m	
Straight Leg run	2x10m	
Spiderman lunge	3x each side	
Bodyweight squat	8	
Carioca	4x10m	Two times each side first
Jog + hip circle	4x10m	Forwards & backwards
Jog + Toe touch	2x10m	
Jog + Scoop	2x10m	
High Knee run	2x10m	
Run + jump squat	2x10m	
Lateral Shuffle	2x10m	Two steps forward one back
Sprints	3x20m	1st 70%, 2nd 80% 3rd 90%

APPENDIX 3. Training program for change of direction training

<u>COD Training</u>

- Progressive overload in loading and intensity
    - Both bilateral and unilateral exercises
- One training session a week vertical and horizontal exercises
- One training session a week lateral
- 10 minutes warm up + 10minutes plyometric + 10 minutes COD and sprints
- 3 weeks blocks
    - 1st block: control landing and learn to decelerate
    - 2nd block: plyometric training and acceleration
    - 3rd block: intensive plyometric and long sprints

- 1st Block:

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Ankle jumps	2x8	Side-to-Side ankle jumps	2x8
Squat jump + landing	2x10	Lateral jump + landing	2x10
Horizontal hop + landing	2x10	Lateral hop + landing	2x10
Horizontal bound + landing	2x10	Lateral bound + landing	2x10
Sprints	2x6x10m	Lateral Shuffle	2x6x10m
COD 45°	2x6x10m	Lateral Shuffle (5m back & fore)	2x6x10m

- 2nd block:

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Ankle jumps	2x10	Side-to-side ankle jumps	2x10
Continuous squat jumps	2x8	Continuous lateral jumps	2x8
Continuous horizontal hop	2x8	Continuous lateral hop	2x8
Continuous horizontal bound	2x8	Continuous lateral bound	2x8
Sprint	2x3x20m	T-run	2x3
X-Drill	2x4	Lateral Shuffle Zigzag	2x4

- 3rd block:

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Ankle jumps	2x12	Side-to-side ankle jumps	2x12
Squat jumps to broad jump	2x6	Lateral bound to stick	2x6
Single leg hop to vertical jump	2x6	Vertical jump to lateral shuffle	2x6x5m
Sprint	2x2x40m	Lateral Shuffle (6m:3m)	2x3x15m
M drill	2x4	Lateral Zigzag Shuffle back	2x4

APPENDIX 4. Training program for AG training group

Small Sided Games (AG) Training

- Same warm up as with COD and COMG training group
- All exercises are done by reacting to either one or several opponents
- Day one horizontal movements and day two lateral movements
- Three two week blocks
- First block: Simple 1vs1 drills
- Same volume as in COD group

1. Block

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Knee Tag	4x15s:30s	Side-to-side chase	4x15s:30s
Evasion Drill	2x6x10m	Tap the cone (1vs1)	4x15s:40s
Linear Shadowing + sprint	4x15s:40s	Meet in the middle	2x6x10m
1 vs 1	2x6	Lateral Shadowing + Sprint	4x15s:40s

2. Block

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Reactive Sprint & Back Pedal	2x3x10+10m	Lateral Shadowing	6x15s:30s
Coverage Drill	2x3x10s:40s	Box Mirroring	6x15s:30s
2vs2	2x4	ZigZag Shadowing	6x15s:30s

3. Block

Day 1. Horizontal and vertical movement		Day 2. Lateral movement	
Name	sets x reps	Name	sets x reps
Sprint Chase	2x2x40m	Lateral Shuffle Sprint	2x4x10m+10m
1 vs 1	2x4	Box Mirroring	4x15s:45s
3vs3	2x4	Lateral Circle Shadowing	4x15s:45s

APPENDIX 5. Training program for combination training

Combination training:

- Same 10 minute warm up as with other two groups
- Each training session includes half of the volume of COD and half of the volume of AG
    - First 10 minutes after warming up COD program and next 10 minutes AG program