Reactive Agility Testing: Impact of different stimuli, deceptive movements and the role of reactive strength

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This thesis is presented in fulfilment of the requirements for the degree of Doctor of Philosophy at The University of Western Australia

December 2013
“I have no special talent. I am only passionately curious”

- Albert Einstein
To my daughter Aimee

“Certain is it that there is no kind of affection so purely angelic as of a father to a daughter. In love to our wives there is desire; to our sons, ambition; but to our daughters there is something which there are no words to express.” – Joseph Addison
STATEMENT OF CANDIDATE CONTRIBUTION

This thesis contains published work and/or work prepared for publication, some of which has been co-authored. The bibliographic details of each of these works and the contribution of the candidate are presented at the start of each relevant chapter and in the list of publications arising from this thesis. In addition, the thesis outline and experimental design were planned and developed primarily by Greg Henry (candidate), with consultation from the project supervisors, Winthrop Prof. Brian Dawson, Assoc Prof. Brendan Lay and Assoc Prof. Warren Young. Also, the candidate carried out all the work involved in planning and conducting the studies described in this thesis, including participant recruitment and management and data collection and analysis. Further, the candidate drafted each of the publications and the final thesis with the project supervisors providing editorial feedback.

Candidate Signature .................................................................

Coordinating Supervisor Signature ..........................................

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PUBLICATIONS ARISING FROM THIS TESIS

The following is a list of publications the candidate has contributed to during the course of the candidature.

Peer reviewed publications included in this thesis:

**Henry, G. J., Dawson, B., Lay, B., & Young, W. B. (2011).** Validity of a reactive agility test for Australian football. *International Journal of Sports Physiology and Performance, 6*, 534-545. (Chapter 4 - Candidate contribution 90%)


Peer reviewed publications not included in this thesis:

ABSTRACT

Our understanding of agility has evolved to now recognise that agility manoeuvres in open play invasion sports, such as Australian football, are commonly reactive in nature, whereby they usually occur in response to sport-specific external stimuli, such as opponent or ball movement. Notwithstanding this, much of what is known about agility and the characteristics of agile athletes is still based on information from historical studies using pre-planned tests. However, these pre-planned agility tests now have questionable validity since they lack the perceptual and decision making component fundamental to contemporary reactive agility tasks. Consequently, several new reactive agility tests, incorporating numerous stimuli, such as flashing lights, arrows or video’s of opponents, have been developed to investigate the specific characteristics involved in reactive agility. Nevertheless, numerous unanswered questions remain, including which type of stimuli may be best suited to examining reactive agility, the impact of complex multi-turn agility tasks or the role of muscular strength in reactive agility performance.

With this in mind, the initial aim of this project was to develop a video-based reactive agility test for Australian football, using a number of guiding principles based on the particular movement qualities of Australian football, combined with the underpinning philosophies of modern reactive agility theory (Chapter 3). However, before this new protocol could be used more broadly to investigate reactive agility, its validity and reliability had to be established (Chapters 4 and 4A). Subsequently, this new protocol was used to investigate, for the first time, other aspects of sport-specific reactive agility, such as the impact of offensive feints on the performance of a defensive player (Chapters 5 and 6) and the role of lower extremity reactive strength in reactive agility performance (Chapter 7).

Therefore, Chapter 4 examined the validity of the new protocol by firstly comparing overall performance on a video-based reactive agility test, a similar light-based test and a planned agility test between three groups of participants; higher standard Australian football players, lower standard...
Australian football players and non-players. Secondly, this study also examined the relative capacity of tests using the different stimuli to distinguish the cognitive and motor sub-components of reactive agility among the different groups of footballers. Subsequent results identified significant differences in the agility time component between the planned test and both the video- and light-based reactive test modes. Furthermore, there were low correlations and common variances of less than 50% between the planned and (both) reactive agility tests. So, collectively these findings confirm previous research showing that planned and reactive agility are unique skills and that reactive agility capacity cannot be effectively assessed using a planned agility test.

Chapter 4 also revealed that although large correlations in agility time \(r = 0.75; r^2 = 56\%\) existed between the light and video-based reactive agility tests, decision time was significantly faster using the light-based stimulus \(p < 0.001\), with a moderate supporting effect size of \(d = 0.80\). Therefore, the perceptual and cognitive challenge resulting from the more sports-specific video stimuli is not effectively replicated using a generic light-based stimulus. Furthermore, on all three test modes both the higher and lower standard groups had faster agility times than the non-playing group, but the largest difference was found between the non-playing group and the higher calibre group. In addition, while there were only small differences observed in agility time between the higher and lower standard groups on the planned \(d = 0.24\) and light-based tests \(d = 0.42\), the largest difference was on the video-based test \(d = 0.82\). Therefore, it was apparent that as the cognitive demand increased from the planned to the light to the video test, there was also a trend for increasing divergence in performance between the playing groups.

Additionally, Chapter 4 revealed that correlations between a 4-m linear sprint test and all agility tests were found to be stronger \((r = 0.71 \text{ to } 0.81)\) for total time (with the initial linear 3 m-approach sprint included in the measurement) than for the agility time measure, where the time for the initial 3 m-approach sprint was removed \((r = 0.32 \text{ to } 0.43)\). Accordingly, this signifies that total time in this test is assessing similar qualities as linear speed or, put another way, linear speed appears to “contaminate” a total
time measure when it includes a straight sprint approach. Therefore, agility
time (with linear sprinting removed as far as is practicable) appears a more
valid measure of reactive agility, as it more effectively isolates the specific
change of direction component. Next, Chapter 4A examined the reliability of
the new video-based reactive agility protocol and verified that the test-retest
(coefficient of variation of 1.4% and intra-class correlation coefficient of 0.81)
and intra-rater reliability (coefficient of variation of 5.2% and intra-class
correlation coefficient of 0.99) of the new video-based protocol were sound.

Chapters 5 and 6 introduced deceptive movements (feints) into the
stimulus video and, for the first time, explored their influence on decision
making speed and accuracy and the impact of the resulting multiple turns on
the physical component of reactive agility. Moreover, the relative impacts of
the feints were also compared between higher and lower standard Australian
footballers. Results from Chapter 5 revealed trivial to small correlations in
agility ($r = -0.13$) and movement times ($r = 0.14$) between the feint and non-
feint modes. This therefore suggests that reactive agility in response to a
feint is a unique skill compared to single-turn reactive agility tasks.
Additionally, the effect sizes and comparisons between the confidence
intervals and smallest worthwhile change values indicated a trend for better
agility and movement times in the higher standard players during feint trials
than the non-feint trials. This was primarily brought about by a worsening of
movement time in the lower standard players in the feint trials ($p = 0.002; d =
1.07; 100/0/0; almost certainly detrimental), but less change in the higher
standard group with the introduction of the feints ($p = 0.23; d = 0.66;
81/13/6; likely detrimental).

Similarly, results from Chapter 6 showed that, at the first decision point
of the feint trials and in the non-feint trials, the playing groups exhibited
similar decision accuracy. In contrast, at the second decision point of the
feint trials there was a large deterioration in accuracy for the lower standard
players ($p = 0.02; d = 1.04$), with little change in the higher standard group ($p = 0.2; d = 0.44$). Therefore, the results from Chapters 4, 5 and 6 collectively
revealed a common trend of superior performance in the higher calibre
athletes and that the differences between higher and lower standard athletes
also increased as difficulty of the task increased; namely the use of a video stimulus or the inclusion of feints and multiple turns. Consequently, these studies verify that reactive agility testing can discriminate Australian footballers of differing playing standards and so, reactive agility (especially scenarios incorporating feints) should receive specific training when developing these athletes, particularly in less experienced players.

However, Chapters 4, 5 and 6 also reveal that the specific reactive agility sub-component primarily responsible for the playing group differences could change depending on the context of the task. For example, in Chapter 4 the primary difference in the group was in movement time rather than decision time. In contrast, during the non-feint trials in Chapter 5 differences in decision time were primarily responsible for the playing group differences, whereas during the more complex feint trials the primary differences were again in movement time. These inconsistencies support the notion that reactive agility is a multi-factorial skill unlikely to be consistently determined by a single element or characteristic and that the precise source of any reactive agility advantage will vary between different athletes and scenarios. Therefore, to allow all athletes to potentially access any superior motor or cognitive skills, reactive agility assessments should include feint trials, as single stimuli (and accompanying single turns) might not challenge more than the universal decision making and motor skills common to many team-sport athletes.

Chapter 6 also identified that incorrect decisions (initial turn in the wrong direction) during non-feint trials and at the second decision time in the feint trials resulted in a significant increase (worsening) of agility time, due to a lengthening in both decision time and movement time in all participants. But, for the first time in reactive agility research, this information was used to quantify the performance cost and practical significance of such decision making errors. Subsequently, it was calculated that during the non-feint trials the time deficit equated to a distance deficit for the defensive player of approximately 0.7 m, while during feint trials the deficit was approximately 3 m. Conversely, incorrect decisions at the first decision point in the feint trials (e.g., successful anticipation of a feint) led to significant improvements in
agility time for the defensive player, equating to a distance advantage to the defensive player of 1.2 m. Accordingly, these findings illustrate both the potential benefit in successful offensive feints and the potential shift in that advantage to the defensive players who can effectively anticipate the movements of their opponents.

Finally, in Chapter 7 reactive agility research was expanded for the first time to investigate the role of reactive strength (lateral, horizontal and vertical unilateral jump performance and kinetics) in reactive agility performance, in particular the motor component. Initial results revealed that there was a weak ($r < -0.33$) relationship between jump performance, kinetic variables and reactive agility movement time. However, asymmetries in favour of the dominant leg were observed for agility (dominant leg superiority $= 5.4\%$; $p < 0.001$; $d = 0.84$) and movement times (dominant leg superiority $= 5.6\%$; $p = 0.004$; $d = 0.86$) as well as for lateral jump distance (dominant leg superiority $= 3\%$; $p = 0.008$; $d = 0.35$) and reactive strength index (dominant leg superiority $= 4.4\%$; $p = 0.03$; $d = 0.28$). Consequently, lateral jump performance and reactive strength index may be more sensitive to reactive agility movement time asymmetries than vertical and horizontal jumps. However, since strength asymmetries are relatively common, these similarities may simply be coincidental rather than functionally linked. This notion was supported by the results from a sub-group of participants ($n = 15$) with the fastest agility movement times (mean $7.1\%$; $p < 0.001$; $d = 2.0$) who displayed no concomitant advantage in performance and kinetic variables on any jump over a group with the slowest agility movement times ($n = 15$). Accordingly, reactive strength as measured by a unilateral drop jump has limited prognostic value in relation to the motor component of reactive agility performance other than potentially identifying leg strength asymmetries that may reflect asymmetries in agility performance. Consequently, while the other results in this thesis validate the importance of the movement sub-component in some reactive agility scenarios, this final study indicates that reactive strength contributes little to this characteristic. Hence, it is likely that other factors such as skill, dynamic balance, core stability and inter- and intra-muscular coordination may play a larger role.
In conclusion, when viewed holistically, results from this series of studies adds to the current body of literature regarding reactive agility and increases our understanding of the factors that contribute to reactive agility performance in various groups of Australian footballers. For example, these results confirm that the sport-specific stimulus used in this current video-based test is a valid and reliable method for discriminating Australian footballers of differing playing standards and is superior to generic reactive agility and planned agility protocols. Also, as there is no discernable relationship between reactive agility performance with and without a feint, and since the gap between higher and lower standard players becomes more pronounced as the complexity of the task increases, it is recommended that reactive agility tests and reactive agility training, incorporate a variety of context-specific feint scenarios. However, reactive strength, as measured by unilateral drop jumps, has limited predictive value for assessing and comparing the motor component of reactive agility.

Nevertheless, coaches should also be aware that one single characteristic is unlikely to be responsible for overall reactive agility performance and that, depending on the nature and complexity of the task and the athletes involved, it can be primarily influenced by strengths and weaknesses in either of the major sub-components of reactive agility; the cognitive and decision making factors or the motor component. Therefore, assessing reactive agility and its subcomponents using the video-based test introduced here will help coaches identify individual strengths and weaknesses and allow them to develop specific training programs to address them.
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<tbody>
<tr>
<td>1RM</td>
<td>1 repetition maximum</td>
</tr>
<tr>
<td>2-D</td>
<td>2-dimensional</td>
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<tr>
<td>3-D</td>
<td>3-dimensional</td>
</tr>
<tr>
<td>AFL</td>
<td>Australian Football League</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>AT</td>
<td>Agility time</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<td>CV</td>
<td>Coefficient of variation</td>
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<td>DT</td>
<td>Decision time</td>
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<tr>
<td>DT2</td>
<td>Decision time 2</td>
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<tr>
<td>FAT</td>
<td>Feint agility time</td>
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<tr>
<td>FDT1</td>
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<tr>
<td>FMT</td>
<td>Feint movement time</td>
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<tr>
<td>FTT</td>
<td>Feint total time</td>
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<tr>
<td>HJ</td>
<td>Horizontal jump</td>
</tr>
<tr>
<td>HP</td>
<td>Higher performance</td>
</tr>
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<td>HS</td>
<td>Higher standard</td>
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<tr>
<td>ICC</td>
<td>Intra-class correlation coefficient</td>
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<tr>
<td>IRI</td>
<td>Inter-response interval</td>
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<tr>
<td>ISI</td>
<td>Inter-stimulus interval</td>
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<tr>
<td>LED</td>
<td>Light emitting diode</td>
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<tr>
<td>LJ</td>
<td>Lateral jump</td>
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<tr>
<td>LP</td>
<td>Lower performance</td>
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<td>LRAT</td>
<td>Light-based reactive agility test</td>
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<td>LS</td>
<td>Lower standard</td>
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<tr>
<td>ms</td>
<td>Millisecond</td>
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<tr>
<td>MT</td>
<td>Movement time</td>
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<td>Non-footballers</td>
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<td>Non-feint agility time</td>
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<tr>
<td>NFL</td>
<td>National Football League</td>
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<td>PLAN</td>
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<td>RSI</td>
<td>Reactive strength index</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SSEH</td>
<td>School of Sport Science, Exercise and Health</td>
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<tr>
<td>SWC</td>
<td>Smallest worthwhile change</td>
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xvii
<table>
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<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>TT</td>
<td>Total time</td>
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<tr>
<td>UWA</td>
<td>The University of Western Australia</td>
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<td>VJ</td>
<td>Vertical jump</td>
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ACKNOWLEDGEMENTS

This thesis was completed part-time over a 7-year period and as such there have been many peaks and troughs in my personal and professional life. Accordingly, this thesis would not have been possible without the assistance and support of several people.

Firstly my supervisors, Prof. Brian Dawson, Assoc. Prof. Brendan Lay and Assoc. Prof. Warren Young, thank you for believing in me and agreeing to direct this project even though I had been away from University life for quite some time and worked in an unrelated field. Your advice and mentorship was invaluable.

The School of Sport Science, Exercise and Health technical support team were always helpful with my many and varied equipment needs. In particular, Peter Griffiths for writing the all-important software and constructing the electronics that were at the heart of this project, thank you for helping me bring my theories and ideas to life.

My colleagues at the Western Australian Fire and Rescue Service for their humour and interest in my “hobby”. Especially, to those who also acted as participants, some several times, from the concept and pilot testing phase right through to the final study, your efforts will always be remembered and appreciated.

To all the participants of the various studies, your effort and patience was truly valued and certainly without you none of this would have been possible.

My sincere thanks to you all.
Introduction
1.1 Introduction

Highly developed agility is an important characteristic for success in team sports such as Australian football, in order to make or evade tackles or capture a ball with an unpredictable bounce (Clarke, 1959; Ellis, et al., 2000; Farrow, Young, & Bruce, 2005; Hawley & Burke, 1998; Sheppard & Young, 2006; Verstegen & Marcello, 2001). Consequently, agility tests are routinely included in assessment and talent identification programs in sports such as the National Football League (McGee & Burkett, 2003) and the Australian Football League (Pyne, Gardner, Sheehan, & Hopkins, 2005, 2006), as well as others (Ellis, et al., 2000; Lawrence & Polglaze, 2000; Tumilty, 2000). Evidence of the importance of agility is also provided by motion analysis studies (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004) and other research showing agility performance successfully discriminates playing ability and position in several sports (Baker, 1999; Gabbett, 2002; Keogh, Weber, & Dalton, 2003; Power, Dunbar, & Treasure, 2005; Pyne, et al., 2006). Yet, notwithstanding the importance of agility in team sports, it remains a relatively poorly understood characteristic (Serpell, Ford, & Young, 2010; Young & Farrow, 2006). This is partly due to the lack of a universally accepted definition of agility within the sports science and coaching communities (Serpell, et al., 2010; Sheppard, Young, Doyle, Sheppard, & Newton, 2006), resulting in the development of a large number of different agility tests, often specific to certain sports (Baker, 1999; Brughelli, Cronin, Levin, & Chaouachi, 2008; Pyne, et al., 2005; Young, Farrow, Pyne, McGregor, & Handke, 2011). However, the validity of many of these historical tests has recently been questioned in light of changes to the way sport specific agility has been viewed and defined (Gabbett, Kelly, & Sheppard, 2008; Sheppard & Young, 2006).

Historically, agility was characterised as a unique entity consisting of isolated pre-planned movements (Sheppard & Young, 2006), resulting in early agility assessments having little perceptual uncertainty or cognitive challenge (e.g., running around fixed markers in planned sequences) (Sheppard & Young, 2006; Sheppard, et al., 2006). However, the modern view of agility
Introduction

acknowledges that on-field changes of direction in open sports such as Australian football usually occur in response to a context-specific external stimulus, such as opponent or ball movement (Bruce, Farrow, & Young, 2004; Farrow, et al., 2005; Sheppard & Young, 2006). Additionally, the stimulus not only initiates the movement but also largely determines the nature of the movement and so, in order to be successful, athletes need to effectively anticipate and respond efficiently to sports-specific stimuli with the most appropriate movement for the given situation (Jeffreys, 2011). This evolution in our understanding of the nature of on-field agility has resulted in a range of reactive agility tests appearing in the literature, which require participants to change direction in response to various stimuli (Farrow, et al., 2005; Serpell, et al., 2010; Sheppard, et al., 2006; Young, et al., 2011). Several of these protocols have also been shown to have superior context and ecological validity than earlier planned agility assessments for team sports such as Australian football (Farrow, et al., 2005; Serpell, et al., 2010; Sheppard, et al., 2006).

Furthermore, a small number of studies have used high-speed video analysis to isolate the perceptual and decision making components of reactive agility (Farrow, et al., 2005; Gabbett, et al., 2008; Serpell, et al., 2010). In doing so, these studies have highlighted the importance of anticipatory and perceptual skill in differentiating athletes competing at different playing levels in various sports. However, as yet, no studies have specifically isolated the (post-decision) motor component of agility to assess the relative importance of that characteristic or that of its own underlying sub-factors, such as leg strength and power. This is despite the role of leg strength and power being a common theme in earlier studies into planned agility (Brughelli, et al., 2008; Hilsendager, Strow, & Ackerman, 1969; Markovic, 2007; Ouverson, 2004; Young, Hawken, & McDonald, 1996; Young, James, & Montgomery, 2002).

Furthermore, to date reactive agility studies have predominantly focussed on performance during relatively simple, single-stimulus, single-turn agility tasks, with little further manipulation of the stimulus undertaken, though some studies have involved a combination of reactive and planned
changes of direction (Farrow, et al., 2005; Veale, Pearce, & Carlson, 2010). However, feint movements are common in many sports and not only increase the cognitive complexity and uncertainty of the stimulus but also result in multiple changes of direction. Yet, while multiple turns have frequently been incorporated in historical planned agility assessments (Baker, 1999; Jackson, Warren, & Abernethy, 2006; Lockie, Jefferies, Schultz, & Callaghan, 2012; McGee & Burkett, 2003; Pyne, et al., 2005; Young, McDowell, & Scarlett, 2001), the impact of feints and multiple changes of direction have yet to be considered in a reactive agility context. Accordingly, it is unclear whether, as the complexity of the agility tasks increase with the inclusion of feints, higher calibre athletes will perform better than lower calibre athletes, based on the reputedly enhanced anticipatory skill, reduced susceptibility to deceptive movements and a better physical ability to negotiate multiple, high intensity (planned) changes of direction in higher calibre athletes (Baker, 1999; Gabbett, et al., 2008; Jackson, et al., 2006; Williams & Ford, 2008).

Further clouding our understanding of reactive agility is that studies so far have each used different stimuli, ranging from lights, arrows, real opponents and videos of real opponents, with no clear consensus as to the ideal mode of stimulus delivery (Farrow, et al., 2005; Oliver & Meyers, 2009; Serpell, et al., 2010; Sheppard, et al., 2006; Young, et al., 2011). Until now, the primary aim of most reactive agility research has been to validate the use of reactive agility tests by comparing performance to similar planned agility tests (Farrow, et al., 2005; Gabbett, et al., 2008; Serpell, et al., 2010; Sheppard & Young, 2006; Sheppard, et al., 2006), rather than direct comparisons of reactive agility performance using different stimuli (Young, et al., 2011). Nevertheless, the ecological validity of generic stimuli such as flashing lights and arrows has been questioned, since they do not resemble the stimuli encountered in sport (Farrow, et al., 2005; Jeffreys, 2011; Serpell, et al., 2010; Serpell, Young, & Ford, 2011; Sheppard & Young, 2006; Sheppard, et al., 2006; Spiteri, Cochrane, & Nimphius, 2012; Veale, et al., 2010; Young & Farrow, 2013; Young, et al., 2011).

In addition, contemporary research into the attainment of expertise (sport included) has shown that anticipatory and decision making skills are
superior in higher standard individuals, but that this advantage is most apparent when the task is domain and context-specific (Jeffreys, 2011; Serpell, et al., 2010; Williams & Ford, 2008; Young & Farrow, 2013). Consequently, from a reactive agility perspective generic stimuli will not provide higher calibre athletes with the opportunity to utilise their enhanced skills, and so sport- and context-specific stimuli are considered more appropriate (Sheppard, et al., 2006; Young, et al., 2011). However, the lack of direct comparisons between different stimuli (e.g., lights versus video-based versus real people) makes any definitive decision on the best form of stimuli difficult.

1.2 Statement of the Problem

The primary purpose of this thesis was to trial an alternative video-based reactive agility test, which could potentially be tailored to each individual athlete’s sprint ability. Subsequently, this new protocol was also used to examine various aspects of agility and the factors underlying this characteristic. For example, the video-based stimulus was compared to a generic light stimulus and a planned agility test to confirm whether a sport-specific stimulus is a more valid and accurate way of assessing reactive agility in different groups of Australian footballers. Furthermore, assessing the sub-components of reactive agility provided an increased understanding of the mechanisms by which differences occur in different athletes in response to the different stimuli.

The ability to manipulate the stimuli in the new video-based reactive agility test to include feint scenarios also allowed an examination into how the response to simple and more complex multi-turn agility tasks differs between higher and lower calibre Australian footballers. Accordingly, this provided the opportunity to investigate how this common evasive tactic can influence overall agility performance and that of each of the agility sub-components. Finally, for the first time, unilateral jump performance was compared to reactive agility performance to scrutinise the relationship between reactive strength and reactive agility and provide an insight into the role that leg strength characteristics play in this important sporting skill.
1.3 Thesis Structure

This thesis is structured around the development and use of a new video-based reactive agility protocol, to provide practical information to assist coaches and athletes to assess and understand agility and its sub-components. The thesis is presented as a series of five separate, but interrelated papers, four of which are already either published or accepted for publication (Chapters 4, 5, 6 and 7). Therefore, these chapters can be read either as part of the entire thesis or independently. However, since each of these papers considers related research questions and uses the same agility test throughout, some relevant information is necessarily repeated. In addition, as each paper was prepared for individual publication those already published are presented in the format, language and referencing style required by those individual journals. However, the other chapters will be referenced as per the American Psychological Association publication manual (2010).

The papers (Chapters 4, 5, 6 and 7) follow on from the Introduction (Chapter 1) and Review of literature (Chapter 2), which provide the context for the studies and outline the specific research aims and hypotheses. Chapter 3 - Video reactive agility test: Developmental background and description details the theoretical basis for the design of this test protocol and explains the structure and method of operation.

Chapters 4 (Paper 1) and 4A address the question of validity and reliability respectively. The construct validity of this new protocol was assessed by comparing performance between different standards of Australian footballers on the video-based test to matching light-based and pre-planned tests. Chapter 4A investigated test-retest reliability of the protocol and the intra-rater reliability of the decision time measure by comparing the measures on two separate assessments. The next two chapters (Chapter 5 - Paper 2 and Chapter 6 - Paper 3) introduced and examined the impact of deceptive movement (feints) on various aspects of agility performance and decision making accuracy and how these may differ between higher standard and lower standard Australian footballers. Next, Chapter 7 (Paper 4) investigated the relationship between multi-plane single-leg jumping performance and
kinetics and reactive agility, to help understand the role of leg strength and power characteristics in agility which, although of great interest to researchers historically, has yet to be examined in a reactive agility context. Finally, the General Discussion (Chapter 8) collated and summarised the findings and conclusions from each of the papers and related them back to the original hypotheses outlined below. This chapter then concluded the thesis by presenting overall conclusions and practical implications of the findings for coaches, with some suggestions for future research.

1.4 Specific aims and hypotheses

Chapter 4 (Paper 1) - Validity of a reactive agility test for Australian football.

Aims

1. Determine the construct validity of the video-based method by comparing agility performance to a generic light-based test and another planned agility test.

2. Determine whether a video-based reactive agility test can discriminate performance differences between three groups of participants differentiated by their level of involvement in Australian football.

3. Isolate the perceptual and physical sub-components of agility and examine their influence on overall performance and how this may vary between athletes playing at different competitive levels.

Hypotheses

• Performance on both reactive agility tests will be slower than the planned test, while performance on the video test will in turn be slower than the light-based test, due to a longer decision time component related to the increased cognitive complexity of the video stimuli (Aim 1).

• Higher calibre footballers will demonstrate superior agility than lower calibre footballers, and both playing groups will perform better than non-
players on all tests and these group differences will be greatest for the video-based protocol (Aim 2).

- The primary source of the group differences will be in the decision time component rather than the physical component and the differences will be greatest in the video-based test (Aim 3).

Chapter 4A - Reliability of a reactive agility test for Australian football.

Aim


Hypothesis

- The new video-based reactive agility test will prove a reliable measure of reactive agility in Australian footballers (Aim 4).

Chapter 5 (Paper 2) - Effects of a feint on reactive agility performance.

Aims

5. Use a new video-based reactive agility test, incorporating a mix of feint and non-feint trials, to examine the effects of deceptive movements on agility performance, and that of its sub-components.

6. Investigate the relationships between feint and non-feint trials to determine whether the skills being measured are the same.

7. Assess how the effects of a feint differ between different standards of Australian footballers and to determine whether higher calibre players exhibit superior agility performance than lower calibre counterparts, due to superior decision making ability or physical change of direction speed (or a combination of these).
Hypotheses

• The inclusion of a feint in the stimulus video will decrease performance (increase time) of the “defensive” player through increases in both decision making and movement time components (Aim 5).

• There will be little relationship between the feint and non-feint trials due to the increased cognitive and physical complexity of the feint trials (Aim 6).

• The higher standard group will perform better across all agility trials but this advantage will increase with the inclusion of the feint and be manifested through slower decision and movement times in the lower standard group (Aim 7).

Chapter 6 (Paper 3) - Decision making accuracy in reactive agility: Quantifying the cost of poor decisions.

Aims

8. Examine the effect of the inclusion of feints on decision making quality by comparing the frequency of incorrect decisions in normal and feint trials.

9. Compare differences in decision accuracy between higher and lower standard Australian footballers, to assess whether the higher standard athletes maintain their level of accuracy due to a lower susceptibility to deception.

10. Compare the time-cost of response errors to successful trials to investigate whether decision making errors will lead to significant worsening in agility performance and identify which of the sub-components may be primarily responsible for this.

Hypotheses

• The introduction of feint movements will reduce decision accuracy compared to non-feint trials (Aim 8).
• Higher calibre players will exhibit better decision making accuracy than lower calibre players. This superior level of accuracy will be maintained in the higher calibre group with the inclusion of a feint, but will decrease in the lower calibre players (Aim 9).

• Decision making errors will lead to significant decreases in agility performance of the “pursuing” player (Aim 10).

Chapter 7 (Paper 4) - The relationship between reactive agility movement time and unilateral vertical, horizontal and lateral jumps.

Aims

11. To examine the relationship between unilateral vertical, horizontal and lateral jump performance, reactive strength and kinetic variables and reactive agility; in particular the movement phase of reactive agility, where the influence of leg strength is thought to be greatest.

12. Compare agility and jump performance between the dominant and non-dominant legs to establish the presence of any asymmetries and investigate whether (due to greater similarity between the movements), lateral or horizontal jumps will be more sensitive to any differences in reactive agility performance between legs.

13. Assess differences in jump performance between the faster and slower agility groups to clarify the relative influence of lateral, horizontal and vertical leg strength characteristics in producing faster agility movement.

Hypotheses

• A strong association between jump performance, kinetic variables and agility performance will be observed but the strongest association will be for the lateral jumps, and collectively these three jumps will explain the majority of the variance in agility performance (Aim 11).

• Asymmetries between the legs during the jump tests will mirror functional differences in agility performance when pushing off each leg, and lateral jumps will demonstrate the greatest sensitivity due to the similarity
between the movements (e.g., small differences in lateral jump ability will predict differences in agility time) (Aim 12).

- After dividing the group into faster and slower groups (based on reactive agility movement times), differences in agility performance between the groups will be accompanied by concomitant differences in jump ability on all jumps, but the greatest difference will be observed in the lateral jumps. (Aim 13).

1.5 Significance

This thesis will provide coaches and athletes with a new, valid and reliable reactive agility test. Importantly, the use of video clips in the stimulus results in a fundamentally stable stimulus and so exactly the same information can be provided to numerous athletes. But, at the same time, the video-based protocol allows the flexibility to also be easily altered to provide different scenarios or contexts depending on the particular needs of a sport, including the use of feints. In addition, this protocol introduces some unique concepts to the field of reactive agility, such as the ability to individually manipulate the stimulus length for each athlete, the use of dummy clips and the notion of an “abort time”. These ideas address some of the weaknesses of earlier research and ensure the test is conducted at a sport-specific intensity and delivered in an equitable manner to all athletes regardless of ability.

Results from study one will clarify the enhanced validity of sport-specific stimuli over a generic (light based) one, and in so doing provide guidance to coaches seeking the most effective stimulus to use during agility training. Chapters 4, 5 and 6 will provide data on the source and scale of differences in agility performance between athletes of differing playing standards and in various contexts. This information will be useful when determining the importance of agility training in developing appropriate training regimes to target individual weaknesses within elite athletes and teams.

Chapters 5 and 6 will, for the first time, specifically examine the impact of deceptive movement (feint) and multiple changes of direction on
reactive agility and its main sub-components. This will provide athletes and coaches with a useful comparison between this common evasive tactic and simple, single-turn agility tasks to ascertain if agility responses are universal, regardless of complexity, or whether the response differs. Moreover, these results will establish how the response differs between athletes of different playing standards and where the differences occur within the agility framework. Finally, Chapter 7 will provide an insight into the relative effectiveness of different single-leg jump tests as predictors of reactive agility ability and symmetry which, in turn, will assist coaches to develop guidelines for agility training; specifically, whether lateral or other non-vertical unilateral strength and power exercises can augment existing agility training programs.
References


Introduction


Introduction


Review of Literature
2.1 DEFINING SPORT-SPECIFIC AGILITY

Agility is acknowledged as an important characteristic for team sport athletes (Ellis, et al., 2000; Hawley & Burke, 1998) but it has also been described as a difficult to define characteristic (Bloomfield, Ackland, & Elliott, 1994; Young, McDowell, & Scarlett, 2001) and, consequently, it is not well understood (Craig, 2004; Jeffreys, 2011; Serpell, Ford, & Young, 2010). Numerous different definitions of agility exist in the literature but, until recently, these were often simplistically based on movements alone with little reference to the context in which the movement occurred (Jeffreys, 2011). Examples of these are, “... the ability to change body direction and position rapidly” (Draper & Lancaster, 1985, p.15), “… the ability to change direction and start and stop quickly” (Little & Williams, 2005, p.76), or the capacity to “explosively start, decelerate, change direction and accelerate again while maintaining body control” (Brown & Ferrigno, 2005, p.72).

In contrast, contemporary research appreciates that agility in team sports is frequently reactive in nature, whereby changes of direction occur in response to, and are largely determined by, external stimuli such as the movement of an opponent or the bounce of a ball (Farrow, Young, & Bruce, 2005; Sheppard & Young, 2006). Accordingly, in addition to the ability to execute agility movements efficiently or rapidly, successful field sport players also need a well-developed ability to anticipate opponent movements and to recognise patterns of play, then quickly decide on the appropriate agility manœuvre. Put another way, the modern view of agility has evolved to incorporate the ability to read and react not simply act (Jeffreys, 2011; Sheppard & Young, 2006; Sheppard, Young, Doyle, Sheppard, & Newton, 2006; Young, Farrow, Pyne, McGregor, & Handke, 2011).

In recognition of the importance of the perceptual and decision making aspects of agility in many sports, Sheppard and Young (2006) have redefined agility as “a rapid whole-body movement with a change of velocity or direction in response to a stimulus” (p.922). By including a response to a stimulus this definition excludes pre-planned change of direction tasks being
classified as agility and the term *change of direction speed* was subsequently coined to differentiate these tasks (Sheppard, et al., 2006; Young, James, & Montgomery, 2002). In addition, the term *quickness* has been used to describe agile movements involving the reaction to a stimulus (Brown & Ferrigno, 2005; Twist, 2001). However, this term seems to have found favour in North America only and relates to a variety of motor skills not strongly related to agility, such as linear speed (Gabbett, Kelly, & Sheppard, 2008; Young, Hawken, & McDonald, 1996; Young, et al., 2001) and, as a result, will not be used here.

For coaches however, changing the definition of agility to exclude planned changes of direction and re-classifying and re-labelling those activities that were historically understood as agility may be confusing and make it difficult to recognise what is *new* agility and *old* agility. Therefore, whilst acknowledging they rarely (but do) occur in team sport (Young & Farrow, 2013), a simpler way to describe activities which involve “… the ability to change body direction and position rapidly” (Draper & Lancaster, 1985, p.15) or “a rapid whole-body movement with a change of velocity or direction” (Sheppard & Young, 2006, p.922) *without* a reaction to a stimulus is as *planned agility* (Bruce, Farrow, & Young, 2004). In contrast, a similar rapid change of velocity or direction that *is* in response to a stimulus can be referred to as *reactive agility* (Bruce, et al., 2004), as per the suggestion from Sheppard and Young (2006). Indeed, many studies that have examined agility in a reactive context have specified this using the term reactive agility in the title, rather than simply agility (Chelladurai, Yuhasz, & Sipura, 1977; Duvnjak-Zaknich, Dawson, Wallman, & Henry, 2011; Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Oliver & Meyers, 2009; Sheppard, et al., 2006; Veale, Pearce, & Carlson, 2010; Young & Willey, 2010). Thus, an alternate view to that of Sheppard and Young (2006) is that all activities that broadly include the common characteristic of a change of direction or velocity can be considered agility but should be differentiated by their context (planned versus reactive).
The deterministic model of reactive agility developed by Young and Farrow (2006) (Figure 2.1) encompasses this idea by acknowledging that the two dominant factors that predict reactive agility performance are the perceptual and decision making elements and the physical change of direction components, each of which can be divided into various smaller sub-components. However, if the perceptual and decision making branch of this model is momentarily ignored, it can be seen that the physical act of changing direction (whether it be planned or reactive) will likely be determined by broad characteristics such as technique and leg muscle qualities. Importantly, that does not imply that the physical component is the same between the reactive and planned modes (research has confirmed they are different: Besier, Lloyd, Ackland, & Cochrane, 2001; Houck, Duncan, & De Haven, 2006), only that the physical component of planned and reactive agility are determined by their own unique mix of technique and leg muscle qualities. Therefore, describing them as planned agility and reactive agility makes the distinction between them clear, whilst still acknowledging their shared elements. Discussing agility in this way also uses familiar language, thereby potentially resulting in an easier transition in understanding of their differences for many coaches, who can then determine how important the response to a stimulus is in their sports and then choose the most appropriate assessment or training method.

Notwithstanding the issues of definition and nomenclature it is undeniable that the majority of agility tasks in team invasion sports like Australian football are reactive in nature (Farrow, et al., 2005; Sheppard & Young, 2006). Consequently, this is the form of agility currently of interest to researchers and is the key theme of this thesis. Several deterministic models of reactive agility have been developed to illustrate the multi-factorial nature of this skill (Hewit, Cronin, & Hume, 2012; Jeffreys, 2011; Young & Farrow, 2006; Young, et al., 2002). One example is the model shown in Figure 2.1 while another is the constraints-based model presented in Figure 2.2 (Jeffreys, 2011), which recognises that similar internal (organismic) factors (perceptual, cognitive, physical and motor control) will shape and limit (or constrain) the agility response.
Figure 2.1: A modified deterministic model of agility adapted from Young & Farrow (2006).
Figure 2.2: A constraints based model of agility (Jeffreys, 2011).
However, the model in Figure 2.2 also includes task (rules of the game and aims of the task) and environmental (playing surface and conditions, location of opponents) constraints that also influence agility performance. Nevertheless, since there has been little research into reactive agility and its specific sub-components the presence and influence of the elements within these models are largely based on hypotheses from other domains rather than empirical agility data. Furthermore, since the broad inter-relationships between the components of reactive agility have yet to be extensively examined, there is little understanding about how changes in one sub-component may, directly or indirectly, impact others and subsequently influence overall performance (Brughelli, Cronin, Levin, & Chaouachi, 2008). Therefore, ultimately the lack of understanding of the practical interactions of the different characteristics within agility contributes to the general lack of understanding of reactive agility. For example, it is currently unclear what influence leg strength and power qualities and/or technique have on the physical ability to change direction (Brughelli, et al., 2008; Young & Farrow, 2006). Additionally, it is unknown whether higher levels of strength or better technique (e.g., superior physical component) will overcome deficiencies in anticipation or decision making speed (inferior perceptual and decision making component), which may cause a player to be in a disadvantageous position in relation to their opponent when they initiate their response.

Notwithstanding this, the common elements from these models provide the foundation for a critical review of the literature concerning reactive agility, its sub-components and the tests used to assess this characteristic. This information will provide the background for the development of a new video-based reactive agility test (Chapter 3) and a foundation for the subsequent studies, which aim to address some of the limitations of earlier tests and advance the understanding of this complex skill.

2.2 PERCEPTUAL AND COGNITIVE FACTORS IN AGILITY

Given that historically little importance was placed on the perceptual component of agility, most previous tests were pre-planned in nature and
typically involved running around static markers. Therefore, planned agility tests likely examined physical factors alone, whereas reactive agility performance is reliant on the successful interaction between the perceptual, decision making and physical sub-components. Several theories have subsequently emerged that could explain the interaction between the sub-components important for agility (Lee, 2011); the cognitive psychology, ecological psychology, constraints-led and dynamic systems theories. While a detailed description of each of these theories is beyond the scope of this project, the dependent variables associated with the constraints-led and cognitive psychology theories have been adopted, in a theoretical sense, to explain our reactive agility findings.

Firstly, the constraints-led theory is the basis for the models in Figures 2.1 and 2.2, whereby various internal and external factors will limit the eventual effectiveness and safety of the agility response. For example, in both models these factors include the athlete’s physical, perceptual and cognitive characteristics (organismic constraints) but in figure 2.2 the constraints include environmental factors, such as field size, or position within the field which may change the spatial demands by affecting the location of opposing players, the sideline or the goal. Furthermore, task constraints such as rules governing the number of steps allowed, could also influence the choice of agility technique. In addition, some of these constraints vary due to the interpersonal interactions between opponents and team-mates which are constantly and instantaneously changing, and ecological dynamics theory suggests that athletes learn to couple particular actions to certain performance environments (Davids, Duarte, Vanda, & Luis, 2013).

Secondly, the cognitive psychology theory contends that relevant and irrelevant information from both internal and external sources (such as some of the constraints listed above) are forwarded for higher-level processing to produce a response (agility manoeuvre) (Schmidt & Wrisberg, 2008). This process is regularly used to explain decision-making in sport and is often illustrated using the 3-stage information-processing model depicted in Figure 2.3 (Farrow & Raab, 2008; Schmidt & Wrisberg, 2008). Consequently, this
model will also be used to frame the discussion on how the common perceptual and cognitive factors from Figures 2.1 and 2.2 may influence reactive agility performance and their relevance when developing a reactive agility assessment, in particular the selection of the stimulus.

![Diagram: Three-stage information-processing model](image)

**Figure 2.3**: Interaction of the three-stage information-processing model to movement output in reactive agility (Schmidt & Wrisberg 2008).

While there is a constant flow of information from internal and external sources, information processing in the agility actions investigated here can conceptually be considered to begin with important input cues such as identifying the movements of opponents and teammates (*stimulus identification*). From that stimulus the athlete generates a number of possible
response options, considers their likelihood of success based on their knowledge, experience and various task and environmental constraints and then selects an appropriate response (e.g., an evasive sidestep) (*response selection*). Then, the action is planned (*response programming*) and once these stages are complete the movement is executed (*output*). The success of the action is then fed back and becomes an important source of input as the game environment changes, based on the preceding action, and can then be used to update the action plan. This is a constant process, with new inputs from the constantly changing game environment being encountered throughout the game; accordingly, the output is being continually attuned in response to the ever-changing game environment.

Few reactive agility studies have specifically investigated the interaction of the perceptual and decision making branch of the model in Figure 2.1. Nonetheless, there is some evidence to suggest that the type of stimulus and the level of familiarity of the athletes can influence stimulus identification and response selection speed and accuracy (Farrow & Raab, 2008; Jeffreys, 2011; Lee, Lloyd, Lay, Bourke, & Alderson, 2013; Serpell, Young, & Ford, 2011). This has important implications when developing a reactive agility test as its sensitivity will therefore be influenced by the stimulus delivery mode, situational familiarity and complexity (Lee, et al., 2013; Mann, Williams, Ward, & Janelle, 2007; Young & Farrow, 2013; Young, et al., 2011).

For example, it is believed that stimuli should closely represent real-world tasks, as generic or non-specific scenarios will not provide higher calibre players with the opportunity to exploit any perceptual and decision making advantage (Lee, et al., 2013; Young & Farrow, 2013). Consequently, the challenge for researchers is to develop ecologically valid methods that capture the essence of the on-field task, whilst still maintaining a degree of flexibility and experimental control (Mann, et al., 2007; Sheppard & Young, 2006; Williams, Davids, Burwitz & Williams, 1993). For that reason, an understanding of how the perceptual and cognitive factors differ between different stimulus modes and athletes is required, including how these factors might change as an athlete’s sport-specific cognitive knowledge base develops (Mann, et al., 2007; Williams & Ford, 2008; Williams & Ward, 2003).
2.2.1 Perceptual skill in agility

A large array of sensory input information is available for athletes undertaking complex sporting tasks, including information arising from within the body (proprioception and interoception) and from the external environment (exteroception). However, both exteroceptive and proprioceptive inputs are considered more important than interoceptive for tasks such as reactive agility (Schmidt & Wrisberg, 2008). Nevertheless, since this current chapter focuses on the perceptual aspects of reactive agility the discussion will centre on the exteroceptive sensory inputs (visual, auditory). In particular, since the visual system plays a key role in detecting, selecting and recognising relevant stimuli (Schmidt & Wrisberg, 2008; Tenenbaum, 2003) and is therefore the dominant exteroceptive input, it will be the primary input discussed.

When discussing the visual system and its importance in complex sporting activities such as reactive agility the distinction should be made between the generalised structural or “hardware” components (e.g., depth perception and acuity) and the visual-perceptual system or “software” components (e.g., visual search behaviours) (Farrow & Raab, 2008; Williams, et al., 1993). Hardware factors have less influence than software factors on sports performance (Williams, et al., 1993), therefore specific attention will be given to the potential role of visual search behaviours in reactive agility performance and how these may differ between various stimulus modes and different calibre athletes.

Visual search behaviours involve locating and discriminating relevant information from the visual field and feeding that into the process illustrated in Figure 2.3 for selection and execution of an appropriate response (Mann, et al., 2007; Tenenbaum, 2003). Distinct differences in the visual search behaviours of expert and non-expert athletes have been identified which may have implications for reactive agility testing and performance (Sheppard, 2004; Tenenbaum, 2003; Williams & Ford, 2008; Young & Farrow, 2013). For example, expert performers have fewer gaze fixations (gaze held on an object or location for at least 100 ms and within three degrees of visual angle) of a
longer duration than non-experts (Lee, 2011; Tenenbaum, 2003; Williams, et al., 1993; Williams & Ford, 2008). Thus, experts use a context control strategy where their gaze is fixed (less fixations, longer duration) on information-rich areas of the display and essential aspects are chunked together into meaningful images (Tenenbaum, 2003). Accordingly, through appropriate training expert performers learn to extract greater amounts of more relevant information from fewer fixations and use that information to make earlier response choices (Farrow & Raab, 2008; Helsen & Starkes, 1999; Tenenbaum, 2003; Williams & Ford, 2008).

In contrast, non-experts use a target control search strategy where the gaze moves across the whole scene to many points (thus more fixations), both relevant and non-relevant. However, a target control strategy is less efficient because firstly, less information can be extracted during the saccadic eye movements and secondly, during elaborate (e.g., multi-movement of multi-player), fast-paced tasks, target control is conducted serially leaving less time to locate and process the information, resulting in missed information and decision making errors (Mann, et al., 2007; Tenenbaum, 2003). These differences in search strategies between experts and non-exerts have implications for reactive agility stimulus selection because, when presented with generic (lights) or unfamiliar (not context or sport-specific) stimuli, expert performers may revert back to a target control strategy. Evidence supporting this theory is provided by Mann and colleagues (2007) who reported that differences between experts and novices for gaze fixation duration are greatest when tests are field-based (familiar), but smaller using video-based stimuli and smaller again when viewed as (unfamiliar) static slides.

Also, in an agility context, Lee (2011) observed that when completing a sidestepping task in response to either a 2-dimensional (2-D) or 3-dimensional (3-D) video of an opponent, participants spent significantly less time fixating on the opponents trunk and more time outside their body using the 3-D stimulus. However, as there was no difference in the time taken to intercept the opponent it is uncertain which strategy was superior. Furthermore, there was no comparison between different athletes so it is unknown if these
strategies will vary further between higher and lower performing players. Even so, collectively these findings support the notion that stimulus complexity may influence visual search behaviour. Therefore, during reactive agility assessments more sport-specific stimuli might offer higher performing athletes the opportunity to use more efficient visual search behaviours, developed through longer and more effective practice regimes (Veale, et al., 2010; Young, et al., 2011).

2.2.2 Cognitive skill in agility

Following the identification of key cues from the visual field, information processing moves on to response selection and programming (Schmidt & Wrisberg, 2008). During these phases athletes must choose an appropriate response (from a range of options) based on their familiarity, knowledge, experience and other task and environmental constraints, and then execute that response. Although numerous processes contribute to skilled movement, cognitive research consistently shows that expert performers in various domains:

- Are faster and more accurate in recognising and recalling complex sport-specific patterns of play (Berry, 2004; Helsen & Starkes, 1999; Williams & Ford, 2008; Williams & Ward, 2003).

- Can more accurately anticipate the actions of opponents and so are less susceptible to deceptive movements (Jackson, Warren, & Abernethy, 2006; Williams & Ford, 2008).

- Have faster and more accurate decision making ability (Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Gabbett, Rubinoff, Thorburn, & Farrow, 2007; Mann, et al., 2007).

These attributes generally relate to superior declarative (what to do) and procedural (how to do it) knowledge, developed through competition experience and structured practice regimes, which can be retrieved faster and results in better players making quicker, more accurate decisions (Baker, Cote & Abernethy, 2003; Berry, 2004). Put another way, these better players
have a superior ability to read, interpret and respond to the play (Abernethy, 2003; Farrow & Raab, 2008; Williams & Ford, 2008). In contrast, lower standard athletes may not see the relevant information (less efficient visual search strategies), or perhaps can see it but not have the declarative knowledge or experience of what to do about it (poor response selection), or know what to do but lack the procedural knowledge or movement skill to execute the action efficiently (poor response programming or execution) (Abernethy, 2003; Helsen & Starkes, 1999).

Therefore, since decision making skill and on-field performance has links with experience and situational familiarity, the nature of the stimulus has important repercussions for agility testing (Young & Farrow, 2013). Firstly, since planned agility tests and tasks do not include a decision making element they are clearly not able to assess this component at all. This has led to doubts over the ecological validity of historical pre-planned tests and to the theory that on-field agility for invasion sports such as Australian football is best measured using a reactive agility protocol (Serpell, et al., 2010; Sheppard & Young, 2006; Sheppard, et al., 2006; Young & Farrow, 2013). This theory is supported experimentally in studies showing that reactive agility tests are able to detect performance differences between different standards of athletes, where planned agility tests do not (Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Serpell, et al., 2010; Sheppard, et al., 2006; Young, et al., 2011).

Secondly, reactive agility studies have also observed that decision making speed is the primary source of differences in performance between different standards of athletes, with the higher standard players making faster decisions (Farrow, et al., 2005; Serpell, et al., 2010). These results confirm that higher standard athletes are able to extract and interpret important cues faster during reactive agility assessments than lesser skilled athletes. However, as has been shown in other domains (Abernethy, 2003; Farrow & Raab, 2008; Williams & Ford, 2008), these studies also provide some indirect evidence that to maximise the opportunity for the superior athletes to use this enhanced cognitive and decision making skill the stimuli in reactive
agility tests should be specific to the sport (Sheppard & Young, 2006; Young & Farrow, 2013).

For example, Young et al. (2011) compared reactive agility in junior (15 - 17 y) Australian footballers and observed that elite players were faster than non-elite players using a test with a video projection of an opponent changing direction. However, in contrast, there were no concomitant group differences on a test using a generic arrow indicator. Although decision making speed per se was not examined, the primary difference between the test modes was the nature of the stimulus, therefore the disparity was, in all likelihood, due to differences in decision making speed and ability (Young & Farrow, 2013; Young, et al., 2011). Accordingly, these findings support the view that the higher standard players were able to extract greater information more quickly in the (familiar) sport-specific task, but had no such advantage in the (less familiar) generic task, as there was little scope for anticipation or interpretation.

Furthermore, Lee (2011) identified that differences in decision accuracy (decision making quality) between higher standard and lower standard soccer players were comparatively greater during a 3-D video simulation involving two opponents (complex but familiar) when compared to an unplanned arrow stimulus (simple but generic), a single defender 3-D video scenario (familiar) and a planned arrow scenario (generic, no perceptual component). Therefore, although accuracy decreased for all players as the stimulus became more complex (e.g., two defender scenario), accuracy in the lesser standard players decreased significantly more than their higher standard peers. Similarly, when Jackson et al. (2006) increased the complexity of their stimulus by introducing deceptive movements (feints) they also observed that decision accuracy was maintained in the higher standard players, but decreased in the lower standard players.

Therefore collectively, these studies support the notion that higher calibre players are able to anticipate opponent actions and postural cues and recognise patterns of play faster and more accurately. However, this superiority in perceptual and anticipatory skill in higher standard players is
more obvious when using sport-specific, rather than generic, stimuli. Furthermore, it is also apparent that as the complexity of the stimulus increases (such as with the inclusion of feints or multiple opponents) greater demands are placed on the decision making process, resulting in decreases in speed and accuracy in lower calibre players, due to limitations in their perceptual and anticipatory abilities (Jackson, et al., 2006; Lee, 2011). Nevertheless, without empirical data from direct comparisons of the decision making speed between generic, simple sport-specific and complex sport-specific stimuli these findings remain speculative. Therefore, more research is required to confirm and quantify how agility responses vary between different athletes using different stimuli and incorporating tasks with varying complexities.

2.2.3 Effect of deceptive movement

A feint typically involves two closely spaced, but opposing movements (stimuli) by an attacking player, which elicits a similar response from a defender, although it might also involve a fake ball pass or shot on goal in some instances (Schmidt & Wrisberg, 2008; Serpell, et al., 2010). Despite the fact that feints are a common tactic in a variety of sports (Jackson, et al., 2006; McClymont, 2005), their effect on decision making speed and accuracy has received little research attention from both a reactive agility and broader perceptual-cognitive expertise context (Abernethy, 2003; Jackson, et al., 2006). Reactive agility tasks involving feints increase the cognitive demands of an agility scenario (McClymont, 2005; Schmidt & Wrisberg, 2008) but also result in multiple changes of direction, thereby increasing the physical task demands as well. Nevertheless, while this underscores the value in using feint scenarios in reactive agility research, almost all of the reactive agility tests to date have incorporated a single stimulus, requiring only one turn (Duvnjak-Zaknich, et al., 2011; Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Gavin, 2008; Oliver & Meyers, 2009; Serpell, et al., 2010; Sheppard, et al., 2006). Indeed, just two reactive agility studies have incorporated more than one turn, one involving a pre-planned shuffling movement prior to the presentation of the stimulus (Farrow, et al., 2005) and in the other the
second turn was a planned response following an initial, reactive response (Veale, et al., 2010).

The basis for the effectiveness of the feint is the double-stimulation paradigm (McClymont, 2005; Schmidt & Wrisberg, 2008), where the reaction to the first of two closely-spaced stimuli is normal, but the reaction to the second is delayed by more than that which would have occurred had it been presented alone (McClymont, 2005; Schmidt & Wrisberg, 2008). This lengthening of the second reaction is due to the psychological refractory period (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008) that is caused by a bottleneck, due to serial processing in the response programming stage of information processing (Figure 2.3). Consequently, the response for the second stimulus is delayed until the response to the first is dealt with (Schmidt & Lee, 2005). In practice, this results in the defending player’s response to the second movement being delayed by more than if it were presented alone, rewarding the attacker with a greater time advantage.

However, due to a superior ability to utilise advance postural cues and a greater understanding of opponent motion information, which may provide an early warning of a feint (Williams & Ford, 2008), expert sports performers are thought to be less susceptible to feints (Jackson, et al., 2006; Williams & Ford, 2008). Support for this notion can be seen in the work of Jackson et al. (2006) who examined the effect of deceptive movement on Rugby players using a video-based temporal occlusion test coupled with a written response. They observed that experts were able to anticipate deceptive movements more often and maintained decision accuracy with the inclusion of feint trials, whereas decision accuracy decreased in lower standard players. However, as there was no perception-action coupling it is unclear whether the written results from that study would extend to a faster and more accurate physical agility response as well. On the other hand, when Serpell et al. (2010) included both deceptive player and ball movements in their examination of reactive agility in Rugby League they observed that elite players were faster than sub-elite players. But, feint trials were not differentiated from single stimulus trials and specific findings about the impact of feints were not offered.
Nevertheless, these two studies provide some support for the theory that higher performing athletes are less susceptible to feints. However, including complex feint scenarios in reactive agility research and specifically examining the impact on decision making speed and accuracy will provide clearer insight into the validity of this hypothesis. Furthermore, by showing that single turn agility tasks were not able to discriminate Rugby players of differing standards, whereas feint tasks could, Jackson, et al. (2006) demonstrated that superior decision making accuracy (and potentially agility performance) of higher standard athletes might only become apparent as the difficulty of the task increases beyond the generic agility skills easily mastered by many athletes (Djevalikian, 1992). Accordingly, this supports the inclusion of feint scenarios in reactive agility research since, had Jackson, et al. (2006) not included feints, no group differences would have been evident.

However, the advantage from a feint is not limited to a time gain brought about through a delay in information processing, but also by causing an opponent to shift momentum in the wrong direction or to adjust momentum (e.g. slow down), putting the opponent in a poorer position from which to undertake subsequent actions. This then requires a substantial (and time consuming) effort to arrest and redirect the body’s inertia (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008). Therefore, while much of the focus of the impact of deceptive movements has been on decision making ability, the multiple changes of direction involved in responding to feints also increases the physical complexity of agility manoeuvres (Young, et al., 2001). Indeed, the use of multiple-turn tasks has been a common feature of historical pre-planned agility research (Little & Williams, 2005; Tumilty, 1993; Young, et al., 1996) and tests such as the T-test (Hawley & Burke, 1998), 3-cone drill (McGee & Burkett, 2003) and Australian Football League (AFL) Draft camp test (Pyne, Gardner, Sheehan & Hopkins, 2005) have successfully discriminated athletes of different abilities and predicted draft status and career progression in both the National Football League (NFL) and AFL. Nonetheless, the impact of deceptive movements and multiple changes of direction on agility performance and movement speed have yet to be specifically considered in a reactive agility context.
Therefore, reactive agility tests involving deceptive movements may have advantages in the ability to detect agility differences between different standard athletes, due to disparities in either the perceptual or physical sub-components of agility, particularly in higher standard athletes. For that reason, a reactive agility test that can be manipulated to include deceptive movements could appeal as having good ecological validity for many field sports.

2.3 PHYSICAL FACTORS

2.3.1 Speed

Linear sprinting speed and agility are both considered important components in team sport performance (Ellis, et al., 2000; Hawley & Burke, 1998) and are commonly thought to be related, whereby a fast athlete should also be an agile one (Barnes & Attaway, 1996; Faccioni, 1994; Gambetta, 1996; Renfro, 1997; Robinson & Owens, 1994; Stewart & de Bes, 2001). However, as with most agility research, studies examining this relationship have typically involved planned agility tasks, but nonetheless have generally found that straight-line speed and agility are relatively independent qualities (Brughelli, et al., 2008; Little & Williams, 2005; Sheppard & Young, 2006; Wheeler, 2009). Recently though, a small number of studies have compared linear speed to reactive agility, with equivocal results. For example, two studies have observed lower correlations ($r = 0.29$ to $0.51$) between speed and reactive agility than between speed and similar planned agility tasks ($r = 0.52$ to $0.74$) (Gabbett, Kelly, et al., 2008; Sheppard, et al., 2006). In contrast, another found a strong relationship between 10 m-straight line speed and both planned ($r = 0.93$) and reactive agility ($r = 0.83$) (Oliver & Meyers, 2009). However, the study by Oliver and Meyers (2009) incorporated a generic light-based stimulus and the timing of the stimulus was largely known, thereby limiting temporal uncertainty. Potentially, this may have allowed an element of pre-planning, resulting in participants approaching and negotiating the turn faster.
Furthermore, it is also noteworthy that the study by Oliver and Meyers (2009) included a 5 m straight sprint approach, meaning the proportion of linear sprinting in that test was longer than the 2 m approach used in alternative protocols (Gabbett, Kelly, et al., 2008; Sheppard, et al., 2006). Subsequently, the larger proportion of straight sprinting may have contaminated the agility test with linear speed, resulting in a stronger relationship than would otherwise have been expected. Indeed, the authors stated “… the determining factor in the reactive test may be the ability to both accelerate at the start of, and again midway through the test, rather than the ability to detect and change body position…” (p. 352). Therefore, based on the limited data available it appears that, as with planned agility, the link between linear speed and reactive agility is weak, but may be artificially inflated when an agility test includes significant amounts of straight line sprinting.

Nevertheless, regardless of the limited functional link between speed and agility there may still exist a practical relationship, with linear sprints being a common transition movement which links together different agility and other sport-specific tasks (Jeffreys, 2011). Evidence for this can be seen in Australian football where over half of all sprints included a change of direction (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004). Further, in Rugby, receiving the ball at high speed just prior to executing an evasive side-step was found to be the most effective strategy for producing missed tackles (Wheeler, Askew, & Sayers, 2010). Consequently, the direct impact of speed on agility is likely to include the effect of sprint technique on the ability to efficiently position the body to respond to a stimulus and produce an effective agility manoeuvre (Sayers, 2000). However, the specific role of agility technique has received little research attention to date.

2.3.2 Technique

Reactive agility is broadly defined as a rapid whole-body movement with a change of velocity or direction in response to a stimulus (Sheppard & Young, 2006). Yet, the actual changes of direction can assume many forms, including a pivot (Cortes, et al., 2009; Twist & Benicky, 1996), a dropstep (Verstegen &
or more classically, a distinct cut using the outside (sidestep) or inside leg (cross-over cut) (Besier, Lloyd, & Ackland, 2003; Besier, Lloyd, Ackland, et al., 2001; Wheeler, et al., 2010). Intuitively, each of these manoeuvres will have its own unique technique (Besier, et al., 2003; Besier, Lloyd, Cochrane, & Ackland, 2001; Cortes, et al., 2009; Cowley, Ford, Myer, Kernozek, & Hewett, 2006), requiring manipulations of a range of sub-components such as stride rate, foot position, posture and muscle activation patterns, with differences in these components influencing performance (Lee, et al., 2013; Sayers, 2000; Sheppard & Young, 2006; Wheeler, 2009; Young & Farrow, 2006).

For example, Bradshaw and colleagues (2010) observed significant differences in foot plant preparation time and total time between different agility techniques (side-step, shuffle and split-step), with the side-step being the fastest (foot plant 0.66 ± 0.07 s and total 1.57 ± 0.10 s) and the split-step the slowest (foot plant 0.75 ± 0.07 s and total 1.71 ± 0.11 s). However, paradoxically, the split-step produced a greater on-field advantage for the offensive player since response time and accuracy of defensive players viewing a video of the three manoeuvres was significantly worse for the split-step. Therefore, although this is yet to be confirmed in agility tasks coupling perception to a sport-specific action, it does indicate that what, at first glance, appears to be the best technique may ultimately prove not to be, depending on the circumstances of the game, underlining the context-specific nature of agility (Jeffreys, 2011).

Additionally, what is seemingly the same agility task (e.g., a side-step) will have a slightly different technique when performed in a reactive manner rather than pre-planned (Besier, Lloyd, Ackland, et al., 2001; Houck, et al., 2006; McLean, Lipfert, & van den Bogert, 2004). For instance, unanticipated sidestepping exhibits a generalised pattern of increased knee valgus and internal rotation moments (Besier, Lloyd, Ackland, et al., 2001), reduced lateral foot placement and hip abduction angles, increased trunk angle (Houck, et al., 2006; Lee, et al., 2013) and increased leg muscle activation (Besier, et al., 2003). Consequently, these differences in technique and
muscle activation patterns also underscore the importance of understanding and distinguishing reactive and planned agility and assessing agility using the most appropriate mode.

Nevertheless, while agility can include various context-specific techniques, there are still likely to be some common elements between them, but it remains unclear what these are and their transferability from one domain to another (Jeffreys, 2011). For instance, some authors have speculated that there may be common underlying leg strength characteristics and that improvements in strength may augment agility (Brughelli, et al., 2008; Jeffreys, 2011).

2.3.3 Leg muscle qualities

Due to the high muscle loads encountered during many agility actions the specific link between agility and leg muscle characteristics, such as strength, reactive strength and power has been of considerable interest to researchers historically (Besier, et al., 2003; Besier, Lloyd, Ackland, et al., 2001; Brughelli, et al., 2008; Hilsendager, Strow, & Ackerman, 1969; Markovic, 2007; Ouverson, 2004; Young, et al., 1996; Young, et al., 2002). Yet, despite this attention the explicit contribution of strength and power to agility performance and the ideal method for training these qualities to maximise agility remains elusive (Brughelli, et al., 2008; Sheppard & Young, 2006; Young & Farrow, 2006). This is partly due to the complexity and variability of agility movements and the choice of tests in earlier studies. For example, although agility is expected to include some universal strength qualities, such as the eccentric strength of the lower extremity prime movers (Young & Farrow, 2006), the specific nature of this will ultimately be determined by the type, intensity and context of the particular agility manoeuvre (e.g., reactive versus planned, single versus multiple turn). However, for simplicity the following discussion will centre on the classical image of agility, namely the single side-step, coupled with the model of agility proposed by Ziemba (1995). Here, agility specifically involves the last two steps of deceleration (following the decision making element), the lateral step (foot plant) and the first step in the new direction. However, this
discussion and its relevance to reactive agility should be viewed with the limitations of the previous research in mind, given that much of it relates to planned rather than reactive agility tasks.

Also, assuming that lower extremity strength and power alone represent the muscle characteristics involved in reactive agility may be rather simplistic, since agility will involve significant intra- and inter-muscular coordination and strength throughout the entire kinetic chain, including core strength and stability (Twist & Benicky, 1996; Young & Farrow, 2006). Finally, agility manoeuvres are predominantly unilateral and involve lateral movements (Brughelli, et al., 2008; Markovic, 2007; Salonikidis & Zafeiridis, 2008), however for the most part current agility-strength research uses bilateral and sagittal plane strength and power tests (Barnes, et al., 2007; Jones, Bampuras, & Marrin, 2009; Peterson, Alvar, & Rhea, 2006; Vescovi & McGuigan, 2008; Young, et al., 1996; Young, et al., 2002). Therefore, whether these types of tests are appropriate for the assessment of agility is questionable and again the discussion should be viewed with that in mind.

**Strength**

During a side-step, high levels of eccentric strength in the hip, knee and ankle extensors are considered important due to the necessity to absorb the initial impact, decelerate the centre of mass and reduce horizontal momentum to a manageable level (Green, Blake, & Caulfield, 2011; Twist & Benicky, 1996; Young & Farrow, 2006; Young, et al., 2002). For example, a planned sidestep can produce peak quadricep activations of up to 149% of maximum voluntary isometric contraction, likely due to high eccentric activation (Colby, et al., 2000). Furthermore, unanticipated sidestepping produces net increases in muscle activation of 10-25% over a planned sidestep (Besier, et al., 2003), indicating even greater muscle loads occur during reactive movements, including eccentric loads.

Nevertheless, a study examining isokinetic eccentric knee flexor strength observed a relatively low association \((r = -0.39)\) with planned agility (505 test), with a similar relationship found between planned agility and
concentric knee flexor strength (Jones, et al., 2009). Therefore, the role of eccentric strength in agility performance may be less important than previously thought, although given the limited number of studies it is difficult to draw a definitive conclusion. Furthermore, since strength training has improved loaded and unloaded jump squat performance via improvements in the eccentric phase (Cormie, McGuigan, & Newton, 2010), there may be scope to also improve agility by enhancing general and eccentric strength in the lower extremities (Jones, et al., 2009).

Other studies have compared various dynamic maximal strength tests with agility, with equivocal results (Young & Farrow, 2006). For example, back squats had a low correlation with planned agility in one study ($r = -0.17$ to $-0.31$) (Markovic, 2007) but a stronger association ($r = -0.78$) in another (Peterson, et al., 2006). Furthermore, although a moderate ($r = -0.51$) correlation was found between 1 repetition maximum (1RM) front squat and the 505 agility test (Hori, et al., 2008), a stronger correlation was evident when maximum strength was expressed relative to body mass ($r = -0.80$) (Nimphius, McGuigan, & Newton, 2010; Peterson, et al., 2006). Therefore, based on the limited evidence available, maximal strength, particularly when expressed relative to body mass, may play a role in planned agility performance; therefore its role in reactive agility and in using strength training to augment agility training should be examined. However, the use of bilateral vertical movements such as the squat may not accurately reflect the primarily single-leg lateral actions involved in many agility tasks. This may help explain these equivocal results and future researchers should bear this in mind. Moreover, agility manoeuvres ideally involve short ground contact times and fast, powerful concentric contractions of the leg extensors and consequently leg extensor power is also thought to be an important determinant of agility performance (Markovic, 2007; Sheppard & Young, 2006).

Power

The potential for leg power to exert a strong influence on agility performance means the relationship between these characteristics has been
more extensively examined than for other types of strength (Barnes, et al., 2007; Djevalikian, 1992; Markovic, 2007; Mayhew, Piper, Schwegler, & Ball, 1989; Negrete & Brophy, 2000; Vescovi & McGuigan, 2008; Young, et al., 1996; Young, et al., 2002). Typically, leg power has been assessed indirectly by using jump height on various vertical jump tests (Barnes, et al., 2007; Jones, et al., 2009; Vescovi & McGuigan, 2008) and variations of Olympic weightlifting such as power cleans (Hori, et al., 2008). Although technically neither jump height nor Olympic weightlifting (weight lifted) are specific measures of leg power, there is often a good relationship recorded between them (Brughelli, et al., 2008). Notwithstanding that, studies have commonly reported only moderate correlations between jump height and agility ($r < -0.5$) (Barnes, et al., 2007; Hori, et al., 2008; Jones, et al., 2009; Vescovi & McGuigan, 2008; Young, et al., 1996). Similarly, moderate associations between 1RM hang power cleans and planned agility performance have also been reported ($r = -0.34$ to $-0.41$) (Hori, et al., 2008).

However, other studies directly measuring power output (via force plate measures, etc.) during various vertical jumps have sometimes reported higher correlations with planned agility times than those simply using jump height (Hori, et al., 2008; Nimphius, et al., 2010; Peterson, et al., 2006). For example, Peterson et al. (2006) observed large correlations between countermovement jump peak power and agility T-test time ($r = -0.74$), as did Nimphius et al. (2010) between unloaded jump squat peak power and the 505 agility test ($r = -0.66$ for non-dominant leg and $r = -0.73$ turning off the dominant leg). Additionally, some moderate to strong associations ($r = -0.38$ to $-0.89$) were also reported between planned agility times and power measured during loaded (20kg to 40 kg and up to 80% of 1RM) jumps squats (Hori, et al., 2008; Nimphius, et al., 2010).

Therefore, while the range of correlations between unloaded vertical jumps and agility are generally modest (Brughelli, et al., 2008; Jeffreys, 2011; Young & Farrow, 2006) stronger relationships were apparent between agility and power measures using countermovement jumps and jump squats, in particular, loaded jump squats (Hori, et al., 2008; Nimphius, et al., 2010). As such, there appears to be some common factors involved in the ability to
generate power under higher stretch-shortening loads, commonly termed reactive strength, and agility performance (Ebben & Petushek, 2010; Young, et al., 1996). This is consistent with the prediction of several authors that such an association is likely, due to the high stretch-shortening cycle loads also thought to also be involved in agility (Besier, et al., 2003; Colby, et al., 2000; Markovic, 2007; Young, et al., 2002).

Reactive strength

Reactive strength has been highlighted as a unique strength characteristic thought to be important in agility performance, because high intensity changes of direction require a quick transition from eccentric contractions (to absorb momentum in one direction), to explosive concentric contractions (to produce movement in the new direction) (Jeffreys, 2011; Young & Farrow, 2006; Ziemba, 1995). Indeed, the potential for harnessing this energy from the stretch-shortening cycle to enhance agility performance has been demonstrated by shorter ground contact times and a significantly earlier transition from knee flexion to knee extension (stretch-shortening cycle) in the plant leg during pre-planned sidestepping in Rugby starters versus non-starters (Green, et al., 2011). Consequently, the starters decelerated for a shorter period and transitioned to acceleration earlier than non-starters, potentially providing an advantage over an opponent, though this was not examined (Green, et al., 2011).

Often, reactive strength is measured using drop jumps from various heights and can be expressed as jump height or, more commonly, a reactive strength index (jump height/ground contact time) since this requires a combination of short ground contact times and explosive movement (Barnes, et al., 2007; McClymont & Hore, 2004; Young, et al., 2002). However, relatively few studies have specifically investigated the association between reactive strength and agility, nevertheless there is some evidence of a relationship, particularly for the strongest athletes (Barnes, et al., 2007; Djevalikian, 1992; Young, et al., 2002). For instance, correlations ranging from -0.22 to -0.71 were observed between drop jump height and reactive strength index and various single and multiple-turn planned agility times.
(Barnes, et al., 2007; Young, et al., 2002), although the resulting common variances of 10 - 50% are relatively modest, indicating a degree of independence (Young & Farrow, 2006). However, Djevalikian (1992) observed that the more powerful athletes tended to also perform better on the Boomerang test ($r = -0.42$ to $-0.65$) than the less powerful athletes ($r= -0.42$ to $-0.47$), leading the author to ponder the importance of motor skill mastery in agility. Likewise, Young and colleagues (2002) observed that a sub-group who displayed a significant advantage (>3%) in turning ability to the left (pushing off the right leg) also displayed a relatively large reactive strength discrepancy (13%) in favour of the right leg. Moreover, the participants with the largest reactive strength asymmetry (>20%) demonstrated a 4% better ability in turning to the left.

Therefore, while superior ability to both change direction and jump off the same leg may be due to reactive strength asymmetries, it may also reflect a general superiority in motor skill (or a combination) in that leg, as it may be favoured during many sporting activities. So, potentially greater motor skill, combined with enhanced reactive strength, could lead to the best performance (Djevalikian, 1992). Consequently, increased power might be useful in agility only if it can be effectively harnessed within an efficient motor pattern and that “… as power is added to a mastered athletic skill, there is an increase in the execution speed of the skill in question (Djevalikian, 1992) (p 60-61)”. Conversely, a powerful athlete who lacks the appropriate motor skill to effectively apply that power to the movement may not perform as well (such as when using the non-dominant leg). Thus, while many athletes may be powerful or skilful it is unlikely that either will be as agile as an athlete who is both powerful and skilled. Moreover, superior agility may only become apparent, particularly in advanced athletes, during high intensity or complex agility tasks (such as those involving multiple movements) where both the leg muscle qualities and the motor skills are highly challenged. This has important implications for agility testing, as an agility test will be more useful if it is able to discriminate athletes with varying degrees of agility skill even in relatively homogenous elite sporting teams.
In conclusion, high-load reactive strength could be more important than absolute strength and/or power for agility performance, particularly in higher standard athletes or where there are asymmetries in strength between the legs. However, given that all these aforementioned studies examined planned (rather than reactive) agility, caution should be exercised in extrapolating these results to reactive agility tasks, where little is known about the strength requirements, other than they are likely to be higher (Besier, et al., 2003). Additionally, the specificity of the reactive strength and power tests used previously are once again questionable, since they typically involve bilateral and vertical actions, in contrast to the single leg, lateral and horizontal actions common to agility manoeuvres (Brughelli, et al., 2008; Meylan, et al., 2009; Sheppard & Young, 2006). Therefore, unilateral tests of reactive strength, particularly if combined with reactive agility tests, may offer greater insight into the role of strength within on-field agility.

Unilateral strength and power

Notwithstanding the theoretical basis for the role of unilateral strength and power in agility, the relationship between these characteristics has received little attention from researchers, with none examining it in relation to reactive agility. Nonetheless, the available data, using planned agility tests, points to a limited association with unilateral strength, particularly when applied in the vertical plane (Djevalikian, 1992; Markovic, 2007; Meylan, et al., 2009; Negrete & Brophy, 2000; Young, et al., 2002). For example, Markovic (2007) observed that, although a one-leg rising test exhibited a stronger correlation with various agility tests ($r = -0.30$ to $-0.44$) than squat jump power ($r = -0.15$ to $-0.35$), standing long jump ($r = -0.12$ to $-0.27$) and 1RM back squat ($r = -0.17$ to $-0.31$), the relationship was not particularly strong. In addition, moderate correlations were reported between various multiple-turn agility tests and a single-leg hop for distance ($r = -0.65$) and single leg vertical jumps ($r = -0.25$ to $-0.52$) (Meylan, et al., 2009; Negrete & Brophy, 2000).

Nevertheless, evidence was presented earlier that strength discrepancies of >10% in favour of one leg can result in superior agility performance when
pushing off that same leg (Young, et al., 2002). Interestingly, this is a finding that is only apparent when single leg strength measures are used and therefore another advantage of using unilateral tests for strength and power is that they may be able to detect functionally important leg strength and skill asymmetries. In contrast however, another study reported that differences in single leg vertical jump performance of <10% were not associated with any significant differences in agility performance in either direction (Djevalikian, 1992). Therefore, vertically applied reactive strength is not particularly sensitive to differences in agility performance and reactive strength asymmetries may only mirror variations in agility performance when the strength differences are large (>10%). Thus, based on the limited evidence currently available, unilateral vertical reactive strength plays a limited role in agility performance, although more research is needed to investigate this further. Nevertheless, the sensitivity of these previous unilateral reactive strength and power tests may be diluted due to the fact that agility movements involve predominantly lateral and horizontal force production, rather than the vertical movements performed in these aforementioned unilateral tests (Brughelli, et al., 2008; Meylan, et al., 2009).

Therefore, as outlined earlier, athletes without the necessary skill mastery may not be able to exploit any strength advantage applied in the vertical plane during the predominantly lateral movements involved in many agility tasks, until such a strength advantage is very large (Brughelli, et al., 2008; Holm, Stalbom, Keogh, & Cronin, 2008; Maulder & Cronin, 2005; Meylan, et al., 2009). Alternatively, unilateral reactive strength and power tests involving significant horizontal and lateral elements may be more sensitive to the differences in agility performance due to the similarity of the actions (Brughelli, et al., 2008; Meylan, et al., 2009). Unfortunately, this notion has received no attention from researchers using reactive agility, and only one study has investigated this in relation to planned agility, surprisingly finding limited association (Meylan, et al., 2009).
Evidence supporting the involvement of lateral forces in agility can be seen in the work of Gavin (2008) and Smith, Dyson, Hale & Janaway, (2006), where lateral and diagonal first step movements and curved-linear sprints respectively produced significantly greater medio-lateral ground reaction forces than forward movements. In addition, other studies have observed that pre-planned sidestepping movements produce increased medial leg muscle activation (Besier, et al., 2003) and increased torso rotation and lean (Houck, et al., 2006; Jindrich, Besier, & Lloyd, 2006) compared to straight line running and walking. Furthermore, when earlier discussing technique considerations in reactive agility, it was noted that unanticipated sidestepping produced increased knee valgus and internal rotation moments (Besier, Lloyd, Ackland, et al., 2001), reduced lateral foot placement and hip abduction angles and increased trunk angles (Houck, et al., 2006; Lee, et al., 2013). Therefore, the different patterns of leg and trunk muscle activation resulting from the greater medio-lateral forces involved in lateral agility manoeuvres is unlikely to be assessed effectively by vertical jump tests (Besier, et al., 2003; Brughelli, et al., 2008; Markovic, 2007).

Consequently, to investigate the leg strength and power qualities involved in changes of direction, tests involving significant lateral and rotational elements seem functionally more appealing (Brughelli, et al., 2008). However, literature examples of this are rare, with only one study (Meylan, et al., 2009) comparing unilateral vertical, horizontal and lateral counter-movement jumps to a 20 m agility test incorporating two 180° turns. In that study, Meylan and colleagues (2009) reported that although the jumps were significantly correlated with each other ($r = 0.36$ to $0.66$) the modest common variance ($r^2 = <44\%$) suggests they are relatively independent and assess different leg strength and power characteristics. However, when comparing performance on the different jumps to agility the lateral jumps exhibited the weakest association ($r = -0.11$ to $-0.40$), while the horizontal jump was found to have highest predictive value ($r = -0.46$ to $-0.59$), with vertical jumps the next best ($r = -0.25$ to $-0.52$) (Meylan, et al., 2009).
Nevertheless, while no previous studies have involved lateral jump tests, the findings from Meylan et al. (2009) are consistent with other studies showing stronger relationships between agility and horizontal, rather than vertical jumps (Negrete & Brophy, 2000; Peterson, et al., 2006). Consequently, Meylan and colleagues (2009) concluded that the weak relationship between lateral jumps and agility was because the majority of the agility test actually involved (horizontal) linear sprinting, resulting in the stronger association with horizontal jumps (e.g., linear speed contaminated the agility test). In contrast, the two changes of direction represented only a very small proportion of the movement, thereby limiting the potential role of lateral leg strength (Meylan, et al., 2009).

Accordingly, these results highlight the need to more effectively isolate the change of direction component in future agility tests to provide a clearer insight into the specific strength characteristics involved in agility, rather than in linear sprinting. Furthermore, up to now, researchers have primarily focussed on the association (correlations) between various strength characteristics and agility (Djevalikian, 1992; Markovic, 2007; Meylan, et al., 2009; Negrete & Brophy, 2000; Young, et al., 2002). However, correlations do not infer cause and effect (Brughelli, et al., 2008; Meylan, et al., 2009) and therefore examining the longitudinal effects of different strength training programs on agility performance will provide additional valuable evidence of the role of various strength and power characteristics within agility (Brughelli, et al., 2008).

Strength and power training

Studies investigating the effect of strength and power training on agility performance have typically examined the effect of different strength, power and/or plyometric training regimes on a broad range of athletic performance measures, rather than regimes designed specifically to improve agility (Markovic, Jukic, Milanovic, & Metikos, 2007; McBride, Triplett-McBride, Davie, & Newton, 2002; Ouverson, 2004; Salonikidis & Zafeiridis, 2008; Taskin, 2009; Thomas, French, & Hayes, 2009). Subsequently, while some of these training programs have enhanced agility performance (Markovic, et al., 2007;
McBride, et al., 2002; Miller, Herniman, Ricard, Cheatham, & Michael, 2006; Ouverson, 2004; Salonikidis & Zafeiridis, 2008; Taskin, 2009; Thomas, et al., 2009), others have observed improvements in various other performance variables, but not agility (Alves, Rebelo, Abrentes, & Sampaio, 2010; Hoffman, Cooper, Wendell, & Kang, 2004; Jullien, et al., 2008; Ouverson, 2004).

For example, a number of studies found that plyometric training led to meaningful improvements in agility performance (Miller, et al., 2006; Taskin, 2009; Thomas, et al., 2009), but another found that although plyometric and sprint training led to significant improvements in vertical and horizontal jump performance, only the sprint group improved their performance on the ProAgility run (Markovic, et al., 2007). Furthermore, studies comparing the effects of strength, power and contrast training, such as reactive strength training using loaded jump squats with 30% or 80% of 1RM squat (McBride, et al., 2002), observed improvements in agility tests such as the L-test and T-test (McBride, et al., 2002; Ouverson, 2004). In contrast, studies involving heavy weight or Olympic weightlifting programs have successfully improved speed, strength and power, but reported no improvements in several planned agility tests such as the 505, T-test or ProAgility (Cronin, McNair, & Marshall, 2003; Hoffman, et al., 2004; Hoffman, et al., 2005; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005), including one case where the strength training was combined with 5 weeks of agility training (Hoffman, et al., 2005).

Accordingly, although there is some limited support for use of loaded jump squat and plyometric training (reactive strength) to enhance agility, the evidence supporting the agility benefits of maximal strength or Olympic weightlifting (power) is weaker. Again, many of these training programs predominantly involve exercises performed in the sagittal plane, rather than lateral and/or horizontal movements (Alves, et al., 2010; Markovic, et al., 2007; McBride, et al., 2002; Ouverson, 2004). However, one notable exception was the study by Miller et al. (2006), who included lateral exercises such as side-to-side ankle hops, lateral jumps over barriers and diagonal and lateral cone hops in a 6-week plyometric training program that successfully produced
improvements in the T-test and Illinois agility test of 4.9% and 2.9% respectively.

Consequently, there may be greater scope for improving agility using exercises combining high stretch-shortening cycle loads (such as plyometric or loaded jumps) with single leg lateral movements like zig-zag or side-to-side hops rather than, or at least in conjunction with, vertical or horizontal jumps (Renfro, 1999; Taskin, 2009; Twist & Benicky, 1996; Yap, Brown, & Woodman, 2000) Furthermore, strength exercises such as lateral or angled walking lunges or lateral crossover step-ups may also provide a more agility-specific strength training stimulus, though these have yet to be specifically examined (Keogh, 1999; Twist & Benicky, 1996; Yap, et al., 2000).

2.4 Assessing Agility

Since well-developed agility is acknowledged as an important characteristic for team sport athletes it is routinely assessed in talent identification and athlete monitoring programs (Gabbett, 2005; Gettman, Storer, & Ward, 1987; Parkin, 1983). Yet, while modern agility theory contends that sport-specific agility is reactive rather than pre-planned (Farrow, et al., 2005; Sheppard & Young, 2006; Sheppard, et al., 2006), planned agility tests are still widely used, even in professional sports such as the Australian Football League (AFL) and National Football League (NFL) (McGee & Burkett, 2003; Pyne, et al., 2005). Historically, the Illinois and T-tests were considered benchmark agility tests (Sheppard & Young, 2006; Tumilty, 1993), although recently the 505 (Figure 2.4a) test has gained more prominence for assessing agility in various team sports (Ellis, et al., 2000). However, as noted earlier, the lack of a reactive or cognitive challenge greatly reduces the ecological validity of all these tests for use in team sports (Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Sheppard & Young, 2006; Sheppard, et al., 2006). Additionally, planned tests fail to effectively mimic the physical demands of on-field agility tasks since the posture, technique and muscle activation patterns are different between planned and reactive changes of direction (Besier, Lloyd, Ackland, et al., 2001; Colby, et al., 2000; Houck, et al., 2006).
Furthermore, test duration and the number and angle of turns used in many previous planned tests don’t adequately reflect physical game demands of many team sports, such as Australian football and Rugby. For example, tests such as the 505, 3-cone and the AFL Draft camp test (Figure 2.4) (Ellis, et al., 2000; McGee & Burkett, 2003; Pyne, et al., 2005) include multiple turns, most >90° and can take up to 8-9 s to complete. However, in a team sport such as Australian football, motion analysis has revealed that more than half of the sprints involve at least one change of direction at an angle less than 90°, with most of these sprints lasting less than 3 s (Dawson, et al., 2004). In addition, in Rugby an evasive side-step involving two changes of direction of 20-60° has been identified as the most effective method of breaking tackles, a key factor in try-scoring (Wheeler, et al., 2010).

In order to improve validity these various reactive agility tests have manipulated different aspects of the main sub-components of reactive agility; the perceptual and cognitive and the physical. Firstly, from the perceptual and cognitive component viewpoint the various reactive agility tests have each used different types of stimuli ranging from an assortment of light-based designs (Besier, Lloyd, Ackland, et al., 2001; Chelladurai, et al., 1977; Oliver & Meyers, 2009), computer based directional indicators (Hertel, Denegar, Johnson, Hale, & Bickley, 1999; Lee, et al., 2013; Young, et al., 2011), another person (Gabbett, Kelly, et al., 2008; Sheppard, et al., 2006; Veale, et al., 2010) or a video projection of one or more people (Farrow, et al., 2005; Lee, et al., 2013; Serpell, et al., 2010; Young, et al., 2011). Secondly, from the physical component viewpoint the movement patterns have included shuffling and other movements but have recently narrowed to now typically involve only one turn in the 45-90° range (Besier, Lloyd, Ackland, et al., 2001; Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Oliver & Meyers, 2009; Serpell, et al., 2010; Sheppard, et al., 2006).

However, although early light-based stimuli exhibited good reliability (Chelladurai, et al., 1977), as outlined in Chapter 2.2, the ecological validity has been queried on the grounds of relevance and familiarity; no field or court sports require players to respond to lights (Sheppard & Young, 2006;
Young & Farrow, 2013) or arrows (Lee, et al., 2013). On the other hand, there is evidence that the use of more sport-specific stimuli in reactive agility assessments potentially offers higher standard players the opportunity to anticipate the actions of opponents more quickly and accurately; thereby providing them with a time advantage over lesser skilled counterparts (Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Serpell, et al., 2010; Young & Farrow, 2013; Young, et al., 2011). In contrast, generic light- or arrow-based stimuli do not provide that same opportunity to use heightened perceptual or anticipatory ability; since the light is either on or off there is no scope for anticipation or interpretation (Bruce, et al., 2004; Sheppard & Young, 2006; Young & Farrow, 2013).

Figure 2.4: a) The 505 agility test, b) The AFL Draft Camp agility test, c) The 3-cone drill agility test.
Sports-specific stimuli such as life-sized video projections of opponents have also been used successfully in several studies to examine reactive agility and so appear to be a useful option in reactive agility assessments (Farrow, et al., 2005; Serpell, et al., 2010; Young, et al., 2011). However, while each of these studies used video projection of opponents for the stimulus, the context of the videos and the resulting movement patterns have varied. For example, Farrow and colleagues (2005) had the player in the stimulus video run into view, receive a Netball and then execute a pass, with the video stopped at the moment of ball release. Meanwhile, the player being assessed side-shuffled back and forth before sprinting forward and reacting to the ball pass by changing direction (approximately 45°). Accordingly, the combined total distance was approximately 5 - 5.5 m and took approximately 3 - 4 s to complete. This protocol was found to be both valid and reliable in Netball players, with the bulk of the difference between elite and novice players due to a disparity in decision making speed (Farrow, et al., 2005).

Another reactive agility protocol developed by Serpell et al. (2010) (Figure 2.5) involves a video of a player sprinting forward approximately 5 m, executing one of 12 different sport-specific movements (ranging from single turns with and without passing a ball, to more complex movements using feints and turns with and without the ball), then turning 45°. This test was completed on average in less than 2 s and successfully discriminated elite Rugby League players from sub-elite players (whereas a planned test did not), with the majority of the difference due to decision making speed.
A third video-based test protocol (Figure 2.6) also involved a single 45° turn in response to a player running with a ball then executing a single turn viewed either from the front, at an oblique angle or from the rear (Young, et al., 2011). The test began with an approximate 4-m straight sprint prior to the stimulus and an approximately 4-m sprint to the finish after the response, taking approximately 2.5 - 3 s to complete. This study compared video-based reactive agility performance to a similar test using an arrow-based stimulus in elite junior Australian footballers and school-boy footballers. Again, no skill group differences were found when using the arrow-based stimulus but the elite group were faster using the video-based stimulus, highlighting the ecological validity advantages of using sport-specific versus generic stimuli (Young, et al., 2011). Accordingly, when viewed collectively, these studies support the construct validity of video-based protocols for assessing reactive agility, due to video protocols being more sensitive to known group differences than planned or other generic stimuli.
Nevertheless, the validity of the two dimensional (2-D) images used in video-based tests has also been questioned (Sheppard & Young, 2006), leading other researchers to investigate the use of three-dimensional (3-D) stimuli in reactive agility tests (Gabbett, Kelly, et al., 2008; Lee, et al., 2013; Sheppard, et al., 2006; Veale, et al., 2010). Sheppard and colleagues (2006) were the first to introduce 3-D style test by using a real person as the stimulus (Figure 2.7) and since then similar versions have been used in a number of other studies (Gabbett, Kelly, et al., 2008; Gabbett, Sheppard, Pritchard-Peschek, Leveritt, & Aldred, 2008; Sheppard, Barker, & Gabbett, 2008; Spiteri, Cochrane, & Nimphius, 2012). This reactive agility test (RAT) protocol incorporates a frontal evasion (players approach front-on to each other) scenario involving another (real) player as the stimulus and has been found to be both a valid and reliable measure of agility in Australian footballers (Sheppard, et al., 2006) and Rugby League players (Gabbett, Kelly, et al., 2008). Test distance was estimated to be 8-9 m long and the target angle appears to have been ≤90°, but both of these factors were dependent on the strategy employed by the participant (distinct cut versus a curved run).
Figure 2.7: Reactive agility test (RAT) (Sheppard, et al., 2006).

However, a closer examination of the results from various studies using this protocol reveal a notable disparity in performance when assessing athletes from different sports (Gabbett, Kelly, et al., 2008; Gabbett, Sheppard, et al., 2008; Sheppard, et al., 2006; Young & Willey, 2010). For example, sub-elite Rugby League players (2.48 ± 0.17 s) (Gabbett, Kelly, et al., 2008) and sub-elite Australian footballers (1.55 ± 0.07 s) (Sheppard, et al., 2006) had a large difference in performance (0.93 s; 60%; $d = 7.72$). Moreover, another group of Australian footballers (1.97 ± 0.08 s) (Young & Willey, 2010) and even junior (16.3 ± 0.7 y) basketball players (male and female) (2.2 - 2.21 s) (Gabbett, Sheppard, et al., 2008) completed this test faster than the well-trained Rugby League players. These differences are particularly noteworthy considering the smallest worthwhile change for this test was calculated to be just 0.016 s (Sheppard, et al., 2006).

Although it is difficult to pinpoint the precise reason for these differences between sports, since decision making speed is the primary discriminating factor between different athletes within sports, differences between sports could also be due to variations in decision making speed (Farrow, et al., 2005; Young & Willey, 2010). However, while little research
attention has been given to differences in decision making speed between athletes from different sports, decision speed in Australian footballers was found to be just $0.07 \pm 0.06$ s (Young & Willey, 2010), while in another study of Rugby League players it was $0.05 \pm 0.04$ s (Gabbett, Kelly, et al., 2008). Therefore, the potential for decision making speed to explain large such disparities in performance between sports is limited.

Alternatively, between-test irregularities in the RAT may indicate some inconsistency in the test operation when administered by different people or using different people as the stimulus. In particular, the way the stimulus is delivered (e.g., the type and amount of cues) will likely vary somewhat (due to fatigue or variations in concentration) when the stimulus person is asked to repeat many stimulus manoeuvres to numerous athletes within a team test session, or between different test sessions repeated across a playing season. Consequently, such variations may, in turn, influence the stability of the stimulus and subsequently the degree of experimental control for the assessor (Young, et al., 2011; Young & Willey, 2010). This potential for instability was underscored by the findings of a study by Young and Willey (2010), who identified that while the coefficient of variation of the tester time component in the RAT was quite small (5.1%) it could still lead to practical difference in stimulus delivery. This was illustrated in one participant for whom the tester time varied by 7% (from 455 ms to 596 ms), though the influence this had on participant performance was not investigated.

Nevertheless, another study did observe that a live human stimulus such as this can be delivered consistently, but only if a number of artificial constraints are imposed, such as coloured tape on the ground and a band tied between the feet to provide visual and tactile limits to step length (Spiteri, et al., 2012). Furthermore, the Sheppard et al. (2006) RAT protocol uses only four simple stimulus movement options, involving either one or two steps forward and then a turn in either direction, but even so, variations in the delivery of this relatively simple action still occurred. Therefore, while it is unknown whether consistency would be further reduced if more complex
scenarios, such as feints and multi-player situations were included, it does appear likely.

Building on both the video and 3-D elements of previous research Lee et al. (2013) introduced a 3-D (stereoscopic) video stimulus, which compared one and two player scenarios and arrow indicators. This study primarily examined biomechanical aspects of reactive agility from a knee injury perspective but successfully identified skill group (higher versus lower performance Soccer players) and stimulus mode differences in joint kinematics and kinetics. Therefore, this emerging technology may provide a future solution to the limitations of the current 2-D (video) and 3-D (real person) stimuli, in that it can deliver a consistent and repeatable 3-D stimulus. However, this technology still has some limitations such as the need for participants to wear glasses to see the image stereoscopically, which may potentially limit validity. In addition, the cost and logistical difficulties of this technology and equipment may limit its use by most sporting clubs and laboratories. Nevertheless, researchers should monitor this technology as it evolves and the cost and availability improves.

Therefore, although field-based 3-D tests may offer the most realistic conditions there are questions over the ability to deliver the stimulus in a consistent manner and the amount of experimental control provided. Consequently, where such 3-D approaches are not acceptable video-based approaches are considered an effective and viable substitute, particularly when compared to other generic stimuli (Mann, et al., 2007). Moreover, in addition to providing a stable and consistent stimulus delivery across multiple test sessions, another powerful advantage of using video-based protocols is the potential to consistently examine and compare player response to complex game scenarios involving numerous players or feint movements. Using complex scenarios is appealing as some distinguishing characteristics identified in skilled performers are that:

• they can more quickly and accurately identify and recollect patterns of play and distinguish relevant objects from background distractions.
• they are more precise in their predictions of what is a likely outcome from a particular pattern of play (Williams & Grant, 1999).

• they can more accurately anticipate the actions of opponents and so are less susceptible to deceptive movements by their opponents (Jackson, et al., 2006; Williams & Ford, 2008).

In conclusion, it is clear that reactive agility in team sport players is a unique skill that is not effectively assessed using planned agility tests, which lack the inherent perceptual and cognitive challenges of on-field agility. In addition, although few studies have directly compared them, sport-specific stimuli are preferred over generic stimuli when assessing reactive agility, to allow higher calibre athletes the opportunity to access their potentially better cognitive and decision making abilities. Further, sport-specific stimuli delivered via both video-based and real-person methods have been used successfully in reactive agility assessments and both have advantages and limitations. However, the capacity for video simulation to perfectly replicate the delivery of a stimulus between separate test sessions and different groups of athletes, and for the ease with which more complex scenarios can be included, means video-based tests will provide the flexibility and experimental control required of an effective reactive agility test (Mann, et al., 2007). Consequently, the superior stability and control offered by video stimuli may outweigh any potential advantage in fidelity from using the 3-D approaches.

2.5 TRAINING AGILITY

Although agility is an important part of team sport training programs (Ellis, et al., 2000; Hawley & Burke, 1998; Verstegen & Marcello, 2001; Ziemba, 1995) a lack of controlled studies comparing different training methods, together with a continuing evolution in the view of the true nature of sport-specific agility, means it is currently unclear what agility training approach should be used to maximise this quality (Serpell, et al., 2011; Young & Farrow, 2013). For example, the view of agility has grown from it being a unique entity consisting of isolated closed movements to now recognising that
on-field agility typically involves the coupling of movement to a sports-specific stimulus, which not only initiates the movement but also largely determines the nature of it (Jeffreys, 2006a, 2011; Serpell, et al., 2011; Sheppard & Young, 2006). However, while these principles are now being more widely incorporated into agility test regimes they have yet to be integrated into agility training or training studies (Serpell, et al., 2011; Sheppard, et al., 2008).

For the most part, historical agility training programs encompassed primarily closed or pre-planned drills and therefore, targeted the physical qualities of agility alone (Barnes & Attaway, 1996; Parsons & Jones, 1998; Serpell, et al., 2011; Yap, et al., 2000). As a result, these traditional agility training programs have successfully improved performance on various pre-planned agility tests (Bloomfield, Polman, O'Donoghue, & McNaughton, 2007; Brughelli, et al., 2008; Young, et al., 2001). In addition, the anticipatory, perceptual and decision making characteristics of athletes can also be independently enhanced following video-based perceptual training (Farrow & Abernethy, 2002; Gabbett, et al., 2007; Serpell, et al., 2011). Therefore, separately, the pre-planned agility (Bloomfield, et al., 2007; Brughelli, et al., 2008; Young, et al., 2001) and the perceptual and decision making abilities of athletes are both trainable (Gabbett, et al., 2007; Starkes & Lindley, 1994). However, it is unclear if these specific training programs will also independently enhance the sub-components of reactive agility, and consequently overall reactive agility performance.

Furthermore, to date there has been only limited research examining the effectiveness of specific reactive agility training on reactive agility performance. In one example, Serpell, et al. (2011) observed that reactive agility performance (in particular, response time) was significantly improved following three weeks of twice-weekly, guided discovery, video-based reactive agility training. In addition, Sheppard, et al. (2008) also found that nine weeks of training partly involving sports-specific reactive agility (1-on-1, 2-on-2 and 2-on-1 tasks) and decision making drills (reading the play and ball carrier identification) also led to improvements in reactive agility
performance, although the potential sources of the improvements were not assessed.

Together, these two studies support the notion that reactive agility, and in particular its perceptual aspect, is trainable using video- and field-based training programs (Serpell, et al., 2011). However, little attention has been paid to the trainability of the physical component of reactive agility, partly because until now it has not been specifically measured within the various reactive agility tests. For example, while planned agility drills can play a role in conditioning team sport (particularly inexperienced) athletes (Jeffreys, 2008; Serpell, et al., 2011; Sheppard, et al., 2008; Young & Farrow, 2013), it is not known to what extent these programs will influence the physical ability to change direction during reactive agility tasks (following the correct decision being made). Moreover, it is unclear whether reactive agility training can also preferentially influence the physical component, should that be a weakness within an athlete’s agility profile (Serpell, et al., 2011). Furthermore, no research has examined whether strength and/or power training can produce improvements in reactive agility alone, or can augment existing agility training, as has been seen in some pre-planned agility studies (Brughelli, et al., 2008; Sheppard & Young, 2006; Young & Farrow, 2006).

Therefore, rather than considering these physical and cognitive factors in isolation, Jeffreys (2006a, 2008, 2011) and Young and Farrow (2013) advocate that effective context-specific agility training should involve numerous training concepts (planned agility, reactive agility and game simulation) at different times throughout an athlete’s development. For example, during the foundation training phase the use of simple, closed drills will allow athletes to master basic, yet crucial, movements, since complex skills are built upon a platform of basic movement skill (Jeffreys, 2008; Young & Farrow, 2013). Furthermore, it is during this phase that well-designed resistance training programs may assist athlete development to again build a foundation of generalised strength upon which higher intensity reactive agility can be developed as movement skill improves (Djevalikian, 1992).
During the development training phase, these foundation movements can be linked together by key transition movements (e.g., linear sprinting and other tasks) with and without the ball, to produce movement patterns common to the sport (Jeffreys, 2008). Additionally, this phase may include a progressive shift from closed to open drills through the introduction of sport-specific and task-specific cues and scenarios. Consequently, this begins the contextualisation of the movements and helps the athlete to learn, choose and execute the right movement for the right situation, or to explore the relative success or failure of various movement solutions in different performance contexts (Davids, et al., 2013). Therefore, the foundation phase builds the basic movement skill which can be then be accessed, applied and developed further in the more sports-specific context of the development phase. Finally, during the peaking training phase, the complexity of the drills and the stimuli may be increased to more closely match the intensity of the sport to maximise the transfer of the training skills to the field (Jeffreys, 2008, 2011). This training phase may involve an increase in game simulation activities where athletes learn to explore how interpersonal interactions and relative spatial positioning between opponents, team-mates, sidelines and goals can influence decision making and performance (Davids, et al., 2013). However, coaches should be mindful of the need for a degree of repetition, which could be provided by video-based reactive agility training using the protocol introduced here. This phase should also provide the opportunity for the athletes to quickly assess movement success and opportunities to adapt their actions to learn the most effective response to a given situation (Davids, et al., 2013; Jeffreys, 2011; Young & Farrow, 2013).

Consequently, agility training should not be static and should involve the progressive manipulation of various physical and perceptual components along a continuum from simple to complex, accompanied by appropriate feedback (Jeffreys, 2008, 2011; Young & Farrow, 2013). Furthermore, based on the results of reactive agility testing, this manipulation should vary between athletes within a team so the training can preferentially address weaknesses within their individual agility profiles. For example, a “fast mover/slow thinker” may require a slightly different training mix from that of a “slow
mover/fast thinker” (Gabbett, Kelly, et al., 2008). Nevertheless, while an individual, periodised approach to agility training may prove to be the most effective method, more research is required to investigate this. In particular, examining how different training approaches, such as perceptually-focussed or physically-focussed programs, could impact different components of agility will offer added insight into improving reactive agility performance.

2.6 Summary

Agility in team sports is typically reactive in nature, where changes of direction occur in response to, and are largely determined by, external stimuli such as the movement of an opponent. Further, the two dominant factors that determine reactive agility performance are the perceptual and decision making elements and the physical change of direction components, each of which can be divided into various smaller elements. However, agility has historically been examined using pre-planned tests with little or no perceptual or cognitive uncertainty. Consequently, the validity of these tests has been questioned, partly because of the lack of a cognitive component, but also because research has shown that reactive agility in team sport players is a unique skill that is not effectively assessed using planned agility tests.

Subsequently, a number of reactive agility tests have appeared in the literature, which have utilised numerous different stimuli ranging from generic light and arrow based indicators, to videos of opponents and real people. However, while higher calibre players are reported to have a superior ability to anticipate opponent actions and postural cues, this advantage is thought to only be available using sport-specific, rather than generic, stimuli. The basis for this theory is that sport-specific stimuli reputedly offer the higher calibre players the opportunity to exploit their superior cognitive and decision making ability, whereas generic stimuli will not, since they offer little scope for interpretation and anticipation. Therefore, while no studies have yet directly compared decision making speed and quality between generic and sport-specific stimuli, the nature of the stimulus remains an important consideration in reactive agility assessments, since it may influence the sensitivity of a test.
Furthermore, it is apparent that as the complexity of the stimulus increases (such as with the inclusion of feints) so too does the demand on the decision making process. In addition, planned agility research has also shown that multiple turns increase the physical effort in changing direction. Therefore, since feints are a common tactic in various sports and, since feints also increase demand on both the perceptual and cognitive and motor components of reactive agility, a reactive agility test that can include deceptive movements could be appealing for many field sports. However, despite their common use and supposed influence, the specific effect of feints on reactive agility performance has received little research attention. Therefore, even though higher standard athletes are purportedly less susceptible to feints, it remains unclear whether the impact of feints on reactive agility performance will vary between athletes of different playing standards, or what the sources of any differences within the key sub-components of agility may be.

Also, although leg strength characteristics, in particular single-leg lateral strength, could be an important determinant of reactive agility performance, no research has investigated the relationship between any strength and power measures and reactive agility. Therefore, little is known about the direct influence of leg strength and power qualities on reactive agility performance, particularly the motor component. In addition, research that has considered this question in relation to planned agility has often used bilateral, vertical and sagittal plane movements to examine strength and power. However, unilateral reactive strength and power tests involving significant lateral elements may be more sensitive to the differences in reactive agility performance, due to the similarity of the actions.

Providing answers to these questions will afford athletes and coaches further insight into sport-specific reactive agility, including what factors are important in maximising performance and differentiating highly agile athletes from their less agile peers. In turn, this will allow coaches to individualise training programs to specifically target weaknesses within the agility profiles of their athletes.
References


Video Reactive Agility Test: Developmental background and description
3.1 Background to test design

Although several new reactive agility protocols have recently been developed to address the validity concerns of historical planned agility tests, our understanding of agility remains limited. This is partly due to the lack of a universally accepted reactive agility protocol and some limitations of those protocols currently in use. Therefore, the initial goal of this thesis was to develop a new reactive agility test specifically for Australian rules football and assess its validity and reliability. Subsequently, this new protocol was used to investigate various aspects of reactive agility and its subcomponents.

However, to develop a reactive agility test that, in turn, matches the specific needs of Australian football, addresses the weaknesses of previous agility tests while also exploiting their strengths, a needs analysis had to be undertaken (Fleck & Kraemer, 1997; Kraemer & Gomez, 2001). Traditionally, a needs analysis examines the specific needs of the sport, such as the movement qualities (biomechanical and strength needs) and quantities (metabolic requirements) and their function within the game (Fleck & Kraemer, 1997; Jeffreys, 2008). However, in this current analysis the principles that support the modern definition of agility, the lessons learnt from previous reactive agility tests and, in some cases, pre-planned agility protocols were also considered. Following on from this analysis a set of guiding principles were developed to underpin the creation of the new reactive agility protocol.

Firstly, modern agility theory dictates that in order to maximise the relevance and validity of agility tests for sports such as Australian football where the ball bounces unpredictably and making and evading tackles is important, an agility test must be reactive in nature (Farrow, Young, & Bruce, 2005; Sheppard & Young, 2006). This notion is supported by a number of studies showing that reactive agility tests are able to detect differences in agility in different groups of athletes where planned agility tests do not (Farrow, et al., 2005; Gabbett, Kelly, et al., 2008; Sheppard, Young, Doyle, Sheppard & Newton, 2006).
Secondly, to truly measure sport-specific agility the stimulus should not only be sport-specific but also context-specific, to allow better athletes to take full advantage of their potentially enhanced decision making and physical abilities (Farrow, et al., 2005; Serpell, Ford, & Young, 2010; Sheppard & Young, 2006; Sheppard, et al., 2006; Veale, Pearce, & Carlson, 2010; Young, Farrow, Pyne, McGregor, & Handke, 2011). Therefore, many early reactive agility tests, which used generic stimuli such as flashing lights or arrows, lacked the necessary sport and context-specificity, and therefore also validity (Sheppard & Young, 2006; Young & Farrow, 2013). However, while tests incorporating context specific stimuli (such as a video projection of one or more opponents) appear to be superior to generic arrow-based versions in detecting differences in overall reactive agility performance between different athletes (Lee, 2011; Young, et al., 2011), no studies have yet directly investigated the differences in decision making speed between these generic and sport-specific stimuli.

In addition to the video-based stimuli used in several studies (Farrow, et al., 2005; Gavin, 2008; Serpell, et al., 2010) the use of a real person as the stimulus has also found favour among other researchers (Sheppard, et al., 2006; Veale, et al., 2010). Nevertheless, while both stimulus modes have various strengths and weaknesses no clear consensus has yet been reached as to which is preferred (Serpell, et al., 2010; Spiteri, Cochrane, & Nimphius, 2012; Young, et al., 2011; Young & Willey, 2010). For instance, several authors have questioned the influence of the inherent variability in the delivery of the real life stimulus on the performance of the test subject (Serpell, et al., 2010; Young, et al., 2011; Young & Willey, 2010).

In contrast, proponents of video-based stimuli argue the consistent reproducibility of this method and the ability to manipulate the content easily to match different game scenarios makes it superior to real life stimuli.
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(Serpell, et al., 2010; Young, et al., 2011). On the other hand, the critics of video stimuli argue that the two-dimensional nature of video protocols are not a realistic representation of the three dimensional stimuli experienced during sport (Spiteri, et al., 2012). However, the artificial constraints necessary to make real life stimuli stable (Spiteri, et al., 2012) may not be achievable when introducing more complex multi-movement or multi-player scenarios. Therefore, since video-based stimuli have proven to be valid and may offer greater consistency during the feint scenarios introduced later in this thesis, a sport-specific video-based stimulus was considered to be appropriate here.

Previous video-based reactive agility tests have used stimulus videos with a fixed duration and set positions of the exit gates (Farrow, et al., 2005; Serpell, et al., 2010; Young, et al., 2011). However, although not yet considered experimentally, this could lead to variability in the physical location of the stimulus depending on the approach speed of the participant, which in turn will influence turn angle. Figure 3.1 illustrates this using a theoretical test design with a fixed pre-stimulus period of 1 second and the middle of the exit gates aligned at 45° to the 4 m-point of the run path, but with all other factors constant. Accordingly, (assuming they have the same decision time) an athlete who runs 3.5 m in the 1 second before the stimulus will have a turn angle of approximately 41°, whereas a faster athlete who runs 5 m in 1 second will face a turn angle of around 54°.

Therefore, since sharper turns are known to lead to decreases in agility performance (Young, McDowell, & Scarlett, 2001) a faster athlete is at a disadvantage due to the fixed length stimulus rather than their own agility capacity. In contrast, tailoring the stimulus video to each individual’s approach speed will ensure it is delivered in the same location or zone for all
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(e.g., 4 m), meaning only intrinsic factors, such as decision making speed and turning ability, will determine performance.

Figure 3.1: Changes in turn angle associated with different approach speeds and fixed length stimulus videos.

Principle 3 - the timing of the stimulus should be individually manipulated to ensure it is delivered in the same location for all participants.

However, a potential disadvantage to the tailored video approach is that the stimulus is always delivered in the same physical location, potentially resulting in decreased temporal uncertainty; thereby allowing athletes to perhaps learn when and where to expect the stimulus. Therefore, where necessary, fake or dummy clips which place the stimulus at different locations/times, but which are not assessed, should be incorporated, to increase the uncertainty for the participants.
Additionally, to gain an insight into the specific movement qualities and quantities historically considered important in Australian football we can look to the types and number of turns and the length of the (planned and reactive) agility tests previously designed for that sport. Combining this with data from motion analysis of elite football games will provide some basis for the physical components of a sport-specific reactive agility test. For example, the test used at the elite Australian Football League draft camp (Figure 2.4b, p. 52) involves five turns (1 x \(192^\circ\), 3 x \(90^\circ\) and 1 x \(45^\circ\)) with segments predominantly 3.5 m long (Pyne, et al., 2005). Also, two recent reactive agility tests designed for Australian football (Figures 2.6 & 2.7, pp. 56 - 57) used a single turn of approximately \(45^\circ\) with 2 - 5 m segments (Sheppard, et al., 2006; Young, et al., 2011). Finally, analysis of movement patterns during games reveals that more than half the sprints involved at least one change of direction between 0-90°, and that almost all lasted less than 6 seconds, with the majority under 3 seconds (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004). Accordingly, tests and agility tasks in Australian football are typically less than 90°, have a duration less than 3 seconds and have short (<5 m) straight sprint segments to minimise the influence of linear speed.

Therefore, using these guiding principles, the following video-based reactive agility test was designed and its validity and reliability for use with Australian footballers tested (Chapters 4 and 4A). Subsequently, this test became the common theme linking the remaining studies, which explored agility and its sub-components.
3.2 Video reactive agility test - Description

A schematic diagram of the video reactive agility test (VRAT) is presented in Figure 3.2 and involves the test participant sprinting forward whilst watching a life-sized video image of an opponent projected onto a screen (Principles 1 and 2). The stimulus person is running away and requires the test participant to chase and, at a predetermined point, the stimulus person turns left or right (Principle 2) requiring the test participant to react, turn and sprint through an exit gate. Therefore, this test provides the high intensity, short sprint, turn and sport-specific stimulus required of an ecologically valid reactive agility test.

Additionally, two other unique features are included that set this protocol apart from previous video-based reactive agility tests. Firstly, the stimulus video length can be individually manipulated to ensure the stimulus is consistently presented when the participant is within the 3 - 4m mark (Principle 7). This subsequently constrains the approach distance to ensure participants receive the stimulus in the same location regardless of how fast they complete the approach run (Principle 3). However, dummy or no turn clips were also included to increase the temporal and spatial uncertainty of the protocol (Principle 4), meaning that only intrinsic factors will determine performance.

Secondly, an in-built abort function ensured a high degree of effort for the approach run, thereby reducing variability in the approach (Young, et al., 2011) and preventing propping or slowing prior to the stimulus. The exit gate was orientated on an angle of 45° (Principle 5) to, and 4 m from (Principle 7), an anchor point at the 7 m mark (taking into account the decision time, deceleration and turn preparation), resulting in a total run distance of approximately 11 m, which during initial pilot testing was completed in a time of 2.0 - 2.5 s (Principle 6).
3.3 TEST PROCEDURE

All agility tests were conducted indoors on a carpeted and sprung wooden floor. A 4 m x 2.5 m painted (Solver Brite-Glo™ White paint) wooden screen was positioned 16 m from the start line and a video projector (Epson EMP-1715) hung from the roof 6 m from the screen at a height of 2.9 m, projecting a 2.5 m high and 3.5 m wide image. The projector was connected to a computer loaded with both the “VidPlay” software (School of Sport Science, Exercise and Health, University of Western Australia) and the requisite stimulus video files. The VidPlay computer was connected via a
network to a second computer containing the “Agility” software (School of Sport Science, Exercise and Health, University of Western Australia).

Infra-red timing gates (School of Sport Science, Exercise and Health, University of Western Australia or Fitness Technology, Adelaide, Australia) and a sync light were connected to the Agility computer via a control unit (School of Sport Science, Exercise and Health, University of Western Australia). The Agility software interfaced an inbuilt timer with the timing gates, sync light, VidPlay computer and projector to start and stop the video and sync light at the appropriate times. In addition, the Agility software also recorded split and total times for the agility and sprint trials and a digital video camera (Sony DCR-VX2100E, JVC GR-DVL300EA) was positioned 4 m behind the start line and set to record continuously through the test session.

### 3.3.1 Speed assessment

Prior to undertaking the agility test participants completed five 11 m straight sprints, with times recorded at both 4 m and 11 m. The 11 m distance was chosen as it was the estimated length of the reactive agility test. Although, the exact length will vary depending on decision and movement times and the specific technique adopted during the turn (cut versus curved run) (Sheppard, et al., 2006). The 4 m-sprint time was more important in that it was used to individually manipulate location of the stimulus to ensure the test (e.g., approach distance and turn angle) was consistent across participants, trials and test sessions. The test began with participants adopting an athletic ready stance behind the start gate and starting at their own volition and, unless otherwise stated, the fastest 4 m time was used to determine delay time, stimulus presentation point, abort time and stimulus time.

### 3.3.2 Video reactive agility test procedure

Groups of up to 10 participants were assessed within the same session. All participants remained outside the laboratory until called in prior to each trial and were then sent out after each trial, so they didn't view each other
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completing the test. Figure 3.3 illustrates the view of the test from the perspective of a person standing at the start line.

![Diagram of the video reactive agility test layout]

**Figure 3.3**: The video reactive agility test layout, viewed from the start line.

To begin each trial participants sprinted forward from the start line and, by breaking the start gate/beam, triggered the timer that in turn initiated the stimulus video and turned on the sync light. Then, in the experimental trials (not the dummy or no turn trials) after a predetermined time, equal to each participant’s 4 m-sprint time, the person in the video changed direction to the left or right. The initiation of this turn in the video was deemed the actual *stimulus presentation point* used for the calculation of both the stimulus video duration and later, the measurement of *decision time*. Specifically, the stimulus presentation point is defined as the:
The first definitive lateral movement of the foot that produces the change of direction.

Participants were instructed to respond as quickly and accurately as possible to the stimulus by turning and sprinting through the appropriate timing gate in a simulated attempt to chase and tackle their opponent. Passing through either exit gate stopped the timer and turned off the sync light.

3.3.3 Abort function

To ensure a near maximal (and consistent) sprint during the approach run an abort feature was incorporated. The abort time was also equal to the 4 m time from the initial sprint test and, if the participant did not reach the 3 m/abort gate before that time, the trial was aborted. Consequently, having the abort time equal to the stimulus presentation point ensured participants were sprinting fast enough to be past the 3 m mark when the stimulus was presented (or the test aborted) but, since it was equal to their fastest 4 m time, it was unlikely they would be beyond the 4 m mark. Accordingly, the stimulus presentation point was controlled to be within the 3 - 4 m zone for each person, a first for a reactive agility test and a valuable addition to agility research by ensuring a consistent approach sprint and turn angle.

3.3.4 No turn and dummy stimulus video clips

A fundamental difference between reactive and planned agility tests is the lack of prior knowledge about the turn location (temporal uncertainty) and direction (spatial uncertainty) and the inability to pre-plan a response. During reactive agility tests, uncertainty is provided by presenting various video stimulus options in a random order. To further increase spatial uncertainty, this protocol included two additional no turn stimulus video clips, or catch trials (Schmidt & Lee, 2005), and two dummy trials where the stimulus presentation point was positioned in a different location. During the no turn trials the stimulus person, and therefore the test participant, continued to run straight, thereby resulting in a three-choice rather than two-choice task (e.g., turn left, right or no turn). Conceivably, if a turn is always
expected participants will prepare by slowing down and propping prior to stimulus presentation, or by guessing which direction to turn with a 50% chance of success and the catch trials are included to prevent this. The data from the two no turn clips were not included during later analysis.

The two dummy video clips prevented participants getting into a rhythm or developing a “feel” for the location of the stimulus. These looked similar to the test clips but the stimulus presentation point was purposely edited to be in a different location (in this instance one was 20 ms earlier and one 28 ms later than the normal stimulus time). Therefore, when completing multiple test sessions (e.g., test-retest reliability, or over a playing season) the existing dummy clips were replaced with two new clips edited to be subtly different again from the previous ones. The results from these dummy trials were also discarded from the data analysis.

3.3.5 Stimulus and delay time

With the exception of the dummy and no-turn clips all stimulus video clips were 600 ms in duration from start to stimulus presentation point which, when added to the 180 ms of internal system latency, resulted in a total time from start to stimulus presentation of 780 ms. However, to individualise each trial the video was paused or delayed for an amount of time after the start gate was triggered (delay time). To calculate this delay time, the constant 780 ms of each clip was subtracted from each individuals’ fastest 4 m-sprint time obtained during the initial sprint test. For example, for a faster runner (840 ms for 4 m) the delay would be 60 ms (840 ms - 780 ms), whereas for a slower runner (1000 ms for 4 m) the delay would be 220 ms (1000 ms - 780 ms).

3.3.6 Data collection

A digital video camera positioned behind the start line captured footage used later for the determination of the decision time and movement time variables. However, to calculate these times, the reviewer must know when the video started and so a sync light was positioned near the 3 m gate, which turned on when the start gate was triggered, indicating when to “zero” the
timer. In addition, the reviewer must also know the moment of stimulus presentation (the person in the video changing direction) but, since the test participant obscures the view of the stimulus person, *reference dots* were inserted into the bottom left and right corners of the stimulus video (Figure 3.4) on two consecutive frames, separated by 2 frames, and repeated. Hence, when played at normal speed they took on a stroboscopic appearance with the fourth pair of dots deliberately positioned to appear on the frame that included the stimulus presentation point. Therefore, when viewing these clips later this stimulus presentation point could be identified, which allowed decision time and movement time to be calculated. The footage from the video camera positioned behind the start was edited using commercial video editing software (Pinnacle Studio V9™, Avid, Burlington, Massachusetts) to remove superfluous content such as the inactive time between trials, catch, rejected and dummy trials. SiliconCOACH PRO™ V6 (Dunedin, New Zealand) was used to de-interlace the footage and view each clip field-by-field, allowing times to be recorded with the in-built stopwatch function. Together, the data from the timing gates and the video record yielded four main measures:

1. **3 m/Abort gate time** - Time from start until 3 m gate.

2. **Total time** - Total time from start to finish.

3. **Decision time** - Echoed the perceptual/cognitive aspects (perception and response selection) of reactive agility. Decision time was calculated as the elapsed time from the stimulus presentation point (4th white reference dot) until the initiation of the response by the test participant, which as outlined earlier, is defined as the first definitive lateral movement of the foot that initiates the change of direction. The concept of decision time was first proposed by Farrow, et al., (2005), who defined it as “the first definitive foot contact initiating the movement of the athlete in the final direction that she moved (p.56)” However, since the goal is to determine decision time as close as possible to pure reaction time, or the *initiation* of the response, a slightly different reference point was introduced here. Therefore, decision time was measured at the instigation of the lateral
movement of the foot rather than when that same foot contacts the ground, resulting in the actual movement time of the foot being removed and moving the measurement closer to the initiation of response.

4. **Movement time** - Considered to reflect the physical component of reactive agility and was determined as the time from the end of decision time until the participant passed through one of the exit gates.

![Figure 3.4: Screen capture showing the test participant obscuring the stimulus person, the location of the sync light and the reference dots.](image)

**3.3.7 Conclusion**

This new test of reactive agility for Australian football has been specifically designed based on an in-depth analysis of that sport and of previous reactive agility and planned agility tests. Accordingly, there are
some common elements with previous reactive agility tests designed for
Australian football, such as changes of direction less than 90° (Veale, et al.,
2010; Young, et al., 2011), short linear sprint sections (Sheppard, et al., 2006;
Veale, et al., 2010; Young, et al., 2011) and the use of the stable stimulus
provided by a life-sized video of an opponent (Young, et al., 2011). However,
some new measures have also been introduced to improve the stability of the
stimulus via the ability to individually manipulate the stimulus video length to
ensure it is delivered in a consistent manner for each different participant.
Furthermore, the use of a chase rather than frontal evasion stimulus scenario
also allowed the introduction of no turn and dummy trials, which provide an
increase in the unpredictability of the stimulus delivery that more closely
matches the uncertainty found in open team sports such as Australian
football.

Nevertheless, although this protocol was specifically designed for
Australian football, before it could be used to broadly examine agility and the
characteristics of agile footballers its validity and reliability had to be
established (Chapters 4 and 4A). Once confirmed, this protocol was used to
investigate the impact of feints and multiple movements on agility
performance (Chapter 5) and decision making speed and accuracy (Chapter 6)
and the leg strength characteristics that contribute to the physical component
of agility (Chapter 7).
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References


Validity of a Reactive Agility Test for Australian Football

This manuscript has been published in the International Journal of Sports Physiology and Performance.


The PhD candidate Greg Henry accounted for 90% of the intellectual property associated with the final manuscript. Collectively, the remaining authors contributed 10%.
ABSTRACT

Purpose: To study the validity of a video-based reactive agility test in Australian footballers. Methods: 15 higher performance, 15 lower performance and 12 non-footballers completed a light-based reactive agility test (LRAT), a video-based reactive agility test (VRAT) and a planned test (PLAN). Results: With skill groups pooled, agility time in PLAN (1346 ± 66 ms) was significantly faster (p = 0.001) than both reactive tests (VRAT=1550 ± 102 ms; LRAT= 1572 ± 97 ms). Also, decision time was significantly faster (p = 0.001; d = 0.8) in LRAT (278 ± 36 ms) than VRAT (311 ± 47 ms). The correlation in agility time between the two reactive tests (r = 0.75) was higher than between the planned and reactive tests (r = 0.41 to 0.68). Higher performance players had faster agility and movement times on VRAT (agility -130 ± 24 ms; d = 1.27; p = 0.004, movement - 69 ± 73 ms; d = 0.88; p = 0.1) and LRAT (agility - 95 ± 86 ms; d = 0.99; p = 0.08, movement - 79 ± 74 ms; d = 0.9; p = 0.08) than the non-footballers. Additionally, higher (55 ± 39 ms; d = 0.87; p = 0.05) and lower (40 ± 57 ms; d = 0.74; p = 0.18) performance groups exhibited somewhat faster agility time than non-footballers on PLAN. Furthermore, higher performance players were somewhat faster than lower performance players for agility time on the VRAT (63 ± 85 ms; d = 0.82; p = 0.16) and decision time on the LRAT (20 ± 39 ms; d = 0.66; p = 0.21), but there was little difference in PLAN agility time between these groups (15 ± 150 ms; d = 0.24; p = 0.8). Conclusions: Differences in decision making speed indicate that the sport-specific nature of the VRAT is not duplicated by a light-based stimulus. Also, the VRAT is somewhat better able to discriminate different groups of Australian footballers than the LRAT. Collectively, this indicates that a video-based test is a more valid assessment tool for examining agility in Australian footballers.

Key words: movement time, decision time, agility time, lateral foot movement.
4.1 Introduction

Agility is an important characteristic to develop for successful performance in many team sports\textsuperscript{10}, including Australian football\textsuperscript{17}, where over 50% of sprints involve a change of direction between 0-90\textdegree\textsuperscript{5}. Previously, agility was routinely examined using pre-planned tasks, but recently it has been recognised that in most team sports directional changes are often initiated in response to some external stimuli such as movements of an opponent or ball\textsuperscript{8,20}. Consequently, due to the absence of a cognitive aspect, and the closed nature of the tasks, many classical planned agility test protocols do not reflect the on-field agility demands of sports such as Australian football, and so have limited ecological validity\textsuperscript{20}. Accordingly, to accurately measure sport-specific agility it is advocated that a “not negotiable” aspect is the inclusion of a decision making component\textsuperscript{8}.

As a result, several reactive agility tests have recently appeared in the literature, coupling simple light- or directional indicator-based stimuli with various movements\textsuperscript{3,4,11,16}. Though reactive in nature, the ecological validity of these protocols has also been questioned since the stimuli are dissimilar to those typically encountered on a sports field\textsuperscript{20,21}. For example, it has been reported that generic light-based tests fail to provide skilled performers the opportunity to exploit potential anticipatory skill superiority\textsuperscript{20,21}, achieved through the earlier acquisition of postural and other cues\textsuperscript{6,7,25}. Accordingly, generic stimuli may not be as effective in distinguishing athletes of differing abilities\textsuperscript{21}. Consequently, newer reactive agility test protocols have sought to enhance specificity by requiring participants to respond to stimuli such as a life-sized video image of a netball pass\textsuperscript{8}, a video of a rugby player changing direction and/or executing a pass\textsuperscript{18} or a real person changing direction\textsuperscript{21,23}. These more realistic stimuli appear to offer enhanced ecological validity over earlier generic light versions. Additionally, they have also successfully discriminated higher and lower performers in netball\textsuperscript{8}, Australian football\textsuperscript{21} and Rugby League\textsuperscript{9,18}, providing evidence of their construct validity.

However, while intuitively appealing to assume that the response to more complex sport-specific stimuli would be different than similar light-
based stimuli, and that the sport-specific stimuli would also be more effective in discriminating agility in players of differing skill levels, this has not been specifically investigated. Therefore, this current study sought to establish the validity of a new video-based reactive agility protocol requiring participants to chase a life-sized video projection of another player. Initially, validity was investigated by comparing agility performance between the video-based protocol, a similar light-based procedure and planned agility task. Additionally, this study aimed to determine whether a video reactive agility test is better able to discriminate performance differences between three groups of participants differentiated by their level of involvement in Australian football, verifying the enhanced construct validity of the video protocol.

4.2 METHODS

4.2.1 Participants

Male participants (n = 42) were assigned to one of three groups according to their level of involvement in Australian football. Higher performance (HP) players (n=15, mean ± SD age, height and mass of 17.6 ± 0.6 years, 182 ± 6 cm and 78.6 ± 7.5 kg respectively) were members of a top-echelon Western Australian Football League under-19 team. The lower performance (LP) group (n=15, age, height and mass of 18.2 ± 0.1 years, 179 ± 4 cm and 71.6 ± 5.0 kg respectively) played for lower grade amateur teams and the non-footballers (NF) (n=12, age, height and mass of 19.3 ± 1.7 y, 180.4 ± 8.2 cm and 73.9 ± 14.0 kg respectively) were trained in various low-agility sports, such as distance running, paddling, surf lifesaving, and had no competitive Australian football experience in the previous three years. This study had the approval of the Human Ethics Committee of the University of Western Australia (UWA) and participants were provided information regarding the risks and subsequently gave informed consent.

4.2.2 Procedures

All testing was conducted indoors on a carpeted sprung wooden floor. During an initial visit to the laboratory, linear speed and reactive agility using
a light-based reactive test (LRAT) protocol were assessed. During a second visit, 48 hours later, a video-based reactive agility test (VRAT) and an analogous planned agility (PLAN) test were completed. Agility trials employed a single 45° change of direction, a pattern common in Australian football (5). Data was collected using a 25 Hz video camera (Sony DCR-VX2100E) positioned 2 m behind the start gate interfaced with infra-red timing gates (School of Sport Science, Exercise and Health, UWA) and a computer loaded with customised “Agility” software (School of Sport Science, Exercise and Health, UWA). During the VRAT (Figure 4.1) the “Agility” computer was networked to another with the custom “VidPlay” software controlling the stimulus video, which was in turn connected to a roof mounted video projector (Epson™ EMP-1715) displaying a life-sized image of another player. The layout for the LRAT was identical to the VRAT except three LED light clusters mounted on a board provided the stimulus instead of the screen and projector. A group of players (n=12) completed the VRAT a second time, one week after the first, to examine test-retest reliability, which for agility time had a coefficient of variation (CV) of 1.4% and an intra-class correlation coefficient (ICC) of 0.81. Furthermore, in a sub-set of trials (n = 36, 20%) decision time was re-assessed by the principal researcher one week after the initial analysis to determine the intra-rater reliability, which was 5.2% (CV) and 0.99 (ICC).

During the initial test session, participants completed a standardised warm-up before undertaking five straight 11 m sprints, with a split time recorded at 4 m. The mean of each participant’s 4 m-splits was used to individually manipulate aspects of the reactive tests such as stimulus presentation point, delay and abort times. Following the straight sprints there was a 5-minute passive recovery period, followed by an agility specific warm-up and five minutes of stretching, during which the LRAT procedure was explained and demonstrated.
Next, five sub-maximal LRAT familiarisation trials were completed, with the stimulus presentation point varied by ± 48 and comprising two turns each to the left and right and one with no turn. This was followed by another 5-minute recovery period, after which the 12 experimental trials commenced which were randomly ordered prior to completion and comprised four turns each to the left and right, two dummy turns (one per side) and two with no turn. The dummy trials appeared the same as the experimental trials, except the stimulus presentation point was altered (± 20-28 ms) which, in conjunction with the no turn option, increased spatial and temporal...
uncertainty. The data from dummy and no-turn trials was discarded, leaving 8 experimental trials (4 left and 4 right) for analysis.

In the reactive trials, the stimulus was presented at a predetermined time (equal to each individual’s mean 4-m straight sprint split) following the initiation of the sprint that, during the LRAT, occurred when the appropriate LED illuminated or, during the VRAT, when the person in the video initiated the change of direction. Specifically, in the VRAT, stimulus presentation was defined as the first definitive lateral movement of the foot that initiated the change of direction, the same definition as used later during data analysis to determine the decision time of the test participant. Participants were instructed to sprint forward as fast as possible, respond quickly and accurately to the stimulus and sprint through the exit gate. Additionally, to help ensure a high-speed approach run and control the physical location of the stimulus presentation, the reactive protocols incorporated a unique abort feature, whereby failing to reach the 3 m/abort gate prior to the abort time elapsing (also mean 4-m straight sprint split time) resulted in the trial aborting, occluding the stimulus. Accordingly, having the abort and stimulus presentation times equal ensured the stimulus presentation point was limited to the 3 - 4 m zone, thereby ensuring consistency for each participant across each test session.

Participants returned to the lab 48 h later and again completed the standard warm-up where the VRAT was explained and demonstrated during the final 5-minute period. Then, five sub-maximal familiarisation trials were completed followed by another 5-minute rest period, after which the 12 experimental VRAT trials were completed (in a different random order to the LRAT), again resulting in eight experimental trials following the discarding of the no turn and dummy trials. During the VRAT a life-sized projection of an opposition player running away from the test participant was used; this person was filmed alone, without a ball and ran straight before performing a cut manoeuvre (except on the no-turn trials), thereby simulating an attempted chase and tackle. The video clips were individually manipulated to make the stimulus presentation point equal to each participant’s mean 4 m-straight sprint time assessed previously. Specifically, the duration of the experimental
clips was 780 ms, and were paused for an extra period (delay time) so the sum (780 ms + delay time) equalled each individual’s stimulus presentation time. To calculate delay time the constant 780 ms of each clip was subtracted from each participant’s mean 4 m-split time; for example, for a 4 m-split of 840 ms the delay would be 60 ms (840ms - 780 ms).

Finally, five minutes after completing the VRAT, participants completed 8 (4 per side) planned agility runs around a marker placed 50 cm short of, and 25 cm offset to the left or right of the 7m mark replicating the pattern used for the reactive agility conditions (but without any external stimulus).

The video record was edited using commercial video editing software (Pinnacle Studio V9™, Avid, Burlington, Massachusetts) to remove superfluous content. The requisite clips were then analysed using siliconCOACH PRO™ V6 (Dunedin, New Zealand) software, allowing times to be recorded (±20 ms). Data yielded from both the recorded video and timing gates provided the following measures, all reported in milliseconds.

1. **3 m time** - from start gate to the abort gate at the 3 m mark.
2. **Decision time (DT)** - elapsed time (±20 ms) from stimulus presentation point until the initiation of the physical response by the test participant, defined as the first definitive lateral movement of the foot which initiates the change of direction.
3. **Total time (TT)** - from start until passing through one of the exit gates.
4. **Agility time (AT)** - Total time minus 3 m.
5. **Movement time (MT)** - The time from response initiation until triggering an exit gate.

### 4.2.3 Statistical analyses

Trials where participants made incorrect decisions were discarded and the mean of the remaining trials used for analysis. A mixed-model ANOVA (group x test) established whether there were group or test effects, and Tukey HSD and paired t-tests were used for post-hoc analyses, with a p value <0.05 denoting significance where appropriate. Additionally, to further
interpret any differences between means, effect sizes (Cohen’s $d$) were calculated and interpreted based on the criteria of Hopkins$^{(13)}$ where $0=$trivial, $0.2=$small, $0.6=$moderate, $1.2=$large, $2.0=$very large and $>4.0$ nearly perfect.

Further, the smallest worthwhile change (SWC) was used in conjunction with raw differences in means and 90% confidence intervals (CI) to determine the practical importance of the differences$^{(2,19)}$. For agility time the SWC was determined to be 15 ms, based on a similar length reactive agility test using a comparable population$^{(21)}$ and for decision and movement times the SWC was 16 and 17 ms respectively, based on similar measures from another reactive agility test$^{(8)}$. A spreadsheet was used to compare the differences in the mean±CI against the SWC to determine the likelihood that any difference is large enough to have an important practical benefit, expressed as the probability (percentage) that the mean difference ± CI is beneficial/trivial/detrimental$^{(2,19)}$. The resulting practical inference was expressed using the descriptors: <1%, almost certainly not; 1-5%, very unlikely; 6-25%, unlikely; 26-75%, possibly; 76-95%, likely; 96-99% very likely; >99%, almost certainly$^{(12)}$. For example, 80/15/5 equates to “likely” (beneficial), “very unlikely” (trivial), “almost certainly not” (harmful) and therefore the change in this example would be interpreted as “likely beneficial”.

Finally, Pearson correlations ($r$) were used to determine the relationships between the dependent variables and interpreted based on the criteria of Hopkins$^{(13)}$ whereby $0=$trivial, $0.1=$small, $0.3=$moderate, $0.5=$large, $0.7=$very large, $0.9=$nearly perfect, $1=$perfect.

4.3 Results

For pooled participant data, in both the reactive test modes total times (VRAT = 2308 ± 152 ms; LRAT = 2330 ± 127 ms) and agility times (VRAT = 1550 ± 102 ms; LRAT = 1572 ± 97 ms) were significantly ($p<0.001$) slower than the planned protocol (Total = 2102 ± 103 ms; Agility = 1346 ± 66 ms), accompanied by very strong effect sizes (1.6 - 2.7) and a 100% likelihood that these times were different when compared to the smallest worthwhile change (Table 4.1). Also, decision time was significantly faster in the light-based test
Validity of a reactive agility test for Australian football

(LRAT) than the video-based test (VRAT) (33 ± 13 ms; p < 0.001; d = 0.8; SWC=98/2/0%) but no significant differences were observed in agility and movement times between the reactive modes. Additionally, very large correlations (r >0.7) were found in total time between the three modes while moderate (PLAN-LRAT r = 0.4), large (PLAN-VRAT r = 0.68) and very large (VRAT-LRAT r = 0.75) correlations were observed for agility time (Table 4.2).

There was a significant group effect for total time and post-hoc analysis revealed that the non-footballers (NF) were significantly (p <0.001-0.002) slower than both lower performance (LP) and higher performance (HP) groups on all tests, with large associated effect sizes (d = 1.58 - 1.91) and 100% probability that these were practically important differences (Table 4.3). In addition, HP had faster agility (d = 1.27; p = 0.004; SWC = 100/0/0%) and movement times (d = 0.88; p = 0.1; SWC 88/9/3%; likely) on the VRAT than NF. Further, HP had faster agility (d = 0.99; p = 0.08; SWC=94/3/3%; likely) and movement times (d = 0.9; p = 0.08; SWC=92/6/2%; likely) than NF in the LRAT.

Finally, HP also had a faster agility time than LP on the VRAT (d = 0.82; p = 0.16; 88/6/6%) and a faster decision time than LP on the LRAT (d = 0.66; p = 0.21; 60/34/6%), with moderate effect sizes indicated.

4.4 DISCUSSION

Initially, this study examined agility performance between a planned and two reactive agility tests, and observed no differences in total time (TT) and agility time (AT) between the reactive tests (d = 0.2; p = 0.07 - 0.12) but also that both reactive tests were significantly slower (p <0.001; d = 1.6 - 2.7) than the planned test (Table 4.1). Additionally, very large correlations in TT (r = 0.73 to 0.82) were observed between the reactive and planned scenarios, but the correlations were smaller for AT (r = 0.41 to 0.68) (Table 4.2).
Table 4.1: Mean±SD total (TT), agility (AT), decision (DT) and movement (MT) times (ms) in planned (PLAN), light-based (LRAT) and video-based (VRAT) reactive agility tests.

<table>
<thead>
<tr>
<th></th>
<th>VRAT</th>
<th>LRAT</th>
<th>PLAN</th>
<th>VRAT v LRAT Diff in mean±90%CI; d; p value;</th>
<th>LRAT v PLAN Diff in mean±90%CI; d; p value;</th>
<th>PLAN v VRAT Diff in mean±90%CI; d; p value;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SWC%</td>
<td>SWC%</td>
<td>SWC%</td>
</tr>
<tr>
<td>DT</td>
<td>311±47</td>
<td>278±36*</td>
<td>-</td>
<td>33±13; 0.8; &lt;0.001; 98/2/0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MT</td>
<td>1094±81</td>
<td>1090±93</td>
<td>-</td>
<td>4±19; 0.04; 0.723; 13/84/3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AT</td>
<td>1550±102</td>
<td>1572±97</td>
<td>1346±66**</td>
<td>21±19; 0.2; 0.07; 70/30/0</td>
<td>226±88; 2.7; &lt;0.001; 100/0/0</td>
<td>204±79; 2.4; &lt;0.001; 100/0/0</td>
</tr>
<tr>
<td>TT</td>
<td>2308±152</td>
<td>2330±127</td>
<td>2102±103**</td>
<td>22±23; 0.2; 0.12; 70/30/0</td>
<td>228±89; 2.0; &lt;0.001; 100/0/0</td>
<td>206±80; 1.6; &lt;0.001; 100/0/0</td>
</tr>
</tbody>
</table>

* = LRAT significantly faster than VRAT, p<0.001
** = PLAN significantly faster than both VRAT and LRAT, p<0.001
Table 4.2: Pearson correlation coefficients for planned (PLAN) agility, light-based (LRAT) and video-based (VRAT) reactive agility test variables (n=42) (TT= Total time, AT= Agility time).

<table>
<thead>
<tr>
<th></th>
<th>VRAT TT</th>
<th>VRAT AT</th>
<th>LRAT TT</th>
<th>LRAT AT</th>
<th>PLAN TT</th>
<th>PLAN AT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRAT TT</td>
<td>1</td>
<td>0.58**</td>
<td>0.82***</td>
<td>0.60**</td>
<td>0.78***</td>
<td>0.44*</td>
</tr>
<tr>
<td>VRAT AT</td>
<td>1</td>
<td>0.66**</td>
<td>0.75***</td>
<td>0.45*</td>
<td>0.68**</td>
<td></td>
</tr>
<tr>
<td>LRAT TT</td>
<td>1</td>
<td>0.65**</td>
<td>0.73***</td>
<td>0.43*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRAT AT</td>
<td></td>
<td>1</td>
<td>0.32*</td>
<td>0.41*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLAN TT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0.56**</td>
</tr>
</tbody>
</table>

* r=0.3-0.5, moderate  
** r=0.5-0.7, large  
*** r=0.7-0.9, very large
Table 4.3: Mean±SD total (TT), agility (AT), decision (DT) and movement (MT) times (ms) in higher (HP) and lower (LP) performance footballers and non-footballers (NF) for a planned agility (PLAN), light-based (LRAT) and video-based (VRAT) reactive agility tests.

<table>
<thead>
<tr>
<th></th>
<th>HP</th>
<th>LP</th>
<th>NF</th>
<th>HP v LP Difference in mean ± 90% CI; d; p value; SWC</th>
<th>HP v NF Difference in mean ± 90% CI; d; p value; SWC</th>
<th>LP v NF Difference in mean ± 90% CI; d; p value; SWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRAT</td>
<td>309±38</td>
<td>303±44</td>
<td>325±60</td>
<td>6±210; 0.14; 0.94; 45/15/40</td>
<td>16±90; 0.33; 0.65; 50/30/20</td>
<td>22±69; 0.43; 0.45; 60/29/12</td>
</tr>
<tr>
<td></td>
<td>267±30</td>
<td>287±38</td>
<td>279±36</td>
<td>20±39; 0.66; 0.21; 60/34/6</td>
<td>12±50; 0.43; 0.53; 44/45/11</td>
<td>8±110; 0.19; 0.85; 43/28/29</td>
</tr>
<tr>
<td>LRAT</td>
<td>1065±70</td>
<td>1095±80</td>
<td>1134±88</td>
<td>30±87; 0.40; 0.56; 60/22/18</td>
<td>69±73; 0.88; 0.1; 88/9/3</td>
<td>39±85; 0.47; 0.44; 67/20/13</td>
</tr>
<tr>
<td></td>
<td>1059±80</td>
<td>1087±94</td>
<td>1138±95</td>
<td>28±93; 0.34; 0.62; 58/21/21</td>
<td>79±74; 0.9; 0.08; 92/6/2</td>
<td>51±99; 0.49; 0.39; 72/15/13</td>
</tr>
<tr>
<td>MT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRAT</td>
<td>1493±76</td>
<td>1556±77</td>
<td>1623±124^</td>
<td>63±85; 0.82; 0.16; 88/6/6</td>
<td>130±24; 1.27; 0.004; 100/0/0</td>
<td>67±97; 0.65; 0.182; 87/6/7</td>
</tr>
<tr>
<td></td>
<td>1533±56</td>
<td>1570±114</td>
<td>1628±94</td>
<td>37±140; 0.42; 0.5; 66/15/19</td>
<td>95±86; 0.99; 0.08; 94/3/3</td>
<td>58±210; 0.38; 0.5; 69/10/21</td>
</tr>
<tr>
<td>LRAT</td>
<td>1326±69</td>
<td>1341±52</td>
<td>1381±73</td>
<td>15±150; 0.24; 0.8; 50/19/31</td>
<td>55±39; 0.87; 0.04; 95/3/2</td>
<td>40±57; 0.74; 0.21; 84/11/5</td>
</tr>
<tr>
<td>PLAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRAT</td>
<td>2224±136</td>
<td>2281±85</td>
<td>2466±141*</td>
<td>57±170; 0.50; 0.43; 72/11/17</td>
<td>242±7; 1.73; 0.002; 100/0/0</td>
<td>185±24; 1.58; &lt;0.001; 100/0/0</td>
</tr>
<tr>
<td></td>
<td>2270±81</td>
<td>2286±85</td>
<td>2480±120**</td>
<td>16±190; 0.25; 0.83; 50/17/33</td>
<td>210±61; 1.91; &lt;0.001; 100/0/0</td>
<td>194±5.7; 1.68; &lt;0.001; 100/0/0</td>
</tr>
<tr>
<td>TT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRAT</td>
<td>2076±65</td>
<td>2055±81</td>
<td>2211±104**</td>
<td>21±180; 0.29; 0.77; 53/16/31</td>
<td>135±3.9; 1.74; &lt;0.001; 100/0/0</td>
<td>156±4.6; 1.85; &lt;0.001; 100/0/0</td>
</tr>
<tr>
<td>PLAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NF significantly slower than both LP and HP, * = p<0.05; ** = p<0.001; ^ = NF significantly slower than HP, p<0.05
Further, it should be noted that the correlations between linear speed, measured via the initial 4-m linear sprint test, and all agility tests were also much stronger for TT (r = 0.71 to 0.81) than AT (r = 0.32 to 0.43), indicating that agility as measured by total time and tests for linear speed are measuring similar qualities. Put another way, it appears that linear speed contaminates the (total) agility measure when it includes a straight sprint approach segment and also over-inflates the relationship between the reactive tests. Consequently, AT appears a more valid agility measure and as such will be the primary performance measure discussed here. Notwithstanding that direct comparisons between planned and reactive tests may be problematic due to variations in the technique used to change direction (curve-linear versus a distinctive cut)\(^{21}\) the differences in AT between the planned and reactive modes, with common variances of less than 50%, supports previous research showing reactive agility and planned change of direction speed are unique skills\(^{8,21}\). Therefore, although several studies are required to prove validity\(^{14}\), these findings add to the growing body of evidence validating the broad reactive agility test paradigm over a pre-planned test\(^ {8,9,16,18,21,23}\).

The LRAT and VRAT both assess reactive agility, confirmed by the similar agility times and very large correlations (r = 0.75), yet a common variance of 56%, whilst supporting a certain degree of commonality, also indicates that some differences remain. Table 4.1 shows that the only significant difference was in DT where the LRAT was significantly faster (p <0.001; d = 0.8) than VRAT. Therefore, a simple light-based stimulus allows participants to make significantly faster decisions, likely due to the reduced cognitive demand in that protocol, e.g., either the light is “on” or “off”, although in this instance participants were not able to translate this into a faster overall performance, even though movement time was the same for each group. This apparent disparity was due to the cumulative effect of small differences in the approach aspects of the tests such as approach time and position within the stimulus zone, resulting in the participants being in a similar spatial location at the initiation of the change of direction. In contrast, during the video-based task, participants require more time to decode a multitude of postural and position cues before instigating a definitive response. Hence, since the
primary difference between the reactive tests is the decision making component, these results substantiate the view that perceptual elements required from complex sports-specific stimuli, such as another person changing direction, are somewhat unique and may not be effectively duplicated using a generic light-based stimulus\(^{(8,16,20)}\). Consequently, the video based protocol appears to be a more valid assessment tool than a light-based procedure for examining agility.

Previously, reactive agility testing has confirmed that higher skilled players have a superior ability to extract and utilise advanced cues from opponents more quickly than lesser skilled peers\(^{(8,9,18,21,23)}\). Further, it is purported that generic stimuli will not provide the opportunity to exploit this perceptual advantage and as such would be less sensitive to any apparent skill group differences\(^{(8,15,20,22,25)}\). This notion is supported by the results in Table 4.3 showing that the HP group had a significantly faster AT than NF on the VRAT (HP faster by \(130 \pm 24\) ms; \(d = 1.27\); \(p = 0.004\)), and a somewhat faster AT on the LRAT (HP faster by \(95 \pm 86\) ms; \(d = 0.99\); \(p = 0.08\)) and PLAN tests (HP faster by \(55 \pm 39\) ms; \(d = 0.87\); \(p = 0.05\)). Also, although the LP group were also faster than NF on all tests the differences were non-significant with only moderate effect sizes on the VRAT (LP faster by \(67 \pm 97\); \(d = 0.65\)) and PLAN tests (LP faster by \(40 \pm 57\) ms; \(d = 0.74\)). These results differ somewhat from those of Wilkinson, Leedale-Brown and Winter\(^{(24)}\) who found no difference between squash and non-squash players on a planned agility test but significant between group differences on a squash-specific reactive agility test. However, in their study the non-playing cohort were active Soccer players (thus agility trained) whereas in this current study, whilst active in various sports, the NF participants were not involved in agility (team) sports, and so unlikely to perform as well in agility tasks. Further, in this current study it is notable that the differences between HP/LP and NF tended to increase, in line with task complexity and skill level (e.g., smallest in the PLAN and greatest on the VRAT and HP more than LP), lending some support to the theory that the video-based test would be more sensitive to any skill-group differences and further supporting the construct validity of the video-based protocol.
Similarly, although there was little difference in AT and small effect sizes between HP and LP on both the PLAN ($d = 0.24$) and LRAT ($d = 0.42$) tests, there were larger, albeit non-significant, differences on the VRAT ($d = 0.82$). As was the case between the playing and non-playing cohorts, this indicates a trend toward an increasing divergence in the ability of the different playing groups to deal with the increasing cognitive demand from the PLAN to the LRAT to the VRAT. Although not as clear as previous studies, which found significant differences in reactive agility between different playing groups$^{8,9,18,21,23}$, the current results indicate that the VRAT appears to be more useful than light-based and planned tests in discriminating between football and non-football athletes, and between different groups of younger Australian football players, again supporting the construct validity of this protocol.

Previously, differences in reactive agility performance between players from different playing standards have been attributed to heightened perceptual and anticipatory ability in the higher standard group, a view supported by data showing superior players exhibited faster decision times using various sport-specific stimuli$^{8,9,18}$. However, in this study no significant differences were observed in DT between the participant groups on any test mode and the increase in DT from the LRAT to the VRAT was actually greater in HP (42 ms; $d = 1.23$; $p <0.001$) than LP (16 ms; $d = 0.4$; $p = 0.13$). This contrasts both with earlier research$^{8, 9, 18}$ and with the theory that better players have enhanced anticipatory skill. In fact, in this instance, the larger differences in AT between NF and HP were primarily due to differences in movement time ($d = 0.88 - 0.9$; $p = 0.08 - 0.1$) rather than decision time ($d = 0.33 - 0.43$). Notwithstanding that in part this is related to the fact that MT makes up a much larger proportion of AT than DT, it also indicates that the physical (rather than cognitive aspect) of agility was chiefly responsible for the improved performance. Potentially, their relatively young age (17-18 y in the playing groups) means the HP players may not have fully developed their cognitive expertise advantage, which may take up to 10 years of dedicated training to mature$^{1}$. Therefore, they may still be reliant on enhanced motor
skill, as evidenced by the faster MT, rather than decision making speed, which may change with experience.

4.5 **Conclusion**

The high correlation between linear speed and agility when the common linear approach segment is included in the agility test indicates that the overall result is unduly influenced by linear speed, therefore the agility time variable may be a more specific measure of agility than total time. The reactive and planned tests measure distinctly different characteristics, supporting previous findings that reactive protocols are a more valid method for determining sport-specific agility ability. Also, although light and video-based reactive tests measure similar qualities, it appears that the cognitive and perceptual challenge is somewhat different and the sport-specific nature of the video test is not replicated with a generic stimulus. Finally, the construct validity of the video-based test is further supported by the fact that it is better able to discriminate football players from non-players and between different playing groups of younger Australian footballers. Therefore, video-based reactive agility tests should be utilised in preference to more generic light-based stimuli for examining sports-specific agility in Australian footballers.

4.6 **Practical applications**

Reactive tests should be preferred over planned agility tests when examining sport-specific agility ability and similarly, video-based protocols should be used in preference to tests using generic stimuli. This notion can extend to the training environment where sport specific scenarios should be used in preference to pre-planned tasks. Finally, a test protocol that allows differentiation of the sub-components of agility will provide coaches with a greater understanding of the agility profile of individuals and teams, allowing a more targeted training approach to address weaknesses and maximise strengths.
References


Validity of a reactive agility test for Australian football


Reliability of a Reactive Agility Test for Australian Football
4A.1 INTRODUCTION

In team sports directional changes are often initiated in reaction to external stimuli such as opponent or ball position (Farrow, Young, & Bruce, 2005; Sheppard, Young, Doyle, Sheppard, & Newton, 2006). Accordingly, valid and reliable tests reflective of these qualities are necessary to assist coaches in identifying talent and designing and evaluating appropriate training interventions (Wilkinson, Leedale-Brown, & Winter, 2009). A number of reactive agility tests have recently been developed and while early examples used generic stimuli such as lights (Besier, Lloyd, Ackland, & Cochrane, 2001; Chelladurai, Yuhasz, & Sipura, 1977; Oliver & Meyers, 2009), these have since been found to have questionable validity, partly because they do not replicate the stimuli encountered in sports (Sheppard & Young, 2006; Sheppard, et al., 2006). Subsequently, alternative reactive agility tests have been introduced, requiring participants to rapidly change direction (45°-90°) in response to more specific stimuli such as a real person (Sheppard, et al., 2006), a video projection of opposition players changing direction (Serpell, Ford, & Young, 2010) or passing a netball (Farrow, et al., 2005), all of which have proven to be valid and reliable models. However, these too have some limitations relating to the stability of the stimulus delivery (Young, Farrow, Pyne, McGregor, & Handke, 2011).

Therefore, to continue the development of valid reactive agility tests for Australian football this current study presents a new video-based reactive agility test (VRAT) protocol. This procedure takes advantage of the stable platform for stimulus delivery offered by video projection whilst providing a scenario more akin to that encountered in the 360° open play nature of Australian football. Specifically, participants are required to chase a life-sized video projection of another player, in contrast to the ball pass and frontal evasion scenarios presented previously. An added advantage of this scenario is it allows the addition of a “no turn” option which increases the spatial uncertainty by producing a three-choice rather than a two-choice task. However, as with any new protocol, reliability must first be established before it can be widely implemented. Accordingly, this study examined test-
retest reliability of the VRAT protocol and the intra-rater reliability of decision time, a more subjective measure, in contrast to other dependent variables such as total time, agility time and movement time which are measured via timing gates.

4A.2 METHODS

4A.2.1 Participants

Male Australian football players (n = 15, mean ± SD age, height and mass of 18.2 ± 0.1 y, 179.4 ± 4 cm and 71.6 ± 5.0 kg respectively), competing for local amateur teams, were recruited for this study and were assessed during the pre-season training phase. This study had the approval of the Human Ethics Committee of the University of Western Australia (UWA) and all participants were provided information regarding the risks and subsequently gave informed consent.

4A.2.2 Procedures

Initially, participants completed 12 trials of a VRAT protocol designed around a single 45° change of direction, a pattern common in Australian football (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004) (Figure 4A.1). To control for environmental and ground conditions, testing was conducted indoors on a carpeted, sprung wooden floor. Data was collected using a video camera (Sony DCR-VX2100E) positioned 2 m behind the start gate in conjunction with infra-red timing gates (School of Sport Science, Exercise and Health, UWA) interfaced with a computer loaded with the customised “Agility” software (School of Sport Science, Exercise and Health, University of Western Australia). The “Agility” computer was in turn networked to another loaded with “VidPlay” software (School of Sport Science, Exercise and Health, UWA) that controlled the stimulus video, which was then connected to a roof mounted video projector (Epson™ EMP-1715) displaying a 2.5 m x 3.5 m image on a 4 m x 2.5 m screen positioned 16 m from the start line.
Forty-eight hours prior to the first agility session participants attended the lab and completed five straight 11 m sprint trials. The mean split time recorded at 4 m during these sprints was subsequently used during the VRAT to individually manipulate aspects of the tests such as delay time, stimulus presentation point and abort time, to ensure consistency (e.g., approach distance and turn angle) across subjects and test sessions.

![Figure 4A.1: Schematic illustration of the video reactive agility test.](image)

The agility session began with a five-minute standardised warm-up followed by a five-minute period of stretching during where an explanation and demonstration of the video reactive agility test was provided. Next, five sub-maximal familiarisation trials were completed, comprising two turns each to the left and right and one with no turn, with the stimulus presentation point varied from that used during the experimental trials. Then, following another 5 min recovery, participants completed the 12 experimental trials,
which were randomly ordered prior to the session and comprised four turns each to the left and right, two dummy turns (one left and one right) and two with no turn. The no turn option and abort function were clearly explained prior to both the familiarisation and experimental trials and participants were instructed to sprint forward as fast as possible, respond to the stimulus quickly and accurately and then move to the exit gate as quickly as they could.

One week after the first test session participants returned to the laboratory to repeat the agility test to allow test-retest reliability to be determined. Initially, participants completed an identical warm-up to that conducted previously after which 12 video agility trials were again completed. These trials were presented in a different order than in the previous session and the two dummy trials were replaced with two new clips to make the session appear different from the first. Finally, at least one week after initially analysing the videos and calculating decision time, a subset of 36 (30%) of the original trials were viewed again by the principal researcher and decision time re-calculated to determine intra-rater reliability.

The video record was edited using commercial video editing software (Pinnacle Systems™, Studio V9™) to remove superfluous content. The requisite clips were analysed using siliconCOACH PRO™ (V6) software, allowing times to be recorded (±20 ms). Data yielded from both the recorded video and timing gates provided the following measures, all reported in milliseconds.

1. 3 m time - From start gate to the abort gate at the 3 m mark.

2. Decision time - Elapsed time (±20 ms) from stimulus presentation point until the initiation of the response by the participant, defined as the first definitive lateral movement of the foot that initiates the change of direction.

3. Total time - From start until passing through one of the exit gates.

4. Agility time - Total time minus 3 m time.
5. **Movement time** - The time from response initiation until triggering an exit gate.

### 4A.2.3 Statistical analyses

Trials where incorrect decisions were made were discarded. The mean of each subjects’ experimental trials were used, with results presented as mean times (ms) ± standard deviation (SD) and differences between groups expressed as absolute and relative differences ± 90% confidence intervals. Test-retest reliability was determined via an intra-class correlation coefficient (ICC) and coefficient of variation (CV). Additionally, a dependent \( t \)-test assessed differences in performance between test 1 and 2 with \( p < 0.05 \) denoting significance where appropriate. Also, to further interpret any differences between means Cohen’s effect size (\( d \)) was calculated and interpreted based on the criteria of Hopkins (2006) where 0=trivial, 0.2=small, 0.6=moderate, 1.2=large, 2.0=very large and 4.0 nearly perfect. Finally, intra-rater reliability of decision time was determined by intra-class correlation coefficient, coefficient of variation and dependent \( t \)-tests.

### 4A.3 Results

#### 4A.3.1 Test-retest

Table 4A.1 shows the mean±SD, absolute and percentage (in brackets) change in means, ICC, CV and effect size analysis for the two test sessions. Only low to moderate effect sizes (\( d = 0.1 - 0.3 \)) were found, although a paired sample \( t \)-test showed that movement time was significantly different \( (p < 0.05) \) from test 1 to 2 \( (d = 0.4) \). However, no other significant differences were apparent. Also, the ICC was acceptable for agility time \( (r = 0.81) \) and movement time \( (r = 0.83) \) but relatively low for total time \( (r = 0.71) \) and decision time \( (r = 0.58) \) while the CV was relatively low (<4%) for all variables except decision time (6.2%).
4A.3.2 Intra-rater

A dependent t-test revealed no significant ($p = 0.69$) difference between decision time from the first (289 ± 87 ms) and second (291 ± 93 ms) assessments. Further, there was a high correlation of 0.99 between the results with a coefficient of variation of 5.2%.

Table 4A.1: Mean±SD, absolute (ms) and percentage change in mean, intraclass correlation coefficient, coefficient of variation (%) of test-retest results for total time, decision time and movement time for the video reactive agility test.

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>Change in mean (%)</th>
<th>ICC</th>
<th>CV</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Time</td>
<td>2283±94</td>
<td>2276±71</td>
<td>-7 (0.3)</td>
<td>0.71</td>
<td>2.0</td>
</tr>
<tr>
<td>Agility Time</td>
<td>1556±78</td>
<td>1540±62</td>
<td>-16 (1.03)</td>
<td>0.81</td>
<td>1.4</td>
</tr>
<tr>
<td>Decision Time</td>
<td>299±48</td>
<td>317±47</td>
<td>18 (6)</td>
<td>0.58</td>
<td>6.2</td>
</tr>
<tr>
<td>Movement Time</td>
<td>1095±80</td>
<td>1065±76*</td>
<td>30 (2.7)</td>
<td>0.83</td>
<td>3.0</td>
</tr>
</tbody>
</table>

* = significantly faster than test 1

4A.4 Discussion

The test-retest ICC for agility time (a more specific agility measure than total time as it removes the initial straight sprint) was 0.81 which was similar to or slightly lower than seen in previous studies (Farrow, et al., 2005; Gabbett, Kelly, & Sheppard, 2008; Serpell, et al., 2010; Sheppard, et al., 2006). An ICC above 0.8 is considered to be acceptable reliability (Farrow, et al., 2005; Sheppard, et al., 2006) and on that basis the agility time in the current video-based reactive agility test is considered as a reliable measure of reactive agility. However, it should be acknowledged that the low standard deviation indicates a relatively homogenous group, which can potentially result in a lower ICC (Hopkins, 2000). Therefore, another useful measure of
reliability for performance tests is the coefficient of variation, a measure of the within-subject variation, often found to be <5% for athletic events (Hopkins, 2000). The CV for agility time in this current study of 1.4% is similar to, or lower, than other reactive agility research (Gabbett, et al., 2008; Oliver & Meyers, 2009) and indicates relatively little within subject variation between the two test sessions, signifying a degree of stability. Additionally, a paired sample t-test also found no significant differences in agility time between test 1 and 2, further supporting the reliability of this measure.

Total time, which is agility time plus the time for the initial 3 m approach sprint, also had a low CV (2%), suggesting a low level of variability between test sessions. When coupled with the lack of significant difference between sessions, this also indicates adequate reliability. In contrast, total time exhibited a slightly less robust ICC (0.71), signifying some loss of rank-order of participants on the second test session, but again the relatively homogenous group may have skewed the ICC downward somewhat. Given that agility time is a more specific agility measure, because it reduces the contamination of linear speed, and it has slightly better reliability, agility time should be the key variable assessed when examining overall reactive agility using a VRAT protocol.

Decision time appears to be somewhat less reliable than both agility and total times, with an ICC of 0.58 and a CV of 6.2%. However, although the reliability of this aspect of reactive agility has not been extensively examined these results are similar to previous studies. For example, Gabbett, Kelly and Sheppard (2008) measured decision time across two repeated test sessions and found a stronger ICC of 0.95 but a CV of 7.8% and Serpell, Ford and Young (2010) also found a weaker ICC of 0.31. It is apparent that the relative magnitude of the variability is somewhat different between this current investigation and that of Gabbett et al.(2008), where the standard deviation expressed as a proportion of the raw measures was significantly less than in the current investigation, indicating a more homogenous cohort, possibly accounting for the lower ICC found here.
Also, the differences in reliability of the decision making measure between the studies of Serpell et al. (2010) and Gabbett et al. (2008) may be due to methodological differences in the way this component was calculated. Whereas Serpell et al. (2010) used the time between video occlusion and participant foot strike, these same authors indicated that Gabbett et al. (2008) used the time between the first kinematic cue of the stimulus person and the first such cue of the participant (although the exact method was not detailed), which is very similar to that used in this study. It was suggested that since this is a somewhat subjective measure it may influence reliability and would require skilled and accurate cue identification (Serpell, et al., 2010). Consequently, the intra-rater reliability of this measure was examined in this current investigation and showed a very high correlation of $r = 0.99$ with very little difference between the two assessments when conducted by a trained reviewer.

This is the first study to examine the reliability of movement time in the context of it being solely the post-response movement, and it exhibited an ICC of 0.83 and CV of 3%, indicating acceptable reliability. However, a paired sample $t$-test revealed that the performance on the second test was significantly faster than the first ($p < 0.05$), suggesting a degree of learning had occurred. It was noted that 11 of the 14 participants were faster on the second test session, similar to previous research using another video-based reactive agility protocol (Farrow, et al., 2005). Since some effort was made to design the protocol to limit learning via the inclusion and replacement of the “dummy” clips, as well as re-ordering the clips, it is unlikely that participants were able to recognise individual clips on the second session. Therefore, participants may simply have become more comfortable with the protocol, particularly the stimulus. This potentially could have resulted in less mental effort devoted to the stimulus identification, allowing them to complete the movement component more quickly. Nonetheless, the available evidence is equivocal as to the reliability of movement time and so when repeat test sessions are required they should be scheduled at intervals of approximately 8 weeks or more, as recommended by Farrow et al. (2005).
In conclusion, agility time measured via the VRAT is a reliable method of examining reactive agility in Australian footballers. Although the reliability of the sub-variable of decision time appears to be somewhat less reliable it was similar to comparable measures from other studies. Using the first definitive lateral movement method for determining this variable has satisfactory reliability when used by a trained practitioner. Movement time also appears to have satisfactory reliability, although there is some evidence that participants may improve on a second test session within a week. As such, some thought should be given to implementing extended gaps (weeks) between repeat test sessions.
References


Effects of a Feint on Reactive Agility Performance

This manuscript has been published in the Journal of Sports Sciences.


The PhD candidate Greg Henry accounted for 90% of the intellectual property associated with the final manuscript. Collectively, the remaining authors contributed 10%.
ABSTRACT

This study compared reactive agility between higher standard (n = 14) and lower standard (n = 14) Australian footballers using a reactive agility test incorporating a life-size video image of another player changing direction, including and excluding a feint. Mean agility time in the feint trials was 34% (509 ± 243 ms; p < 0.001; effect size 3.06) longer than non-feint trials. In higher standard players, agility time was shorter than for lower standard players in both feint (114 ± 140 ms; p = 0.18; effect size 0.52; likely beneficial) and non-feint (32 ± 44 ms; p = 0.22; effect size 0.47; possibly beneficial) trials. Additionally, the inclusion of a feint resulted in movement time increasing over three times more in the lower standard group (197 ± 91 ms; p = 0.001; effect size 1.07; almost certainly detrimental) than the higher standard group (62 ± 86 ms; p = 0.23; effect size 0.66; likely detrimental). There were weak correlations between the feint and non-feint trials (r = -0.13 to 0.14; p > 0.05), suggesting that reactive agility involving a feint is a unique skill. Also, higher standard players are more agile than their lower standard peers, whose movement speed deteriorates more as task complexity increases with the inclusion of a feint. These results support the need for specific training in multi-turn reactive agility tasks.
5.1 INTRODUCTION

Agility is important for success in team sports (Brown & Ferrigno, 2005; Hawley & Burke, 1998; Verstegen & Marcello, 2001) and several tests have been developed to assess this characteristic, many of which are pre-planned (Draper & Lancaster, 1985; Sheppard & Young, 2006). However, agility has recently been redefined to recognise that directional changes in sport often occur in reaction to an external stimulus, such as the actions of an opponent (Sheppard & Young, 2006). Accordingly, various reactive agility tests have recently appeared in the literature, involving changes of direction in response to sports-specific stimuli such as the movement of an opponent (Sheppard, Young, Doyle, Sheppard, & Newton, 2006; Veale, Pearce, & Carlson, 2010) or a ball pass (Farrow, Young, & Bruce, 2005).

Although many pre-planned agility assessments involved multiple turns, reactive agility tests have typically incorporated a stimulus requiring only one turn. Nevertheless, these single-turn models can discriminate standards of Netballers (Farrow, et al., 2005), Australian footballers (Sheppard, et al., 2006) and Rugby League players (Gabbett, Kelly, & Sheppard, 2008) of differing standards. However, a common tactic to evade tackles in sports such as Australian football or Rugby (Jackson, Warren, & Abernethy, 2006) is to use a feint to deceive an opponent into turning the wrong way and produce a time advantage (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008). Often, this involves two closely spaced movements (stimuli) by the attacking player, requiring a similar response from a defensive player, although it might also involve a fake ball pass, among others (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008). Therefore, on-field agility can often involve multiple turns in response to several closely spaced stimuli, but little research has examined this common ploy in an agility context, particularly with the coupling of perception and a sport-specific action.

In one example, Jackson et al. (2006) examined the effect of deceptive movement on Rugby players but coupled it with a written response and found that response accuracy decreased more in lower standard players on the
deception trials. Also, Serpell, Ford and Young (2010) included both deceptive player and ball movements when examining agility in Rugby League players but they did not differentiate performance from single-movement trials. Therefore, the specific effects of the feint were not determined, although it was observed that the elite players were faster than sub-elite players. These results lend support to the theory from other cognitive research that expert performers can more accurately anticipate the actions of their opponents and are therefore less susceptible to feints (Jackson, et al., 2006; Williams & Ford, 2008).

The basis for the effectiveness of the feint is the double-stimulation paradigm (McClymont, 2005; Schmidt & Wrisberg, 2008), where the reaction to the first of two closely-spaced stimuli is normal, but the reaction to the second is delayed by more than that which would have occurred had it been presented alone (McClymont, 2005; Schmidt & Wrisberg, 2008). This lengthening of the second reaction is the psychological refractory period (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008) caused by a bottleneck attributable to serial processing in the response-programming stage of information processing. Consequently, the response for the second stimulus is delayed until the response for the first is dealt with (Schmidt & Lee, 2005). Therefore, in practice, when an attacking player feints, the defending players’ response to the second movement could be delayed more than if it were presented alone, rewarding the attacker with a greater time advantage.

Additionally, the advantage of the feint is not limited to a time gain brought about through a delayed response but an added practical aspect is that by being deceived with a feint the defender is accelerating and building momentum in the wrong direction, which must be checked prior to turning and attempting to catch the opponent (Schmidt & Lee, 2005). An inability to overcome this distance and momentum disadvantage can magnify any decision-time deficit; consequently it is not unusual to see a player deceived by a feint beaten by their opponent. Nonetheless, while common in sport, little is known about the practical use of the feint or whether the effects vary between athletes of different playing standards.
Therefore, this study sought to use a new video-based reactive agility test, incorporating a mix of feint and non-feint trials, to examine the effects of a feint on agility performance and test the hypothesis that the inclusion of a feint would decrease performance of the “defensive” player. Second, it was hypothesised that any decrease in performance would be manifested through both longer decision making and movement-time components. Additionally, performance was compared between Australian footballers of different competition standards to determine whether any changes in performance varied between them. Previously, single-turn reactive agility research has shown that higher standard players exhibit superior agility performance than lower standard counterparts (Farrow, et al., 2005; Gabbett, et al., 2008; Sheppard, et al., 2006; Wilkinson, Leedale-Brown, & Winter, 2009). Also, higher standard Rugby League players have demonstrated better agility when a reactive agility test included fake movements and/or ball passes (Serpell, et al., 2010) and higher standard Rugby players had grater decision accuracy during tasks inclusive of deceptive movements (Jackson, et al., 2006). Therefore, a third hypothesis was that the higher standard group in this study would perform better across all agility trials and this advantage would increase with the inclusion of the feint. Also, the inter-relationships between the agility components both within and between the feint and non-feint tasks were examined to determine whether performance on simple and more complex tasks was related and which of the subcomponents exerted the greatest influence. Finally, it was predicted that there would be little relationship between the feint and non-feint trials due to the increased complexity of the feint trials, indicating that multiple-turn reactive agility is a unique skill.

5.2 Methods

Male participants (n = 28) were assigned to two groups according to their playing standard in Australian football. The higher performance footballers (n = 14, mean ± SD age, stature and mass of 23 ± 2 y, 182 ± 7 cm and 81.7 ± 9.0 kg respectively) were semi-professional Australian footballers and the lower performance group (n = 14, mean ± SD age, stature and mass of
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21 ± 2 y, 178 ± 5 cm and 77.0 ± 8.7 kg respectively) were amateur players. The University of Western Australia (UWA) Human Ethics Committee gave approval for the study and all participants were provided information on the risks and benefits of the study and subsequently gave their informed consent.

5.2.1 Procedures

Testing took place indoors on a carpeted, sprung wooden floor. All agility trials used a video reactive agility test (Henry, Dawson, Lay, & Young, 2011) (Figure 5.1) designed around an initial 45° change of direction, a common pattern in Australian football (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004). Data were collected using a video camera (Sony DCR-VX2100E) positioned 2 m behind the start line and infra-red timing gates (Fitness Technology, Adelaide, Australia) interfaced with a computer loaded with customised “Agility” software (School of Sport Science, Exercise and Health, UWA, Crawley, Australia). This computer was networked with another containing “Vidplay” software (School of Sport Science, Exercise and Health, UWA, Crawley, Australia) that controlled the stimulus video and was in turn linked to a roof-mounted projector displaying a life-sized image of a player onto a 4 m x 2.5 m screen, positioned 16 m from the start line.

After a standard warm-up, five straight 4 m-sprint trials were conducted, the best of which was used to calculate stimulus/delay and abort times in subsequent agility trials. Next, after an explanation and demonstration of the reactive agility test procedure, five sub-maximal practice trials were completed, including one turn each to the left and right, another with no turn and two feint trials (one each side). Then, after a five-minute recovery period the 14 experimental trials were completed with at least 90 s recovery between them. The experimental trials included three turns each to the left, right, feint left/turn right, feint right/turn left and two with no turn, and were randomly ordered before the assessment. For all trials the stimulus person was filmed from behind running away from the camera and for the feint trials they initially stepped in one direction (e.g., feint to the left with the left foot) then, using that same foot, quickly reversed
direction and ran out of view (to the right). The inclusion of the no-turn option increased both spatial and temporal uncertainty, helping to avoid pre-planning and prevent participants from slowing and propping before the stimulus. Data from the no-turn trials were later discarded, resulting in 12 trials remaining (6 feint and 6 non-feint).

**Figure 5.1:** Schematic illustration of the video reactive agility test.

For agility trials, triggering the start gate initiated the video stimulus and at a predetermined time, equal to each participant's 4 m-sprint time, the stimulus person changed direction (or feinted, then turned), to which the test participant responded by turning and sprinting through the exit gate in a simulated attempt to tackle. Through manipulation of the stimulus video the stimulus presentation point was limited to the 3-4 m distance zone, thereby
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providing a stable stimulus location for all participants. To achieve this, each experimental video was 600 ms from start to (initial) stimulus presentation which, when added to the mean 180 ms of internal system latency, resulted in a consistent stimulus time of 780 ms. To individualise stimulus presentation, the clip was paused for a period (delay time) to allow the stimulus presentation to match the 4 m-sprint time assessed previously. Specifically, to calculate delay time the constant 780 ms of each clip was subtracted from each participant’s shortest 4 m-sprint time. For example, for a faster runner (840 ms for 4 m) the delay would be 60 ms (840 ms - 780 ms), while for a slower runner (1000 ms for 4 m) the delay was 220 ms (1000 ms - 780 ms).

Additionally, an abort feature ensured a near-maximal sprint during the approach run and, since it was equal to the 4 m-sprint times assessed previously, helped to limit the stimulus presentation point to the 3-4 m distance zone. Thus, if the 3 m/abort gate was not triggered before the abort time elapsed the video was aborted, occluding the stimulus and the trial was rejected and repeated. To recognise the stimulus presentation point when viewing the video during later analysis, several pairs of white “reference” dots were inserted into the bottom corners of the stimulus video, they appeared on two consecutive frames then were separated by 2-4 frames, thus taking on a stroboscopic appearance when played normally. The fourth pair of dots was deliberately positioned on the frame that included the first stimulus and the seventh pair referenced the second stimulus in the feint trials, allowing decision and movement times to be determined during later review. The no-turn option and abort function were explained to participants before both the practice and experimental trials and participants were instructed to sprint forward, respond to the stimulus quickly and accurately and run to the exit gate as quickly as possible.

The video record was edited (Pinnacle Systems™, Studio V9™) to remove the no-turn and aborted trials. Clips were analysed using SiliconCOACH PRO™ software, allowing times to be recorded (±20 ms). Data yielded from the video record and timing gates provided the following measures, all recorded in milliseconds:
1. *Decision time 1* - The time from the first stimulus (the only turn in non-feint trials or the first in the feint trials) until the response initiation by the participant, both defined as *the first definitive lateral movement of the foot which initiates the change of direction*.

2. *Decision time 2* - Time from the second stimulus (the second turn in feint trials) until the initiation of the second response by the test participant. Unlike decision time 1, it was necessary to define this as the ground contact of the foot that initiates the turn for both the stimulus and the participant, a definition used previously (Farrow, et al., 2005; Young & Willey, 2010). The alternative definition was necessary as the participant orientation was such that the preferred reference point of initial lateral movement of the foot for the second response was not readily identifiable in the video.

1. *3 m time* - Time from start to the 3 m abort gate.

2. *Total time* - Time from start to finish.

3. *Agility time* - Total time minus 3 m time.

4. *Movement time* - Time from response initiation (the second response in feint trials) until triggering an exit gate.

5. *Inter-stimulus interval* - Time between the two stimuli in the stimulus video.

6. *Inter-response interval* - Decision time 2 minus Decision time 1.

5.2.2 Statistical analyses

The mean of each participant’s trials was used for analysis and results are presented as mean times (ms) ± standard deviation (SD) and differences between groups as raw and percent difference ± 90% confidence intervals. Mixed-model ANOVA (group x test) and independent *t*-tests were used to determine group or test differences, with *p* <0.05 denoting significance where appropriate. Additionally, to further interpret the differences between means, Cohen’s effect sizes (*d*) were calculated and interpreted based on the
criteria of Hopkins (2006), where 0.0 = trivial, 0.2 = small, 0.6 = moderate, 1.2 = large, 2.0 = very large, 4.0 = nearly perfect.

Furthermore, the smallest worthwhile change was calculated, and used in conjunction with raw differences in means and confidence intervals to determine the practical importance of the observed differences (Sheppard, Barker, & Gabbett, 2008). For agility time, the smallest worthwhile change was 15 ms, based on a similar length reactive agility test using a comparable population (Sheppard, et al., 2006). Conversely, the smallest worthwhile change for decision and movement times were calculated as 16 and 17 ms respectively, based on measures from another reactive agility test (Farrow, et al., 2005). A spreadsheet was used to compare the differences in the means against the smallest worthwhile change to determine the likelihood (percentage) that the mean difference ± 90% CI is beneficial/trivial/detrimental and expressed using the descriptors: <1%, almost certainly not; 1 - 5%, very unlikely; 6 - 25%, unlikely; 26 - 75%, possibly; 76 - 95%, likely; 96 - 99% very likely; >99%, almost certainly (Hopkins, 2007). For example, 80/15/5 equates to “likely” beneficial, “very unlikely” trivial, “almost certainly not” harmful and therefore is interpreted as “likely beneficial”.

Finally, Pearson correlations (r) were calculated to establish the relationships between dependent variables and determine their influence on performance and were interpreted by the criteria of Hopkins (2006), where 0 = trivial, 0.1 = small, 0.3 = moderate, 0.5 = large, 0.7 = very large, 0.9 = nearly perfect, 1 = perfect.

5.3 RESULTS

5.3.1 Feint vs non-feint

Overall, with the skill groups pooled, both agility (508 ± 243 ms; 34%; p <0.001; d = 3.06) and movement times (130 ± 199 ms; 11%; p = 0.002; d = 0.88) were longer in the feint trials than the non-feint trials. In contrast, while decision time 1 was longer (24 ± 53 ms; 8%; p = 0.02; d = 0.43) in the
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feint trials than non-feint decision time 1, decision time 2 was shorter than both feint decision time 1 (48 ± 73 ms; 17%; p = 0.002; d = 0.80) and non-feint decision time 1 (73 ± 66 ms; 23%; p <0.001; d = 1.15).

5.3.2 Differences between higher and lower performance footballers

While skill-group differences were small in all reactive agility tests, the effect sizes and qualitative interpretations of the confidence interval compared with those of the smallest worthwhile change (probability beneficial/trivial/detrimental effect) revealed a trend for better agility (feint: p = 0.18; d = 0.52; 88/6/6; likely beneficial; non-feint: p = 0.22; d = 0.47; 74/22/4; possibly beneficial), decision (feint decision time 1: p = 0.18; d = 0.59; 74/24/2; possibly beneficial; non-feint: p = 0.07; d = 0.73; 87/12/1; likely beneficial) and movement times (feint: p = 0.06; d = 0.56; 95/4/1; very likely beneficial) in the higher standard players. In contrast, the higher standard players had a slightly longer decision time 2 (p = 0.82; d = 0.07; 34/45/21; unclear) in the feint trials and movement time in the non-feint trials (p = 0.61; d = 0.34; 59/25/16; unclear) (Table 5.1).

Table 5.2 shows that the inclusion of the feint resulted in a modest lengthening of movement time (p = 0.23; d = 0.66; 81/13/6; likely detrimental) for the higher performance group but larger deterioration for the lower performance group (p = 0.002; d = 1.07; 100/0/0; almost certainly detrimental).

5.3.3 Relationships among decision times and agility

There were moderate to large (r = 0.46 to 0.75) correlations between the non-feint agility components (total, agility and movement times) and almost perfect (r > 0.9) correlations between these same variables in the feint trials (Table 5.3). However, the association between these variables for the non-feint and feint trials were trivial to small (r < 0.1). Generally, decision times had little relationship with agility performance, with the exception of the non-feint decision time 1 and non-feint movement time (r = 0.61; p = 0.001; large) and decision time 2 and feint agility time (r = 0.51; p =
0.006; large). Finally, there were strong correlations between the inter-response interval and feint agility time (r = 0.53; p = 0.003; large) and decision time 2 (r = 0.75; p <0.001; very large), but the inter-stimulus interval was not related to any variable (r < 0.3).

Table 5.1: Mean±SD (ms) agility, decision and movement times in higher (HS) and lower standard (LS) footballers.

<table>
<thead>
<tr>
<th>Group</th>
<th>Time</th>
<th>Difference in mean (%) ± 90% confidence interval</th>
<th>Effect size</th>
<th>Practical inferencea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feint agility time</td>
<td>HS 1958 ± 109</td>
<td>114 (6) ± 140</td>
<td>0.52</td>
<td>Likely beneficial (88/6/6)</td>
</tr>
<tr>
<td></td>
<td>LS 2072 ± 293</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feint decision time 1</td>
<td>HS 271 ± 44</td>
<td>30 (10) ± 38</td>
<td>0.59</td>
<td>Possibly beneficial (74/24/2)</td>
</tr>
<tr>
<td></td>
<td>LS 302 ± 58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feint decision time 2</td>
<td>HS 240 ± 63</td>
<td>5 (2) ± 44</td>
<td>0.07</td>
<td>Unclear (34/45/21)</td>
</tr>
<tr>
<td></td>
<td>LS 235 ± 75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feint movement time</td>
<td>HS 1196 ± 115</td>
<td>106 (12) ± 92</td>
<td>0.56</td>
<td>Very likely beneficial (95/4/1)</td>
</tr>
<tr>
<td></td>
<td>LS 1302 ± 241</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a with reference to smallest worthwhile change of 15, 16 and 17 ms for agility, decision and movement times respectively, stated with regard to HS vs. LS. Likelihood of an important practical impact, positively or negatively expressed using the descriptors: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99% very likely; >99%, almost certainly (Hopkins, 2007).
**Table 5.2**: Difference in movement time (MT) between feint and non-feint trials in higher (HS) and lower standard (LS) footballers (percentage differences shown in parentheses).

<table>
<thead>
<tr>
<th>Group</th>
<th>Non-Feint Time±SD (ms)</th>
<th>Feint Time±SD (ms)</th>
<th>Difference in mean MT ± 90% confidence interval</th>
<th>Effect size</th>
<th>Practical inference&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS</td>
<td>1133 ± 66</td>
<td>1196 ± 115</td>
<td>62.84 (5) ± 86</td>
<td>0.66</td>
<td>Likely detrimental (81/13/6)</td>
</tr>
<tr>
<td>LS</td>
<td>1105 ± 93</td>
<td>1302 ± 241&lt;sup&gt;b&lt;/sup&gt;</td>
<td>197.21 (15) ± 91</td>
<td>1.07</td>
<td>Almost certainly detrimental (100/0/0)</td>
</tr>
</tbody>
</table>

<sup>a</sup> with reference to smallest worthwhile change of 17 ms, stated with regard to feint vs. non-feint times.

<sup>b</sup> LS feint MT significantly worse than non-feint, p<0.05.

**Table 5.3**: Pearson correlation coefficients for speed and feint and non-feint agility variables (n=168).

<table>
<thead>
<tr>
<th></th>
<th>NFTT</th>
<th>NFAT</th>
<th>NFMT</th>
<th>FTT</th>
<th>FAT</th>
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<th>IRI</th>
<th>ISI</th>
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NFTT = non-feint total test time; NFAT = non-feint agility time; NFMT = non-feint movement time; FTT = feint total test time; FAT = feint agility time; FMT = feint movement time; FDT1 = feint decision time 1; DT2 = decision time 2; NFDT1 = non-feint decision time 1; IRI = inter-response interval; ISI = inter-stimulus interval.

* significant at <0.05

** significant at <0.001
5.4 Discussion

This study examined the effects of a feint on reactive agility performance and its sub-components and how these might differ according to playing standard of Australian footballers. In the pooled data and each of the skill groups (Table 5.1), the inclusion of a feint resulted in a worsening of overall performance, supporting the first hypothesis. In practical terms, the difference between the feint and non-feint trials is the addition of a second stimulus, quantified as the inter-stimulus interval (pooled mean ± SD = 440 ± 6 ms). However, the resultant effect on participant response was magnified, with a difference in agility time between the feint and non-feint trials of 508 ms. Accordingly, this indicates that a feint worsens the performance of the defensive player more than the offensive player, also supporting our first hypothesis.

Several factors contribute to this discrepancy. First, until the delivery of the second stimulus, the feint and non-feint trials should appear the same. Hence, subtracting the common element of decision time 1 (300 ms) from the inter-stimulus interval provides the start point of the perceived difference (this could be negative if the inter-stimulus interval is small or decision time 1 is long); equating in this instance to 140 ms. Second, there is the second decision making period (238 ms) and third, an increased movement time in the feint trials of 130 ms. The resultant total (508 ms) is identical to the observed disparity in feint and non-feint performance, with similar results in the two skill groups (higher standard measured = 468 ms vs. tallied = 472 ms and lower standard = 550 ms vs. 570 ms).

Additionally, while there were strong correlations between agility time and movement time in both the feint and non-feint scenarios, decision time had less influence on performance. Notwithstanding that a large proportion of agility time is accounted for by movement time (feint = 62%, non-feint = 74%) these results support our second hypothesis, that the deterioration in performance with the inclusion of a feint arises from the addition of a second decision making period and longer movement times, as momentum is checked.
Effects of a feint on reactive agility performance

...and the movement direction corrected. Further, the differences in performance between the feint and non-feint trials, combined with small or trivial correlations in the agility and movement times recorded between the test modes (Table 5.3), means that reactive agility in response to a feint appears to be a unique skill compared with a similar single-turn agility task. Accordingly, this supports our fourth hypothesis and therefore, since the feint is also a commonly used tactic in sport, it is recommended that team sports participants devote specific training for this type of activity.

Specific reasons for the weak relationship between the feint and non-feint agility task and the large decrease in performance are unclear, but are probably because of the greater complexity of the cognitive component compounded by the increased difficulty of the motor element. Since feint trials require multiple decisions and movements the individual subcomponents are more difficult. In compounding this difficulty by coupling perception and action, the effects of the feint are magnified as the time stress and division of energy involved in such fast and complex tasks can adversely affect concentration, decision clarity and skill execution (Grehaigne, Godbout, & Bouthier, 2001). Had these components been presented separately, performance might not have been as badly affected. Accordingly, this highlights the importance of coupling perception and action in a test for reactive agility because maintaining this linkage is necessary to preserve the ecological validity of the test, by replicating on-field tasks (Williams & Grant, 1999). Further, such coupling is crucial when examining skill-group differences, which are more evident in ecologically valid test environments (Mann, Williams, Ward, & Janelle, 2007; Serpell, Young, & Ford, 2011).

The relationship between decision time 2 and both inter-response and inter-stimulus intervals provided no evidence of any lengthening attributable to psychological refractoriness. Although no control decision time was calculated, the inter-response interval (397 ms) was similar to that used in other research for an inter-stimulus interval (440 ms) (Kahneman, 1973; Schmidt & Lee, 2005; Smith, 1969). The lack of a meaningful psychological refractory period in this study could be because of the inter-stimulus interval
being greater than the minimum purported to invoke such a response, which according to Schmidt and Lee (2005) is approximately 350 ms, and increases as the inter-stimulus interval shortens. Consequently, an interval of 60-100 ms is recommended for maximum effectiveness as a feint in sport (Schmidt & Wrisberg, 2008), but this was not achievable in this instance while ensuring the first stimulus was realistic enough for participants to respond as if it were a “real” movement (Schmidt & Wrisberg, 2008).

For skill group differences, the effect sizes and practical inferences indicated a trend for better performance in the higher standard players across all agility trials (Table 5.1), supporting our third hypothesis and consistent with other reactive agility research (Farrow, et al., 2005; Gabbett, et al., 2008; Sheppard, et al., 2006). Additionally, larger differences occurred during the feint trials, indicating that the inclusion of a feint did not adversely affect higher standard players as much as the lesser standard players. Again, this supports our earlier hypothesis and underpins the validity of reactive tests in examining sport-specific agility and the importance of including feint scenarios in these assessments.

An additional advantage of “faking” in sport is that an opponent turns and builds momentum in the wrong direction, which must be reversed to initiate the real turn (Schmidt & Lee, 2005). This is the first study to examine this in an agility setting, revealing that movement times were longer ($d = 0.88$; $p = 0.002$) in the feint trials ($1249 \pm 193$ ms) than the non-feint ($1119 \pm 81$ ms), thereby supporting this contention. Partly, this is related to the increased distance to the finish caused by initially turning in the wrong direction (Schmidt & Gordon, 1977; Schmidt & Lee, 2005), but also related to the need to overcome the momentum developed before correcting movement direction. Further, the increase in movement time from non-feint to feint was more than three times greater in lower than higher standard players (Table 5.2) even though the better first decision in the higher standard players resulted in a slightly longer inter-response interval (higher standard $410 \pm 71$ ms vs. lower standard $384 \pm 97$ ms; $p = 0.42$; $d = 0.31$), resulting in the higher standard players moving for longer in the wrong direction before turning to
the correct side. Therefore, it appears that enhanced decision making speed in higher standard players initially puts them further out of position which paradoxically appears to make higher standard players more susceptible to deception, as proposed by Jackson et al. (2006). However, despite this disadvantage the higher standard group finished quicker and so were ultimately better able to overcome the deception produced by the feint, leading to better overall performance. This is probably attributable to superior physical ability or athleticism, as evidenced by a shorter movement time in that group. This highlights the importance of also maximising the physical components of agility through specific agility training, match simulation or strength and conditioning programs.

Contrary to the feint trials, Table 5.1 shows that while higher standard players recorded shorter agility times than the lower standard players during non-feint trials ($d = 0.47$; possibly beneficial) most of the difference was attributable to better decision making speed (decision time $d = 0.73$; likely beneficial) rather than movement ability (movement time $d = 0.34$, unclear), a finding consistent with previous single-turn agility research (Farrow, et al., 2005). Yet, in this current study decision time had only a weak relationship with agility time ($r = 0.26$; $p = 0.18$), indicating that its direct influence on overall performance is small. However, in contrast, decision time had a stronger correlation with movement time ($r = 0.61$; $p = 0.001$), which in turn, had a moderate to strong association with agility time ($r = 0.46$; $p = 0.02$) and total time ($r = 0.66$; $p <0.001$). Therefore, a better decision time could indirectly impact movement ability by reducing the turn angle, which has a flow-on effect to turn time, highlighting the multi-faceted nature of agility (Verstegen & Marcello, 2001). Again, this complex interaction will be evident when the decision making and response are coupled. This further supports the need for performance-based tests with good ecological validity for meaningful studies of sport-specific skills such as reactive agility (Mann, et al., 2007; Serpell, et al., 2011; Williams & Grant, 1999).

Since, during non-feint trials, decision making factors accounted for a greater proportion of the skill group differences than physical factors, and
Effects of a feint on reactive agility performance

since there was little difference in movement time between the groups, even moderately trained team sports players have the movement skill to negotiate a single-turn agility task as effectively as their higher standard counterparts. Moreover, it is the cognitive rather than physical components that are more likely to discriminate between them. In contrast, the motor component exerts greater influence during multi-turn activities and consequently movement speed deteriorates further in lower standard players during more intense play. Therefore, there appears to be a physical ceiling effect; as the task becomes more complex, lesser-standard athletes are less able to cope physically and performance declines further. This could be because of differences in physical characteristics such as reactive strength and impulse generation that contribute to turning ability (Green, Blake, & Caulfield, 2011; Sheppard & Young, 2006; Young & Farrow, 2006). However, no studies have examined the relationship between these characteristics and reactive agility (Jeffreys, 2011; Sheppard & Young, 2006). Alternatively, the energy and concentration required for dealing with the more complex cognitive component might have interfered with the response selection and execution more in the lesser-standard players, resulting in the longer movement time (Grehainge, et al., 2001), again highlighting that it is the effective coupling of these components that determines overall performance (Serpell, et al., 2011).

In conclusion, agility performance is worsened when incorporating a feint, brought about through a lengthening of movement time and the addition of a second decision making component. Additionally, there is no discernable relationship between agility performance with and without a feint, indicating that agility in response to a feint is a unique skill. Also, higher standard Australian footballers tended to be more agile than lower standard players and this difference was accentuated during complex multi-turn tasks.

During non-feint agility tasks the skill-group difference is attributable primarily to shorter decision times, whereas in feint trials differences in movement times account for most of this. Further, there is a greater deterioration in movement time in lesser-standard players with the
introduction of a feint, indicating that higher standard players have superior motor ability that plays a crucial role in maintaining performance during complex agility tasks. It is recommended that reactive agility training should involve both feint and non-feint scenarios, as the ability to respond to these are unique skills. These skills are trainable through sport-specific reactive agility training or match simulations (Serpell, et al., 2011), accompanied by appropriate strength and conditioning programming to improve players’ abilities to change momentum and direction.
References


Effects of a feint on reactive agility performance


Effects of a feint on reactive agility performance


Effects of a feint on reactive agility performance
Decision Making Accuracy in Reactive Agility: Quantifying the Cost of Poor Decisions

This manuscript has been published in the Journal of Strength and Conditioning Research.


The PhD candidate Greg Henry accounted for 90% of the intellectual property associated with the final manuscript. Collectively, the remaining authors contributed 10%.
ABSTRACT

Decision making accuracy and time cost of incorrect responses was compared between higher (n = 14) and lower standard (n = 14) Australian footballers using a reactive agility task incorporating both feint (two stimuli and turns) and non-feint (single stimulus and turn) scenarios. Accuracy was assessed as whether the participant turned in the correct direction at each stimulus. Pooled decision accuracy at the first (or only) decision time was 94 ± 7% and decreased to 83 ± 20% at the second decision time (p = 0.01; d = 0.69). Decision accuracy was similar between the playing groups at decision time 1 (higher standard 95 ± 6 vs. lower standard 92 ± 7%; p = 0.6; d = 0.42) but somewhat better in the higher standard group at decision time 2 (88 ± 22% vs. 78 ± 17%; p = 0.08; d = 0.50). However, while there was only a small decrease in decision accuracy from decision time 1 to 2 (p = 0.2; d = 0.44) in higher standard players the decrease was two fold greater in the lower standard group (p = 0.02; d = 1.04). When categorised solely as correct or incorrect decisions, agility time was longer for incorrect decisions on both feint (incorrect DT2 only) (2649 ± 405 vs. 1973 ± 360 ms; p <0.001; d = 1.76) and non-feint trials (1640 ± 131 vs. 1506 ± 101 ms; p = 0.001; d = 1.13). In contrast, incorrect decisions at decision time 1 during feint trials resulted in shorter agility times (1732 ± 241 vs. 2029 ± 388 ms; p = 0.008; d = 0.92). In conclusion, decision making errors generally worsen reactive agility performance, although successful anticipation of a feint can improve performance. Additionally, higher standard footballers are less susceptible to a feint, supporting the theory that those players have superior ability to anticipate and respond to deceptive movements. Accordingly, training to improve decision making accuracy, particularly involving feint movements, may principally benefit lower standard players and should be regularly programmed.
6.1 INTRODUCTION

Expert performers are able to recognise an opponent’s postural and motion information earlier in the execution of a skill than lower standard players (3, 4,11,24). In addition, higher standard athletes also demonstrate greater decision making accuracy and a superior ability to anticipate game events and opponent actions (1,7,12,24). Consequently, in tackle-based sports, superior decision making speed and accuracy might have important practical benefits as it allows players to more quickly and accurately change direction in response to an opponent’s movements (2,4), thus helping to either apply or avoid tackles.

Further, higher standard players from various sports have also demonstrated faster decision making during reactive agility tasks involving a response to opponent and/or ball movements (2,4,17,19,21,23). Yet, even though expert performers are also reported to respond to the movements of their opponents more accurately (6,7,12), few reactive agility studies have specifically investigated response accuracy, despite the fact that response errors have been observed during single-turn reactive agility tasks (4,5). For example, first and second grade Rugby League players had incorrect responses on 10 - 16% of trials using a real person stimulus, although no differences were apparent between these groups. Consequently, it is currently unclear whether, in addition to faster decision making speed, higher standard players exhibit superior decision making accuracy during high-intensity, multi-movement agility tasks.

Also, logic would suggest, even when movement direction is corrected, that decision making errors will result in a significant time cost. However, there is a paucity of research in this specific area, resulting in an incomplete understanding of what the full cost of errors, or error corrections are in an agility context, and how this might impact overall agility performance. For example, whether time deficits due to errors during response selection and programming can be mitigated during the
motor response, potentially due to superior physical attributes such as speed and power, is unknown (4,5,8,23).

Additionally, previous reactive agility research has incorporated single-turn tasks, but when pursued, players commonly employ a feint in order to deceive opponents into turning the wrong direction and produce a time advantage for the offensive player (13,15,16). A feint typically involves two closely spaced physical, or ball movements by the attacking player, requiring a similar response from a defensive player (15,16). However, although frequently used and designed to deceive, little research has considered how the use of a feint impacts decision accuracy in agility tasks coupled with a physical response. One study has observed that response accuracy was maintained in higher standard Rugby players during feint trials, but decreased significantly in lower standard players, indicating that lower standard players are less able to discriminate deceptive movements from the legitimate ones (11). However, although the participants were encouraged to visualise themselves as the defender and to make a physical movement in response to the video, the specific response was a written one and therefore, perception was not coupled to a sport-specific action with the associated game-specific time pressure (11). Such a coupling is important when examining potential expert advantage in sport, since differences are more apparent during ecologically valid tasks (7,12,18).

Therefore, since the use of feints are common in sport and will add to both the cognitive and motor challenge of the defensive players, the first aim of this study was to examine whether the inclusion of such tactics will have a negative impact on decision making accuracy. Furthermore, since decision making accuracy has been observed to be superior in higher standard players (5,11), this study also investigated the relative impact that the inclusion of deceptive movements has on decision accuracy in Australian football players of differing standards. It was hypothesised that a larger decrease in decision accuracy would be observed in lower standard players due to an inferior ability to recognise and respond to feint
movements. Finally, we examined the time-cost of response errors, and whether any time deficit during response selection and programming can be overcome during the motor segment of the reactive agility task.

These investigations can provide greater understanding of the effectiveness of feinting and whether the accuracy of the response can discriminate between Australian footballers of different playing standards. Better insight into whether appropriate supplemental decision making and/or physical training has the potential to improve decision accuracy, enhance anticipation of deceptive movement or improve the physical response to a feint may also be provided. Such an insight might assist strength and conditioning coaches to provide appropriate training and advice to athletes about the physical and cognitive aspects that influence agility performance.

6.2 Methods

6.2.1 Experimental approach to the problem

This study is the first to examine the effect of a feint on decision making accuracy and subsequent reactive agility performance by quantifying and comparing the performance on trials where participants initially turned in the wrong direction against trials with correct responses. It was predicted that the inclusion of a feint would reduce decision accuracy in all participants and secondly, that those incorrect decisions would lead to a decrease in overall performance. Furthermore, decision making accuracy during a reactive agility task will be compared between athletes of different playing standards to determine whether higher standard players exhibit better decision making accuracy than lesser standard players in both feint and non-feint tasks.

6.2.2 Subjects

Male participants \((n = 28)\) were divided according to their level of participation in Australian football. The higher standard footballers \((n =\)
Decision making accuracy in reactive agility

14, mean ± SD age, height and mass of 23 ± 3 y, 182 ± 7 cm and 81 ± 9 kg respectively) were semi-professional Australian footballers while the lower standard players were mid-grade amateur players (n = 14, mean ± SD age, height and mass of 21 ± 2 y, 178 ± 4 cm and 77 ± 8 kg respectively). The University of Western Australia Human Ethics committee granted approval for the study and participants were provided information regarding the risks and benefits of the study and subsequently gave informed consent.

6.2.3 Procedures

All tests were conducted indoors on a carpeted, sprung wooden floor. Agility trials used a video reactive agility test designed around an initial 45° change of direction and are described in detail elsewhere(8) (Figure 6.1). Data were collected using a video camera (Sony DCR-VX2100E) positioned 2 m behind the start line and infra-red timing gates (Fitness Technology, Adelaide, Australia) interfaced with a computer loaded with customised “Agility” software (School of Sport Science, Exercise and Health, University of Western Australia, Crawley, Australia). The “Agility” computer was networked with another containing “Vidplay” software (School of Sport Science, Exercise and Health, University of Western Australia, Crawley, Australia) that controlled the stimulus video. The “Vidplay” computer was in turn linked to a roof-mounted projector displaying a life-sized image of a player onto a 4 m x 2.5 m screen, positioned 16 m from the start line. Previously, this protocol was found to have good test-retest (coefficient of variation of 1.4% and intra-class correlation coefficient of 0.81) and intra-rater reliability (coefficient of variation of 5.2% and intra-class correlation coefficient of 0.99) (8).

Following a standardized warm-up, five straight 4 m-sprint trials were completed and the fastest time used to calculate abort time and to manipulate stimulus/delay times in subsequent agility trials. After an explanation and demonstration of the reactive agility test procedure, participants completed five sub-maximal practice trials, including one turn each to the left and right, another with no turn and two feint trials (one to
each side). After another five-minute recovery period, the 14 experimental trials commenced, randomly ordered prior to the assessment, and consisting of three turns each to the left, right, feint left/turn right, feint right/turn left and two with no turn. The no turn option was included to increase spatial and temporal uncertainty and therefore be more reflective of game demands; however the data from these no-turn trials was later discarded, resulting in 12 trials remaining for analysis (6 non-feint and 6 feint).

Figure 6.1: Schematic illustration of the video reactive agility test.

For agility trials, triggering of the start gate initiated the video stimulus, and at a time set to each participant’s 4 m-sprint time, the projected stimulus person changed direction (or feinted, then turned), to
which the participant responded by turning and sprinting through the appropriate exit gate in a simulated attempt to tackle. Additionally, an abort feature ensured a near maximal sprint during the approach run and if the 3 m/abort gate was not reached before the abort time elapsed, the trial was aborted, occluding the stimulus and the trial was repeated. The abort time was equal to the 4 m-sprint time assessed previously and, along with manipulation of the stimulus video length, assisted in limiting the stimulus presentation point to the 3 - 4 m distance zone for each subject.

Participants were instructed to sprint forward, respond to the stimulus as quickly and accurately as possible and then sprint to the exit gate. The video record was analysed using siliconCOACH PRO™ (V6) software, allowing times to be recorded (±20 ms) and data yielded from both the video record and timing gates, which provided the following key measures:

1. 3 m time - Time from start to the 3 m abort gate.

2. **Decision time 1 (DT1)** - The time from the first stimulus presentation (the only turn in non-feint trials or the first turn in the feint trials) until the response initiation by the test participant, both of which were defined as *the first definitive lateral movement of the foot which initiates the change of direction*.

3. **Decision time 2 (DT2)** - The time from the second stimulus (the second/real turn in the feint trials) until the initiation of the second response by the participant. Unlike DT1, this was defined as the ground contact of the foot that initiates the turn, a definition used previously (4). The different definitions for DT1 and DT2 were necessary as the orientation of the subject was such that the preferred reference point of initial lateral movement of the foot was not readily identifiable in the video for the second response.

4. **Total time** - Total elapsed time from start to finish gates.
5. *Agility time* - Total time minus 3 m time.

6. *Movement time* - Time from response initiation (the second response in feint trials) until triggering an exit gate.

7. *Decision accuracy* - Percentage of total trials where the initial reaction was in the correct direction.

### 6.2.4 Statistical analyses

Decision accuracy in the trial and skill groups was compared using independent *t*-tests. Agility, decision and movement times were compared using independent *t*-tests between groups wholly inclusive of either incorrect or correct decisions to determine the time/performance cost of wrong turns. Where appropriate, a *p* value of <0.05 was used to determine significance.

To further interpret the differences between means, Cohen’s effect sizes (*d*) were calculated and interpreted based on the criteria of Hopkins (9), where 0.0 = trivial, 0.2 = small, 0.6 = moderate, 1.2 = large, 2.0 = very large, 4.0 = nearly perfect. Additionally, the smallest worthwhile difference was calculated and used in conjunction with differences in means and 90% confidence intervals (CI) to determine the practical importance of the differences. The smallest worthwhile difference for agility time was determined to be 15 ms based on a similar length reactive agility test using a comparable population (21) and, based on another reactive agility test (4), was 16 and 17 ms respectively for decision and movement times. A spreadsheet was used to compare the differences in the mean and confidence intervals against the smallest worthwhile differences and the likelihood that the change is large enough to have an important practical impact, positively or negatively, and expressed using the descriptors: <1%, almost certainly not; 1-5%, very unlikely; 6-25%, unlikely; 26-75%, possibly; 76-95%, likely; 96-99% very likely; >99%, almost certainly (10).
6.3 RESULTS

6.3.1 Decision accuracy

With the skill groups pooled, decision accuracy at DT1 (94 ± 7%) was higher ($d = 0.69; p = 0.01$) than DT2 (83 ± 20%). Further, decision accuracy was similar between the playing groups at DT1 ($p = 0.60; d = 0.42$) but somewhat better in the higher standard group at DT2 ($p = 0.08; d = 0.50$) (Table 6.1). Finally, decision accuracy at DT2 was significantly lower than DT1 for the lower standard players ($p = 0.02; d = 1.04$) but similar at both time points for the higher standard group ($p = 0.2; d = 0.44$).

6.3.2 Decision making cost

In the non-feint trials, where initial responses were in the wrong direction, non-feint DT1 ($p = 0.004; d = 0.81$) and agility times ($p = 0.001; d = 1.13$) were longer than when players turned in the correct direction, whilst movement time was similar ($p = 0.12; d = 0.50$) (Table 6.2). Similarly, in feint trials where incorrect decisions were made at the second decision point (DT2), decision ($p <0.001; d = 1.56$), agility ($p <0.001; d = 1.76$) and movement times ($p <0.001; d = 1.18$) were all longer than if the initial movement direction was correct (Table 6.3). In contrast, in feint trials where the first of the two reactions (feint DT1) was incorrect the agility ($p = 0.008; d = 0.92$) and movement times ($p = 0.002; d = 1.14$) were shorter (Table 6.3).
**Table 6.1:** Mean±SD decision accuracy (% correct) at decision time 1 (DT1) and 2 (DT2) for higher (HS) and lower (LS) standard footballers (Effect size shown in parentheses).

<table>
<thead>
<tr>
<th>Group</th>
<th>Accuracy</th>
<th>Difference ± 90% confidence interval (effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>HS vs. LS</td>
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<tr>
<td>DT1 accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS</td>
<td>95 ± 6</td>
<td>3 ± 4</td>
</tr>
<tr>
<td>LS</td>
<td>92 ± 7</td>
<td>(0.42)</td>
</tr>
<tr>
<td>DT2 accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS</td>
<td>88 ± 22</td>
<td>10 ± 13</td>
</tr>
<tr>
<td>LS</td>
<td>78 ± 17</td>
<td>(0.5)</td>
</tr>
</tbody>
</table>

* Correct responses at DT2 significantly less than at DT1 in lower standard, p<0.05.

DT1 - Response to the first stimulus in the feint trials or the only stimulus in the non-feint trials.

DT2 - Response to the second stimulus in the feint trials.

**Table 6.2:** Mean±SD agility, decision and movement times for non-feint trials wholly inclusive of correct (C) or incorrect (IC) decisions at the first decision time point (DT1).

<table>
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<th>DT1 decision</th>
<th>n</th>
<th>Time (s)</th>
<th>difference in mean ± 90% confidence interval</th>
<th>d</th>
<th>Practical inference¹</th>
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<td>1.64 ± 0.13*</td>
<td>0.13 ± 0.07</td>
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<tr>
<td></td>
<td>C</td>
<td>147</td>
<td>1.51 ± 0.11</td>
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<tr>
<td>Non-Feint Decision time 1</td>
<td>IC</td>
<td>8</td>
<td>0.41 ± 0.15*</td>
<td>0.10 ± 0.06</td>
<td>0.81</td>
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<tr>
<td></td>
<td>C</td>
<td>160</td>
<td>0.31 ± 0.09</td>
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<tr>
<td>Non-Feint Movement time</td>
<td>IC</td>
<td>7</td>
<td>1.19 ± 0.16</td>
<td>0.07 ± 0.07</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>160</td>
<td>1.12 ± 0.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ with reference to smallest worthwhile change of 0.015, 0.016 and 0.017 s for agility, decision and movement times respectively. Practical inference stated with reference to C vs IC.

* IC trials significantly slower than C, p<0.05

DT1 - Response to the first stimulus in the feint trials or the only stimulus in the non-feint trials.
### Table 6.3: Mean±SD agility, decision and movement times for feint trials wholly inclusive of correct (C) or incorrect (IC) decisions at either decision time 1 (DT1) or 2 (DT2).

<table>
<thead>
<tr>
<th>Decision at DT1 only</th>
<th>n</th>
<th>Time (s)</th>
<th>Difference in mean (%) ± 90% confidence interval</th>
<th>Practical inference ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feint Agility time</td>
<td>IC</td>
<td>13</td>
<td>1.73 ± 0.24†</td>
<td>0.30 (15) ± 0.18</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>127</td>
<td>2.03 ± 0.39</td>
<td></td>
</tr>
<tr>
<td>Feint DT1</td>
<td>IC</td>
<td>13</td>
<td>0.23 ± 0.12</td>
<td>0.04 (15) ± 0.07</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>127</td>
<td>0.27 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>Feint Movement time</td>
<td>IC</td>
<td>13</td>
<td>0.98 ± 0.13†</td>
<td>0.27 (22) ± 0.12</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>127</td>
<td>1.26 ± 0.31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision at DT2 only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feint Agility time</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Feint DT2</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Feint Movement time</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

¹ with reference to smallest worthwhile change of 0.015, 0.016 and 0.017 s for agility, decision and movement times respectively. Practical inference stated with reference to C vs IC.

* IC trials significantly slower, p<0.001; † IC trials significantly faster, p<0.05

DT1 - Response to the first stimulus in the feint trials or the only stimulus in the non-feint trials.

DT2 - Response to the second stimulus in the feint trials.


6.4 Discussion

This study examined the effects of a feint on decision making accuracy between different standards of Australian footballers during a reactive agility task. Decision accuracy (94 ± 7 %) at the first decision time (DT1), which was prior to the feint in those trials, was higher than observed previously using the same protocol without feint movements (2), although fatigue and caffeine loaded conditions were included, which can influence decision accuracy (2,7). Additionally, the level of accuracy seen here was also higher than during a similar test using a real player as the stimulus (5), but lower than another test incorporating a video of another player (4). Accordingly, the nature of the stimuli appears to influence decision accuracy, likely due to the quantity and specificity of the cues provided (20).

For example, in a video-based ball-pass scenario (4) the stimulus was actual ball release and elite players were able to respond before release (negative decision times), with almost perfect accuracy. Potentially, a ball pass stimulus may provide early postural and movement cues, such as head and torso rotation. Consequently, higher standard players are able to predict pass direction confidently, assisted by the lack of deceptive movements or fake passes. In contrast, opponent evasion and chase protocols (2, 5) require a response to the movements of an opponent which provide fewer obvious advance cues, as evidenced by longer decision times and lower accuracy.

Additionally, the three-dimensional (real opponent) stimulus used by Gabbett et al. (5) resulted in the lowest decision accuracy of all the protocols, even though it offers the greatest ecological validity and therefore the greatest potential for sport-specific cues (4,20). Subsequently, the lower accuracy may result from there being a large amount of cues available, which may distract the defensive player from the crucial early cues, which may not be the case during a two-dimensional
video-based task, as these reportedly limit the quantity and specificity of cues available (20).

Further, a degree of variability in the time to produce the side-step stimulus using the real life scenario has also been observed, which might potentially influence the overall response time (25) and impact response accuracy. Alternatively, the difference in decision accuracy between this current study and other reactive agility studies could be due to differences in the ability to predict movements between a front-on evasion scenario (5) and the chase scenario in this study. Accordingly, coaches and researchers should carefully consider the nature of the scenario used as the stimulus (during both training and assessment) to ensure it is related to the specific needs of their sport.

This study also examined accuracy at the second decision point (DT2) of a multi-movement task and revealed that, with the skill groups pooled, accuracy decreased significantly to 83 ± 20 % ($p = 0.01; d = 0.69$), sustaining our first hypothesis. Although the specific reason is unclear, it is likely due to the uncertainty produced by the feint (as is the purpose). Alternatively, the speed, difficulty and effort involved in fast, complex multi-movement motor tasks might reduce the energy available for the cognitive component, negatively impacting decision clarity, and in turn decision accuracy (7,8). Accordingly, this supports the continued use of this tactic by offensive players. Additionally, since perceptual and anticipatory skills are trainable characteristics (1,6), including tasks using deceptive movements (18), these findings also support the need to incorporate sports-specific feints into agility training to enhance response speed and reduce error rate by defensive players by exposing them to the scenarios they are likely to encounter during match-play.

Previously, higher standard athletes were reported to exhibit greater decision making accuracy (1,7,12,24), however this was not observed in the current study. Decision making accuracy at each decision point, although generally greater in the higher standard players, was not
significantly different between the playing groups, with only small associated effect sizes (Table 6.1). However, it was also revealed that the decrease in accuracy from the first to second decision time points was twice as large in the lower standard group as compared to the higher standard players. This resulted in the accuracy at decision time 2 in lower standard players being significantly lower than at decision time 1 (Table 6.1), whereas there was little change in the decision accuracy of the higher standard players with the inclusion of the feint. This pattern is consistent with previous findings (11) using video occlusion coupled with a written response. Accordingly, deceptive agility movements appear to have only a minor effect on decision accuracy in higher standard footballers, whereas lower standard players appear less able to effectively recognise and respond to the feint, leading to a significant reduction in decision making accuracy. Therefore, this supports our second hypothesis, which contended that any playing group differences would increase with the inclusion of a feint due to an enhanced decision making skill in higher standard players (1,7,12,24).

Additionally, the observation that there was little difference between the groups at the first decision time indicates the players in this study seem equally skilled in recognising cues and predicting actions when the task was a simple single-turn activity. This may possibly be because these stimuli were not sufficiently difficult to challenge more than the universal perceptual and cognitive skills common to many team-sport athletes (11). In contrast, coupling deceptive movements and multiple turns might have increased the perceptual, cognitive and motor challenge to the point that the lower standard players were less able to effectively distinguish and interpret the available cues and maintain decision accuracy, leading to the larger decrease in this group.

The ability to maintain decision accuracy in the higher standard players is likely a result of superior ability to identify and utilise opponent postural and motion information earlier and more accurately in the execution of a skill (11, 24). Additionally, it could be due to visual search
strategies such as gaze fixation frequency and duration and scanning patterns, with the lower standard players not attending to the appropriate cues when the second stimulus was presented (22,24). Other factors such as superior pattern recall, strategic decision making ability or enhanced situational expectations (24) are less likely to have been responsible since the current task was a one-on-one scenario. Therefore, the opportunity to draw on these experiences were limited due to the lack of opponents and other domain and context specific information.

Logically, turning errors during an agility task should increase overall response times, and although this was observed in some examples, it was also contradicted in others. For example, as expected, incorrect decisions made during non-feint trials (non-feint DT1) and at the second decision time (DT2) in the feint trials did result in significant worsening of agility time (Tables 6.2 & 6.3). This increase was caused through both lengthening in movement time, as movement direction was corrected, and decision time. The lengthening of the decision time indicates some delay and confusion in information processing or response selection, whereas the longer movement time implies a delay in response execution (14,15). This is likely due to the deceptive movement or, in the non-feint trials, just the possibility of deceptive movement by an opponent.

Previously, the length on the single-turn reactive agility test was estimated to be 11 m which, by subtracting the initial 3 m- approach run, results in the distance for the portion of the test measured by agility time being 8 m. Therefore, using this distance to estimate mean velocity provides a useful indication of the practical impact of an incorrect decision, since the worsening of agility time in the non-feint trials equates to a distance cost for the defensive player of 0.71 m. Further, assuming the feint response adds a further 2 m (1 m for the step in the wrong direction and another for the first corrected step) to the run length, the same premise shows that the incorrect decisions in a feint trial can result in a defensive player losing over 3 m on their opponent. In practice, the loss of such ground during a pursuit would give offensive players a
significant advantage, potentially allowing them to pass a ball more easily, or score.

Another important observation was that on 15 of 21 occasions when there were errors at DT2 during feint trials, the participants did not complete the trial, they simply gave up once they realised they were deceived. The practical significance of this if repeated on a sporting field is also clear; it would have resulted in an offensive player attacking freely. Further, on those error trials that were corrected, completed movement times were much slower than for correct trials, due to the difficulty in arresting the momentum built up in the wrong direction. Therefore, deceptive movements can have several negative effects on agility performance. Firstly, decision accuracy decreases; secondly, the perception of those mistakes might lead to players giving up a chase; and finally, even where movement direction is corrected, there is a greatly increased time and distance deficit to overcome. Therefore, the use of feints in agility and other game actions by offensive players should be strongly encouraged and defensively, athletes should also regularly practice against these, to reduce error rates and improve response speed.

In contrast to non-feint DT1 and DT2 in the feint trials, incorrect decisions at the first decision point in feint trials (feint DT1, Table 6.3) led to significant improvements in agility time. In those instances, responding in the “wrong” direction to the first stimulus ultimately proved to be correct upon presentation of the second stimulus, negating the need for a second turn and leading to faster movement times. Once again, assuming an 8 m run (since they did not have the additional movements associated with the feint) and combining this with agility time, the faster movements produced in this instance now equate to a distance advantage of 1.2 m to the defensive player, improving their chances of making a successful tackle. Conceivably, this “error” at the first turn might be due to successful anticipation of the feint, but since the participants’ intent is unknown, it is uncertain if they anticipated or guessed incorrectly but “got lucky” and found themselves moving in the correct direction once the
second turn was initiated. Nonetheless, these results provide an insight into the potential benefit of effective anticipation, which if successful, may shift any advantage of evasive movements and feint to the pursuing player.

In conclusion, the introduction of a feint into a reactive agility task reduces decision accuracy, leading to substantial reductions in overall performance for the pursuing player. However, successful anticipation of a feint may improve performance and shift the advantage to the pursuing player. Finally, the use of a feint also results in a significant decrease in decision making quality in lower standard Australian football players but does not affect higher standard players. Accordingly, these results provide support for the potential for all players, but especially lesser standard players, to improve performance by training to improve their ability to anticipate, recognise and respond to simple and complex agility movements such as those inclusive of feints and other deceptive actions.

6.5 Practical applications

Given that incorrect responses to single and multi-turn agility results in significant time and distance being lost by defensive players when chasing an offensive player, training-induced improvements in reactive agility performance and decision making speed and accuracy have the capacity to enhance the ability to avoid or make tackles that influence a game. This potential is supported by the fact that effective anticipation of feint movements can improve a defensive players’ position by more than 1 m on their opponent.

Therefore, since decision making quality is trainable, in addition to physical preparation, coaches should devote some training time to improving game- and situational-awareness and decision making quality and speed. This training should incorporate a variety of feint scenarios to expose players to this tactic and reduce its influence on decision accuracy and agility performance (6, 18). Potentially, this may be achieved through
Decision making accuracy in reactive agility

video-based perceptual training and reactive agility training using game-specific stimuli, which have previously proven successful (6,18,19). Additionally, escalating the cognitive challenge over time by moving from relatively simple one on one activities to more complex multiplayer scenarios or small-sided games should be programmed. This should be useful in helping to maximise decision making speed and accuracy and in minimising any disadvantage caused via offensive feints and incorrect decisions.
References


Decision making accuracy in reactive agility


Relationships Between Reactive Agility Movement Time and Unilateral Vertical, Horizontal and Lateral Jumps

This manuscript has been accepted for publication in the Journal of Strength and Conditioning Research.


The PhD candidate Greg Henry accounted for 90% of the intellectual property associated with the final manuscript. Collectively, the remaining authors contributed 10%.
ABSTRACT

This study compared reactive agility movement time and unilateral (vertical, horizontal and lateral) jump performance and kinetics between dominant and non-dominant legs in Australian rules footballers (n = 31), to investigate the role of leg reactive strength characteristics in reactive agility performance. Jumps involved jumping forward on one leg, then for maximum height or horizontal or lateral distance. Agility and movement time components of reactive agility were assessed using a video-based test. Correlations between each of the jumps were strong (r = -0.62 to -0.77), but between the jumps and agility movement time the relationships were weak (r = -0.25 to -0.33). Dominant leg performance was superior in reactive agility movement time (4.5%; p = 0.04), lateral jump distance (3%; p = 0.008) and lateral reactive strength index (4.4%; p = 0.03) compared to the non-dominant leg. However, when the subjects were divided into faster and slower performers (based on their agility movement times) the movement time was significantly quicker in the faster group (n = 15; 12%; p < 0.001), but no differences in jump performance or kinetics were observed. Therefore, although the capacity for jumps to predict agility performance appears limited, factors involved in producing superior lateral jump performance in the dominant leg may also be associated with advantages in agility performance in that leg. However, since reactive strength, as measured by unilateral jumps appears to play a limited role in reactive agility performance, other factors such as skill, balance and coordination, as well as cognitive and decision making ability, are likely to be more important.

KEY WORDS: reactive strength, leg asymmetry, change of direction

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7.1 INTRODUCTION

Well-developed agility is important for team sport success as it contributes to game-changing actions such as making or evading tackles (27, 30, 31). However, while agility has historically been assessed using pre-planned tasks, the contemporary view of agility is that changes of direction occur in response to external stimuli such as opponent and/or ball movements (6, 26, 27). Consequently, this evolution has led to the development of several new reactive agility tests (6,8,23,26,28,29) which have since confirmed the importance of both decision making and physical components in successful reactive agility performance (6,8,9,28,29). However, numerous other physical sub-factors such as leg reactive strength, power and reactive strength are also thought to be involved in the motor component of successful agility performance (3,17,32). However, although widely examined using pre-planned agility tasks (1,7,19,20,22,25,34), these specific associations have yet to be considered using reactive agility (27, 34).

Since pre-planned and reactive changes of direction are unique skills (6,8,28), with different patterns and magnitude of leg muscle activation (2,12), results from research using pre-planned tasks are not readily transferable to reactive agility tasks. Therefore, little is known about the common strength factors involved in reactive agility and how they contribute to variability in agility performance. Contributing to this is the fact that strength measures used previously have generally lacked ecological validity when compared to agility movements (3, 24); some examples being bilateral and vertical movements such as countermovement jumps, squat jumps and back squats, often with low stretch-loads (14,17,22). In contrast, agility movements typically involve only one leg (3), under high stretch-shortening cycle loads (reactive strength) (28), and producing a combination of vertical, horizontal and lateral ground reaction forces (3, 19). Yet, strength measurements in these planes have rarely been used. Consequently, the nature of the relationship between single-leg strength in non-vertical planes and reactive agility remains largely unknown.
Given their specificity to these agility actions, unilateral drop jumps that involve high stretch-shorten cycle loads could offer a more valid alternative for examining the nature of any association between reactive strength and agility (27, 34). In particular, unilateral horizontal and lateral jumps, which closely mimic agility actions, might have greater predictive value for reactive agility and thus assist coaches in developing effective strength and conditioning alternatives with which to supplement agility training (3). Additionally, the use of unilateral strength movements also affords the opportunity to detect jump and reactive strength asymmetries and investigate any potential functional links with reactive agility performance when pushing off from different legs (10). Previously, vertical jump reactive strength asymmetries have mirrored planned agility asymmetries, when the reactive strength differences were large (>10%) (34). However, it is unclear whether (due to greater similarity in the movements) lateral or horizontal jumps would be more sensitive to differences in reactive agility performance between legs. If so, this may provide coaches with a simple test that will provide an insight into functional deficiencies that mirror agility performance.

Accordingly, this study examined relationships between unilateral vertical, horizontal and lateral jump performance, reactive strength and kinetic variables and reactive agility performance. The movement phase of reactive agility was of particular interest as leg strength is primarily involved during that component, rather than the decision making phase. In addition, since the reactive agility protocol used in this study was specifically designed to ensure the movements were conducted at very high intensities (8) (as expected during most sports) the physical loads experienced closely represented those expected of a sport-specific agility task. Accordingly, it was predicted that a strong association between jump performance, kinetic variables and agility performance would be observed but that the strongest association would be for the lateral jumps. However, it was also expected that (collectively) these three jumps would explain much of the variance in agility performance, as agility actions are thought to involve a combination of these movements (3, 19).
Also, it was anticipated that asymmetries between the legs during the jump tests would mirror functional differences in agility performance when pushing off each leg and that the lateral jumps would demonstrate the greatest sensitivity, again due to the similarity between the movements (e.g., small differences in jump ability would predict differences in agility time). Finally, it was predicted that after dividing the whole group into faster and slower sub-groups (based on reactive agility movement times), any differences in agility performance between the sub-groups would be accompanied by concomitant differences in jump ability on all jumps, but that the greatest difference would be observed in the lateral jumps, due to the common strength factors involved in these movements. Consequently, this study aimed to provide an insight into the relative effectiveness of different single-leg jump tests as predictors of reactive agility, ability and symmetry. This should assist coaches to develop guidelines for agility training; specifically, whether lateral or other non-vertical unilateral reactive strength and power exercises may augment existing agility training programs.

7.2 Methods

7.2.1 Experimental approach to the problem

This study investigated the relationship between performance on three different unilateral jumps and reactive agility. Specifically, the jumps involved three variations of a unilateral leg power test (24) and a video-based reactive agility test developed and validated previously in Australian footballers (8). The jump task required a horizontal jump forward a distance equal to 120% of individual leg length onto one leg and then immediately for maximum vertical height or horizontal or lateral (>45°) distance. Mean agility and movement times, jump performances, reactive strength indices and various kinetic variables were compared with each other and between the dominant and non-dominant legs, and also for faster and slower agility performers. This allowed an assessment of which type of jump best predicts agility movement performance, any functional agility asymmetries, as well as providing information on the role of multi-directional reactive strength in agility performance.
7.2.2 Subjects

An *a priori* power analysis (GPower V3.0.1, Dusseldorf, Germany) revealed a sample size of 26 would result in statistical power of 0.80 at an alpha level of 0.05 and an effect size of $r = 0.5$. Therefore, to allow for drop-out, 31 trained males with a recent (within 2 years) involvement in Australian football were recruited for this study (mean ± SD age, height and mass of $29 ± 5$ y, $181 ± 6$ cm and $83 ± 8$ kg respectively). The Human Ethics Committee of The University of Western Australia approved the study design and subjects were informed of the risks and subsequently gave informed consent.

7.2.3 Procedures

All testing was conducted on a carpeted sprung wooden floor and in the morning (during the summer pre-season period for those subjects still playing) and all wore rubber soled sports shoes and light athletic clothing. All subjects were asked to refrain from strenuous exercise the day prior to the test session, not to consume caffeinated drinks on the day of the testing or eat within 2 hours of the session. However, they were encouraged to drink water upon arriving and during the warm-up to ensure they were well hydrated. During the first test session, height, mass and leg length, measured from the superior aspect of the greater trochanter of the femur to the floor, were measured (16). After a 10-minute standardised warm-up, three maximal 4 m linear sprints were completed, with a 90-second recovery between each, with the fastest time later used to manipulate stimulus duration during the reactive agility test. After another 5-minute recovery the three (vertical, horizontal and lateral) jumps were described, demonstrated and practiced until subjects successfully completed five on each leg for each jump. The video-based reactive agility test (Figure 7.1) was then explained and demonstrated and subjects completed eight sub-maximal practice trials, including three turns each to the left and right and two with no turn.
In the second testing session subjects completed three practice trials of each jump and after a five-minute recovery, the 18 experimental jumps were completed. The experimental jumps included three jump variations in which subjects started with two feet together at a point measured from the front edge of a 40 x 30cm square marked on a force platform (AMTI, Watertown, Massachusetts). The distance of that point from the front edge of the square was equal to 120% of their individual leg length (e.g., leg length = 930 cm, start point = 1116 cm). The subjects then jumped forward onto one foot on the force platform within the marked square and immediately upon landing (minimising ground contact time) then jumped for maximum horizontal or lateral distance or height, to then land again on two feet. Using this
approach, the three variations of jumps were to jump forward (HJ), jump laterally at a 45° angle (LJ) and to jump vertically (VJ). Three trials of each jump off each leg were completed with 90 s recovery in between, and the mean of the best two jumps was used for analysis. The reliability of the horizontal jump test has been previously established (24).

After a 5-minute rest period, three reactive agility familiarization trials were completed, then after another 5-minute rest, ten experimental reactive agility trials were performed, including three turns to the left and right, one dummy turn each to the left and the right and two with no turn, with 90 seconds recovery between each trial. The design of the reactive agility test (Figure 7.1) has been detailed elsewhere (8) but in brief, subjects sprinted forward 3 - 4 m whilst watching a life-sized projection of another player who is running away and who then turns left or right. The subject must react as quickly and accurately as possible to also turn and sprint through exit gates, simulating a chase to tackle scenario. Previously, this protocol was found to have good test-retest (coefficient of variation of 1.4% and intra-class correlation coefficient of 0.81) and intra-rater reliability (coefficient of variation of 5.2% and intra-class correlation coefficient of 0.99) (8, 9).

7.2.4 Data collection and analysis

Jump trials

A 100 Hz Basler video camera (A602fc, Basler Vision Technologies, Ahrensberg, Germany) placed perpendicular to the jump path captured footage to determine distance in the lateral and horizontal jumps. This was achieved using siliconCOACH PRO™ V6 software (Dunedin, New Zealand) to first obtain a scale factor from reference marks placed on the floor where the subjects were jumping. Subsequently, these were used to measure the distance from the toe of the take-off foot to heel of the rearmost foot upon landing (± 0.01 m), whereas vertical jump height was determined from flight time using the equation (15):

\[ \frac{(9.81 \times \text{flight time}^2)}{8} \]
Kinetic data was collected using an AMTI force plate (AMTI, Watertown, Massachusetts), sampling at 2000 Hz connected to a video camera, and a computer running Vicon Nexus (V1.7) software (Vicon, Oxford, United Kingdom). Ground reaction force data was filtered using a fourth order, dual pass Butterworth filter with a cut-off frequency of 30 Hz and the forces (F) described relative to the force plate where Fx was medio-lateral, Fy anterior/posterior and Fz vertical. A customized MatLab (MathWorks, Natick, Massachusetts) software program analysed the force data, which was subsequently normalized to the body mass of each subject.

In addition to jump distance and height, total ground contact time, reactive strength index (RSI) (jump height or distance divided by total ground contact time) (18), mean ground reaction force and peak push-off ground reaction force in each of the three planes were calculated. Using the jump distance or height, the best two trials were identified and mean values for the above kinetic variables used for analysis.

Agility trials

A 100 Hz Basler camera (A602fc, Basler Vision Technologies, Ahrensberg, Germany) positioned 4 m behind the start line recorded the agility trials, and by using siliconCOACH PRO™ V6 software (Dunedin, New Zealand) combined with infra-red timing gates (Fitness Technology, Adelaide, Australia), the following times were recorded (±5 ms):

1. **3 m time** - from start gate to abort gate (at the 3 m mark).

2. **Total time** - from start gate to exit gate.

3. **Agility time** - total time minus 3 m time.

4. **Movement time** - from the subjects’ response initiation until passing through an exit gate.

Finally, subjects were also ranked based on the mean movement time during the agility test and divided into faster (fastest 15) and slower (slowest
15) agility sub-groups. Also, leg dominance was determined based on the preferred kicking leg of each subject.

7.2.5 Statistical analysis

Differences in jump and agility performance between the dominant and non-dominant legs were assessed using dependent t-tests while independent t-tests were used to compare the faster and slower agility sub-groups, with an alpha level of \( p < 0.05 \) applied for both. Cohen’s effect sizes (\( d \)) were also calculated and interpreted based on the criteria of Hopkins (11), where 0.0 = trivial, ≥0.2 = small, ≥0.6 = moderate, ≥1.2 = large, ≥2.0 = very large, ≥4.0 = nearly perfect. Pearson correlations (\( r \)) were used to determine relationships between jump variables and agility movement times and were interpreted based on the criteria of Hopkins (11), whereby 0 - 0.1 = trivial, 0.11 - 0.3 = small, 0.31 - 0.5 = moderate, 0.51 - 0.7 = large, 0.71 - 0.9 = very large, 0.91 - 0.99 = nearly perfect, 1 = perfect. Standard linear regression analysis was used to estimate the contribution of combined jump performances as predictor variables for reactive agility variance. Initially, since lateral jumps were predicted to have the strongest influence this was entered alone at Step 1 and then performance on the other two jumps were added at Step 2 to assess the additional contribution of these variables to explaining agility variance (\( R^2 \)). Standardized beta coefficient’s were used to establish the contribution of each jump to the predictor model with \( p < 0.05 \) considered significant.

7.3 Results

Mean, standard deviation and Pearson correlations for pooled agility and movement times and the lateral, horizontal and vertical jumps are presented in Table 7.1. The correlations between the jumps were large or very large (\( r = 0.62 \) to 0.77) but were weaker when compared to agility movement performance, with the highest correlation of -0.33 (\( p = 0.07 \)) between vertical jump height and movement time. Similarly, Table 7.2 presents the kinetic data and the correlations between agility and movement times. The association between pooled kinetic variables and movement time were
Relationships between reactive agility movement time and unilateral jumps

typically weak, with the highest association being with horizontal jump mean vertical force output (Fz) \((r = 0.32; p = 0.08)\). However, this correlation shows that as the force output increased movement time also increased (worsened). The highest negative correlation (indicating a faster movement time) was between lateral jump peak lateral force output (Fx) \((r = -0.26)\), but this was also weak. The correlations between the vertical mean and peak force on all the jumps and agility time were somewhat stronger and significant, but the coefficient of variation indicates the associations were not particularly strong \((r^2 = <24\%)\).

Table 7.3 presents the standardized \((\beta)\) and un-standardized beta coefficients \((B)\), standard error of the beta coefficient and \(p\) values for lateral jumps and the model as a whole. The total variance in agility movement performance explained by lateral jump was \(R^2 = 6\%, F(1, 29) = 1.92, p = 0.17\). After entering vertical and horizontal jumps into the model at Step 2 the variance explained by the model as a whole increased \((R^2\) change) by 5% to a total of 11%, \(F(3, 27) = 1.15, p = 0.35\). Therefore, collectively the jumps explain a relatively minor amount of the total variance of agility movement time.

Table 7.4 illustrates the differences in agility and jump performance (distance and reactive strength index) when pushing off the dominant and non-dominant legs. Both agility (difference = 5.4%; \(p < 0.001; d = 0.84\)) and movement times (5.6%; \(p = 0.004; d = 0.86\)) were significantly faster when turning off the dominant leg. Similarly, subjects jumped significantly further (3%; \(p = 0.008; d = 0.35\)), with a higher reactive strength index (4.4%; \(p = 0.03; d = 0.28\)) using the dominant leg during lateral jumps. In contrast, subjects jumped slightly further or higher using the non-dominant leg during the horizontal (1.8%; \(p = 0.09; d = 0.2\)) and vertical jumps (6.9%; \(p = 0.12; d = 0.26\)), although no significant differences in any kinetic variables between the legs on any jump were found and correlations between kinetic variables and reactive agility performance were moderate \((r < -0.44)\). Table 7.5 illustrates agility and movement times, jump performance and reactive strength indices in faster \((n = 15)\) and slower \((n = 15)\) agility sub-groups.
Table 7.1: Mean ± SD and correlations between agility and movement times and lateral, horizontal and vertical jumps.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Correlation coefficient</th>
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<tr>
<td></td>
<td>(n=31)</td>
<td>Agility time</td>
</tr>
<tr>
<td>Agility time (s)</td>
<td>1.48±0.07</td>
<td>1</td>
</tr>
<tr>
<td>Movement time (s)</td>
<td>1.03±0.05</td>
<td>0.37†</td>
</tr>
<tr>
<td>Lateral jump (cm)</td>
<td>205±15</td>
<td>-0.12</td>
</tr>
<tr>
<td>Horizontal jump (cm)</td>
<td>225±18</td>
<td>-0.15</td>
</tr>
<tr>
<td>Vertical jump (cm)</td>
<td>30±4</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

† = p < 0.05; †† = p < 0.001 - Correlation significant
Table 7.2: Mean ± SD lateral, horizontal and vertical jump kinetic variables and correlations between agility (AT) and movement times (MT) (n=31).

<table>
<thead>
<tr>
<th></th>
<th>Lateral Jump</th>
<th></th>
<th>Horizontal Jump</th>
<th></th>
<th>Vertical Jump</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AT Correlation</td>
<td>MT Correlation</td>
<td>AT Correlation</td>
<td>MT Correlation</td>
<td>AT Correlation</td>
</tr>
<tr>
<td>Mean Fz (bw)</td>
<td>-18.1±1.4</td>
<td>0.43†</td>
<td>0.22</td>
<td>-17.9±1.2</td>
<td>0.40†</td>
<td>0.32</td>
</tr>
<tr>
<td>Peak Fz (bw)</td>
<td>-24.7±2.4</td>
<td>0.45†</td>
<td>0.21</td>
<td>-25.0±2.5</td>
<td>0.48†</td>
<td>0.27</td>
</tr>
<tr>
<td>Mean Fy (bw)</td>
<td>-0.1±0.4</td>
<td>-0.16</td>
<td>-0.07</td>
<td>2.8±0.6</td>
<td>-0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>Peak (push off) Fy (bw)</td>
<td>2.3±0.4</td>
<td>-0.01</td>
<td>-0.11</td>
<td>5.4±0.8</td>
<td>-0.10</td>
<td>0.21</td>
</tr>
<tr>
<td>Minimum (braking) Fy (bw)</td>
<td>-3.3±1.0</td>
<td>0.02</td>
<td>-0.17</td>
<td>-0.9±0.6</td>
<td>-0.06</td>
<td>-0.07</td>
</tr>
<tr>
<td>Mean Fx (bw)</td>
<td>5.4±0.7</td>
<td>-0.24</td>
<td>-0.14</td>
<td>-0.1±0.2</td>
<td>-0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>Peak Fx (bw)</td>
<td>7.7±1.2</td>
<td>-0.21</td>
<td>-0.26</td>
<td>N/A</td>
<td>-0.23</td>
<td>-0.11</td>
</tr>
</tbody>
</table>

bw = normalized to body weight  N/A = not available
† = p < 0.05 - Correlation significant
Table 7.3: Multiple regression unstandardized beta coefficients ($B$), standard error of $B$, standardized coefficients ($\beta$) and p values for lateral jump performance (Step 1) and lateral jump combined with horizontal and vertical jumps (Step 2) (n=31).

<table>
<thead>
<tr>
<th></th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(constant)</td>
<td>1208.84</td>
<td>126.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral jump</td>
<td>-0.86</td>
<td>0.62</td>
<td>-0.25</td>
<td>0.17</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(constant)</td>
<td>1204.63</td>
<td>138.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral jump</td>
<td>-0.11</td>
<td>0.98</td>
<td>-0.03</td>
<td>0.91</td>
</tr>
<tr>
<td>Horizontal</td>
<td>-0.28</td>
<td>0.99</td>
<td>-0.09</td>
<td>0.78</td>
</tr>
<tr>
<td>Vertical</td>
<td>-2.91</td>
<td>3.31</td>
<td>-0.24</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Note: $R^2 = .06$ for Step 1, $\Delta R^2 = .05$ for Step 2 (p > 0.05)
Table 7.4: Mean ± SD and differences in agility and movement times and lateral, horizontal and vertical jumps when pushing off using the dominant and non-dominant legs.

<table>
<thead>
<tr>
<th></th>
<th>Dominant leg push-off (n=31)</th>
<th>Non-dominant leg push-off (n=31)</th>
<th>p value</th>
<th>Percent difference</th>
<th>Effect size (qualitative descriptor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility time (s)</td>
<td>1.48±0.07</td>
<td>1.56±0.12</td>
<td>&lt;0.001††</td>
<td>5.4</td>
<td>0.84 (moderate)</td>
</tr>
<tr>
<td>Movement time (s)</td>
<td>1.06±0.06</td>
<td>1.12±0.08</td>
<td>0.004†</td>
<td>5.6</td>
<td>0.86 (moderate)</td>
</tr>
<tr>
<td>LJ distance (cm)</td>
<td>208±16</td>
<td>202±15</td>
<td>0.008†</td>
<td>3.0</td>
<td>0.35 (small)</td>
</tr>
<tr>
<td>LJ RSI (cm•s⁻¹)</td>
<td>595±96</td>
<td>570±83</td>
<td>0.03†</td>
<td>4.4</td>
<td>0.28 (small)</td>
</tr>
<tr>
<td>HJ distance (cm)</td>
<td>223±18</td>
<td>227±19</td>
<td>0.09</td>
<td>1.8</td>
<td>0.2 (small)</td>
</tr>
<tr>
<td>HJ RSI (cm•s⁻¹)</td>
<td>663±101</td>
<td>679±88</td>
<td>0.25</td>
<td>2.4</td>
<td>0.16 (trivial)</td>
</tr>
<tr>
<td>VJ height (cm)</td>
<td>29±4</td>
<td>31±5</td>
<td>0.12</td>
<td>6.9</td>
<td>0.26 (small)</td>
</tr>
<tr>
<td>VJ RSI (cm•s⁻¹)</td>
<td>84±16</td>
<td>89±19</td>
<td>0.14</td>
<td>5.9</td>
<td>0.28 (small)</td>
</tr>
</tbody>
</table>

† (p < 0.05); †† (p < 0.001): Dominant leg better than non-dominant; LJ = lateral jump; HJ = horizontal jump; VJ = vertical jump; RSI = reactive strength index.
Table 7.5: Mean ± SD and differences between faster and slower agility groups\textsuperscript{a} on agility and movement times, lateral and horizontal jump distance, vertical jump height and reactive strength index (RSI).

<table>
<thead>
<tr>
<th></th>
<th>Faster Group (n=15)</th>
<th>Slower Group (n=15)</th>
<th>p value</th>
<th>Percent difference</th>
<th>Effect size (qualitative descriptor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility time (s)</td>
<td>1.47±0.07</td>
<td>1.48±0.07</td>
<td>0.60</td>
<td>0.6</td>
<td>0.14 (trivial)</td>
</tr>
<tr>
<td>Movement time (s)</td>
<td>0.99±0.02</td>
<td>1.06±0.05</td>
<td>&lt;0.001††</td>
<td>7.1</td>
<td>2.0 (very large)</td>
</tr>
<tr>
<td>Lateral jump distance (cm)</td>
<td>207±14</td>
<td>204±17</td>
<td>0.59</td>
<td>1.5</td>
<td>0.19 (trivial)</td>
</tr>
<tr>
<td>Lateral jump RSI (cm•s\textsuperscript{-1})</td>
<td>586±44</td>
<td>579±54</td>
<td>0.71</td>
<td>1.2</td>
<td>0.14 (trivial)</td>
</tr>
<tr>
<td>Horizontal jump distance (cm)</td>
<td>230±16</td>
<td>220±19</td>
<td>0.19</td>
<td>4.5</td>
<td>0.57 (small)</td>
</tr>
<tr>
<td>Horizontal jump RSI (cm•s\textsuperscript{-1})</td>
<td>682±62</td>
<td>660±68</td>
<td>0.35</td>
<td>3.3</td>
<td>0.34 (small)</td>
</tr>
<tr>
<td>Vertical jump height (cm)</td>
<td>31±5</td>
<td>29±4</td>
<td>0.27</td>
<td>6.8</td>
<td>0.44 (small)</td>
</tr>
<tr>
<td>Vertical jump RSI (cm•s\textsuperscript{-1})</td>
<td>89±17</td>
<td>83±15</td>
<td>0.34</td>
<td>7.2</td>
<td>0.37 (small)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Faster group was the 15 participants with the fastest mean movement times during the agility test. The slower group were the 15 with the slowest movement times

†† (p < 0.001): Faster group better than slower group
Compared to the slower sub-group, the faster sub-group had significantly faster movement times (7.1%; $p < 0.001$; $d = 2.0$) but there were no other differences and only small to trivial effect sizes observed in jump performance and kinetic variables.

7.4 DISCUSSION

The association between reactive strength and reactive agility has yet to be clearly established (3), so we examined this by comparing unilateral vertical, horizontal and lateral jump performance with performance on a video-based reactive agility test (8). The jumps chosen were considered a good measure of reactive strength under fast stretch–shorten cycle loading (24), which is the type of strength considered important in agility tasks (27, 28, 32). Additionally, modifying traditional single-leg drop-jumps to include jumps in multiple directions also more closely mimics the agility tasks, which also predominantly involve single-leg lateral and horizontal actions (3).

Correlations between performances on the various jumps were moderate to very large, with the strongest relationship between lateral and horizontal jumps, which indicates some commonality between the skill and reactive strength requirements for the different jumps. However, the relationship between performance and kinetic variables on each of the jumps and reactive agility movement time were weak, with vertical jumps showing the strongest association. Therefore, these results do not support our hypothesis that lateral jumps would exhibit the strongest relationship due to the similarity of the movements and strength requirements. In addition, regression analysis also showed that (collectively) all the jumps explained only 11% of the variance in agility movement time, also contradicting the previous prediction. Therefore, leg strength as measured by unilateral drop jump has limited predictive value in relation to the motor component of reactive agility performance, similar to that observed in previous research using pre-planned agility (19).

Accordingly, reactive strength does not seem to be an important contributor to agility movement performance, and other skill-based factors may play a larger role (3, 19, 22, 33). Nonetheless, it is also believed that
athletes will generally turn faster off their dominant or stronger leg (5, 19, 34) and that any asymmetries in jump performance between the dominant and non-dominant legs will be reflected in agility movement times using the different legs. Our results did provide some support for this hypothesis since those subjects who had faster movement times when pushing off their dominant leg also jumped significantly further laterally, with a higher reactive strength index using that leg. Yet, in contrast, the horizontal and vertical jumps were slightly better using the non-dominant leg. Therefore, superior reactive agility is associated with a concomitant advantage in jumping ability and potentially the reactive strength in the dominant leg, but only when applied laterally, likely due to the similarity between the skills and actions in each of these tasks.

That superior vertical jump ability in the non-dominant leg did not result in enhanced performance is at odds with previous research reporting that vertical drop jump asymmetries also mirror (planned) agility asymmetries (34). However, it is believed that the discrepancy in vertical jump height may need to be large (>10%) (5, 34) before any differences in agility are noted, as vertically applied force may play a lesser role than lateral force production. Our results support this notion, since a 7% advantage in vertical jump height using the non-dominant leg (less than the 10% threshold) was not accompanied by a better movement time using that leg; indeed, subjects were slower when turning off that leg. In contrast, a 3% advantage in lateral jump distance was associated with a 5.5% difference in reactive agility movement time, in accordance with our hypothesis that the lateral jumps are more sensitive to differences in agility movement ability. However, since asymmetries of approximately 8% are considered common in jump assessments in normal athletic populations (4, 21), the similarity between lateral jump and agility asymmetries seen here might simply be coincidental rather than functionally linked, a view supported by the weak correlations. Nevertheless, coaches seeking diagnostic tools with which to identify functional weaknesses in athlete agility profiles should still consider single-leg lateral jump tests in preference to vertical jumps, although the overall role of reactive strength in complex agility tasks may still be limited (3, 13).
After dividing the subjects into faster and slower agility sub-groups, no significant differences in jump performance were found and so our hypothesis that such an association would occur is rejected. Therefore, the factors involved in producing asymmetrical jump performance between the legs do not appear to be important in producing more agile athletes overall. Additionally, the lack of differences in reactive strength and kinetic variables recorded between the faster and slower movement time groups also support the notion that factors other than reactive strength may be involved in specific reactive agility performance. Therefore, although jump assessments appear to have limited capacity to predict reactive agility performance (19), there is evidence that there are potentially some common (non-strength) factors involved in producing asymmetries in single-leg lateral jumps and reactive agility. Accordingly, lateral jumps could provide an insight into functional imbalances that, even when small, might mirror meaningful differences in agility performance.

Nonetheless, it is unlikely that one characteristic alone is responsible for either agility or unilateral jump success. Indeed, overall reactive agility performance will be largely influenced by cognitive and decision making factors rather than the motor component (6, 8, 9, 28) and when specifically considering the motor component of agility, factors such as skill, balance, stability and coordination, are likely to play a more significant role in performance than reactive strength (17, 30, 34). Therefore, a context-specific task-based approach to agility training would seem to offer the most potential for maximizing agility performance (13).

7.5 Practical applications

Including single-leg lateral jumps in a test battery will help coaches identify potential asymmetries in reactive strength, which may reflect both the motor component of reactive agility and overall performance. This will provide a greater understanding of the agility profile of athletes and allow for the development of more specific training regimes. However, since measuring jump kinetics offers little extra information, only distance and reactive strength index need to be measured. Coaches should also recognise that
reactive strength appears to play a limited role in reactive agility performance and that numerous other non-strength factors (e.g., skill, balance) are likely to be more important. Therefore, sports-specific reactive agility tasks and scenarios should be the cornerstone of agility-training regimes.
References


General Discussion
8.1 Thesis Summary

We now understand that on-field agility often involves a response to a context-specific external stimulus, such as opponent or ball movements (Jeffreys, 2011; Sheppard & Young, 2006; Young & Farrow, 2013). Accordingly, a number of new reactive agility tests have been introduced to investigate the specific characteristics involved in reactive agility, but unanswered questions remained (Serpell, Ford & Young, 2010; Veale, Pearce, & Carlson, 2010). Partly, this is because reactive agility research is still relatively new and numerous stimuli have been trialled, with no clear consensus yet as to which may be the most effective. Nevertheless, while sport-specific stimuli such as real people or video of real people are considered more ecologically valid than generic stimuli (flashing lights or arrows) few studies have directly compared them.

With this in mind, the initial aim of this research was to develop a video-based reactive agility test (VRAT) that could be tailored to the individual sprint abilities of different athletes and provide a stable platform from which to examine reactive agility (Chapter 3). The ability to manipulate the location of the stimulus to match the individual sprint speeds of the athletes is an innovative new addition to reactive agility research and addresses a weakness of earlier protocols, which used fixed-length stimulus video clips. The development of this test was also based on a number of other guiding principles established following an in-depth needs analysis of Australian football. This analysis took into account many factors, such as the movement qualities (biomechanical and strength needs) and quantities (metabolic requirements) of Australian football, as well as the principles that support the modern definition of reactive agility. Moreover, in addition to the tailored video element outlined above, this new protocol introduced several other new concepts to the field of reactive agility. These included the notion of an abort time to ensure a consistent and high intensity approach sprint, the use of dummy clips and no turn trials and a chase scenario rather than the frontal evasion scenarios favoured in earlier research. However, before this
new reactive agility protocol could be used, its validity and reliability had to be established.

Therefore, Chapter 4 examined the validity of this protocol by comparing performance on the video-based test, a similar light-based reactive agility test and a planned agility test between three groups: higher calibre and lower calibre Australian football players and non-players. A secondary aspect of this study was to examine the capacity of the VRAT to differentiate the two primary sub-components of agility, namely the cognitive and motor elements, and investigate the relative influence of each of these in the performance between the different groups of athletes. Chapter 4 identified that, with the playing groups pooled, there were significant differences in the agility time component between the planned test and both the reactive test modes (light-based and video-based). When combined with low correlations and common variances of less than 50%, these results confirmed previous findings that reactive agility and planned agility are unique tasks (Farrow, Young, & Bruce, 2005; Serpell, et al., 2010; Sheppard, Young, Doyle, Sheppard, & Newton, 2006).

In addition, although the relationship between pooled agility time in both the light and video-based reactive agility tests was strong (agility time $r = 0.75; r^2 = 56\%$), pooled decision time was significantly faster in response to the simple light-based stimulus ($p < 0.001; d = 0.8$) than the video-based stimulus. Therefore, the perceptual and cognitive elements required from complex sports-specific stimuli, such as another person changing direction, are to some extent, unique and are not effectively duplicated using a generic light-based stimulus. Accordingly, these findings support the notion that sport-specific stimuli have superior ecological validity compared to more generic stimuli such as lights or arrow-based indicators (Young, Farrow, Pyne, McGregor, & Handke, 2011).

Furthermore, when considering the participant groups separately, it was observed that both playing groups (higher standard and lower standard) had faster agility times than the non-playing group on all three tests. However, the largest difference on all the tests was between the non-playing
group and the higher standard group. Moreover, while agility time also differed between higher and lower standard groups on the planned \((d = 0.24)\) and light-based test \((d = 0.42)\), the largest difference was on the video-based test \((d = 0.82)\). Accordingly, these results indicate a trend toward an increasing divergence between the playing groups as the cognitive and physical demand increased from the planned to the light to the video test. Seemingly, this supports the theory that higher standard athletes are able to anticipate the movements of their opponents more effectively and, as a result, are more agile. However, in contrast to this theory and that of previous research (Farrow, et al., 2005; Gabbett, Kelly, & Sheppard, 2008; Young & Willey, 2010), the major source of the differences between the groups in this study was in movement time rather than decision time, possibly because this was the first study to explicitly isolate the (post-response) movement time. Alternatively, in the younger athletes (mean age 18 y) used in this study, perceptual and cognitive expertise may not have matured sufficiently for any decision making advantage to materialise in the higher calibre players (Baker, Cote, & Abernethy, 2003). Hence, in this instance the higher standard players appear to have relied on superior motor skill to change direction more effectively. Consequently, this highlights the potential for motor skill mastery to be an important factor differentiating agility skill in Australian footballers.

Chapter 4 also identified that the association between linear speed (measured by the initial 4 m linear sprint test) and all agility tests were stronger for total time \((r = 0.71 \text{ to } 0.81)\) (3 m approach sprint included) than for agility time \((r = 0.32 \text{ to } 0.43)\) (3 m approach sprint removed). Likewise, although not presented in the relevant chapters, when similar correlations were calculated for the data from Chapters 5 and 7 the relationship between 4 m sprint time and total time was consistently higher than with agility time (Table 8.1). Furthermore, the correlation between 4 m linear sprints and the movement time component of reactive agility is typically weaker than with both total time and agility time.
Collectively, these large to very large correlations between 4 m sprint time and total time in these three studies implies that total time measurement in the VRAT is assessing similar qualities to linear speed or, more precisely, acceleration. This differs from most previous agility research, which indicates the link between linear speed and planned and reactive agility is typically modest (Brughelli, Cronin, Levin, & Chaouachi, 2008; Gabbett, et al., 2008; Little & Williams, 2005; Sheppard & Young, 2006; Sheppard, et al., 2006; Wheeler, 2009). In contrast, the smaller correlations observed for agility and movement times across these three studies suggest they are measuring somewhat independent qualities. These differences are likely due to the fact that a larger proportion of linear sprinting (e.g., the initial 3 m approach) is incorporated in the total time measurement. In contrast, in the agility time measure, agility-specific motor tasks such as deceleration and lateral movements, as well as the cognitive and decision making components, form a larger proportion of the manoeuvre. Consequently, when viewed together the findings from these three studies support the notion introduced in Chapter 2.3.1; that linear speed "contaminates" total test time when it includes longer straight sprint segments. As such, the total time measurement is not recommended for use when examining reactive agility performance.

So, coaches or researchers interested in overall reactive agility ability should use agility time, which isolates the specific agility components more
effectively from straight-line acceleration, making it a more valid agility measure. However, researchers more interested in the specific sub-components of agility may wish to focus more on the decision time or movement time measures, both in isolation, or in conjunction with agility time. Therefore, the specific choice of measurement when conducting a reactive agility test should be driven by the particular goal of the assessment. An example of this can be seen in Chapter 7 where movement time was the primary focus of the assessment, while agility time was a secondary consideration and decision time largely ignored. This is because the specific focus of the research was the role of strength in the movement component of reactive agility.

Chapter 4A examined the reliability of the new video-based reactive agility protocol and the various measurements outlined above. Initial results verified that the test-retest (coefficient of variation of 1.4% and intra-class correlation coefficient of 0.81) and intra-rater reliability (coefficient of variation of 5.2% and intra-class correlation coefficient of 0.99) of the agility time measure from VRAT were sound. However, while the test-retest reliability of the decision time measure was not as robust as agility time, it was comparable to similar measures from other reactive agility studies (Gabbett, et al., 2008; Serpell, Ford & Young, (2010). In addition, while the intra-class correlations and coefficients of variation for movement time were also found to be acceptable, mean movement time improved during the second test session. This indicates that learning may occur from one test to another if they are conducted within one week. As such, repeat test sessions should be scheduled at intervals of at least 8 weeks, as suggested by Farrow et al., (2005). Therefore, while decision time and movement time measures may be more useful for some researchers pursuing specific information about the sub-components of agility, researchers should take these reliability factors into account. Nevertheless, the combined results from Chapters 4, 4A, 5 and 7 indicate the agility time measure is both a reliable and valid measure of reactive agility and should be used in the first instance.

Chapters 5 and 6 included deceptive movements (feints) in the stimulus video and, for the first time, specifically examined the impact these had on
reactive agility and its subcomponents. Chapter 5 revealed that there were trivial to small correlations between agility and movement times between the feint and non-feint trials. Therefore, reactive agility in response to a feint appears to be a unique skill compared to a similar single-turn reactive agility task. In addition, both chapters revealed similar performance group trends to those seen in Chapter 4 (e.g., increasing divergence between playing groups as the task became more complex). For example, in Chapter 5 the effect sizes and qualitative interpretations of the confidence intervals compared to the smallest worthwhile change, revealed a trend for better agility and movement times in the higher standard players during feint trials compared to non-feint. Primarily, this was brought about by a significant slowing in movement time in the lower standard players between the non-feint and the feint trials, but little change in the higher standard group. Likewise, in Chapter 6 decision accuracy during feint trials was similar between the playing groups at the first decision point, but the inclusion of the feint resulted in a larger deterioration in accuracy for the lower standard players, whereas there was only a modest change in the higher standard group.

Therefore, when the results from Chapters 4, 5 and 6 are viewed collectively, a common trend emerges of superior performance in higher calibre athletes. Accordingly, reactive agility is a factor that can discriminate Australian footballers of different playing standards and consequently is a characteristic that should receive specific training when developing these athletes. Furthermore, these studies also show that the video-based reactive agility test introduced here is a valid and effective method for detecting these differences. However, it is also apparent that generic stimuli or simple single-turn tasks may not effectively discriminate certain groups of players, as these scenarios may only challenge the universal decision making and agility qualities common to many team sport athletes. Accordingly, differences may only be exposed in some groups of athletes when undertaking more complex tasks, such as those including feints and multiple turns.

Notwithstanding these comments, together these studies also reveal some contradictory results about which sub-component of reactive agility was chiefly responsible for the noted playing group differences. For instance, in
Chapter 4 the primary difference in agility performance between higher standard players and the lower standard and non-players was due to physical factors (movement time) rather than cognitive factors (decision time). However, results from the non-feint trials in Chapter 5 revealed the opposite, whereby during the simple single-turn activity decision time was faster in the higher calibre groups which is consistent with other reactive agility research (Farrow, et al., 2005; Gabbett, et al., 2008). However, during the more complex feint trials in Chapter 5, the primary time difference was again movement time rather than decision time. Chapter 6 also revealed a significant decrease in decision accuracy for the lower standard group during the feint trials. Therefore, it appears the cognitive component was, to a certain degree, challenged more in the lower standard players with the introduction of the feint, but apparently this did not impact decision making speed or overall performance.

Consequently, the results from Chapter 4 and, to some extent, Chapter 5 are somewhat inconsistent with the notion that higher standard players would have significantly faster decision times and would be less susceptible to feints (Farrow, et al., 2005; Gabbett, et al., 2008; Sheppard, et al., 2006) due to their reportedly superior ability to detect, in advance, key postural cues from their opponents (Williams & Ford, 2008; Williams & Ward, 2003). As alluded to earlier, perhaps the single (turn) stimuli only challenged the universal cognitive skill and knowledge base common to many team-sport athletes, thus allowing the higher standard athletes to access their knowledge base faster, as evidenced by the faster decision time in the non-feint trials in Chapter 5. Overall, in the feint trials, while the higher standard players were still able to use their superior ability to identify and utilise postural and motion information to identify the feints more accurately (Chapter 6), the challenge was such that they were not able to access their knowledge base any faster (Chapter 5) than the lower standard players were able to access their own (more limited) information base. Nevertheless, it appears the higher standard players were able to use enhanced motor skill, reactive strength, athleticism or other physical factors to successfully negotiate the multiple turns with greater speed, hence their faster movement times (Chapter 5). In contrast,
the lower standard players did not have the motor skill, reactive strength or coordination necessary to maintain movement performance when the physical load and complexity increased, as a result of multiple changes of direction.

These observed inconsistencies do support the notion that agility is a multi-factorial characteristic (Hewit, Cronin, & Hume, 2012; Jeffreys, 2011; Young & Farrow, 2006) and it is unlikely that one component alone will be largely responsible for overall performance. Furthermore, the collective results of the studies in this thesis indicate that the specific source of any advantage will vary between different standards of athletes in different scenarios and, by extension, will therefore also vary within a group of athletes from one team. For that reason, it is important that coaches use tests such as the video-based reactive agility test to assess not only the overall agility performance of their athletes, but also the source of the differences within the various sub-components. This will allow coaches to categorise players as suggested by Gabbett and colleagues (2008) (e.g., fast thinker/slow mover, slow thinker/fast mover, fast thinker/fast mover, slow thinker/slow mover). Such a distinction will assist coaches to design agility training programs that specifically address the individual weaknesses of each type of player.

Other notable outcomes of Chapter 6 were firstly, that with the skill groups pooled, incorrect decisions made during non-feint trials and at the second decision time in the feint trials, resulted in a significant worsening of agility time, due to a lengthening in both decision time and movement time. Accordingly, the longer decision time indicates some delay and confusion in information processing or response selection (resulting in the incorrect decision), whereas the longer movement time implies a delay in response execution, as movement direction was corrected. Secondly, the performance cost and practical significance of those incorrect decisions was, for the first time, quantified. Subsequently, it was revealed that in the non-feint trials the time deficit equated to a distance deficit for the defensive player of approximately 0.7 m, while during the feint trials the deficit was approximately 3 m. However, this does not provide the complete picture of the practical significance of successful feints. On most occasions (15 of 21),
when there were errors during the second movement of the feint trials, participants did not complete the trial, but gave up once they realised they were deceived; thereby providing complete freedom for the attacking player if repeated on the field.

However, in contrast, incorrect decisions at the first decision point in feint trials (e.g., potentially due to a successful anticipation of a feint by the defensive player) led to a significantly faster agility time for the defensive player. This was because the player was already moving in the correct direction when the second (correct) movement occurred, equating to a distance advantage for the defensive player of approximately 1.2 m. Therefore, this provides clear evidence for the potential advantage of anticipating movements of an opponent and, given that the use of feints are common in sport, the value in designing specific training programs to improve this capacity from both an offensive and defensive perspective.

Finally, Chapter 7 expanded reactive agility research to investigate the role of reactive strength in reactive agility performance, in particular the motor component. This is the first time such an examination has taken place in a reactive agility setting and follows on from numerous studies using planned agility tasks (Barnes, et al., 2007; Gavin, 2008; Markovic, 2007; Meylan, et al., 2009; Negrete & Brophy, 2000; Nimphius, McGuigan, & Newton, 2010; Young, James, & Montgomery, 2002). The primary findings of this study were firstly, that the relationship between performance and kinetic variables on each of the jumps and reactive agility movement time were weak, with regression analysis revealing the total reactive agility movement time variance explained collectively by the jumps was just 11%. Secondly, both agility (difference = 5.4%; \( p < 0.001; d = 0.84 \)) and movement times (5.6%; \( p = 0.004; d = 0.86 \)) were significantly faster when turning off the dominant leg and participants also jumped significantly further (3%; \( p = 0.008; d = 0.35 \)), with a higher reactive strength index (4.4%; \( p = 0.03; d = 0.28 \)), using the dominant leg, but during lateral jumps only. Thirdly, the 15 most agile participants had significantly faster agility movement times (7.1%; \( p < 0.001; d = 2.0 \)), but there were no differences observed in jump performance and kinetic variables for this sub-group.
Therefore, including single-leg jumps in a test battery could help coaches to identify leg reactive strength asymmetries, which might have a meaningful impact on the motor component of reactive agility, when pushing off the stronger leg. Nevertheless, coaches should also be aware that asymmetries in leg strength are relatively common and as such, the asymmetries in both lateral jumping and agility might be coincidental rather than functionally linked. Therefore, the observation that the group with the fastest movement time exhibited no advantage in jump performance, RSI or kinetics indicates that reactive strength, as measured by a unilateral drop jump has limited predictive value in relation to the motor component of reactive agility. Hence, while the other studies in this thesis confirm the importance of the movement sub-component in overall reactive agility performance, this final result indicates that reactive strength may make only a limited contribution, and that other factors such as skill, dynamic balance, core stability and inter- and intra-muscular coordination may play a larger role.

When combined, the results of these studies sustain the theory that agility is a multi-factorial characteristic that will not be determined by one factor in isolation. Earlier, two models (Fig 2.1 and 2.2, p. 23 and 24 respectively) were presented that outlined some of the factors thought to influence reactive agility. However, these models did not fully capture the complex interactions between these sub-factors and, given that research into reactive agility is still relatively new, much of the basis for these models in a reactive agility context is theoretical rather than based on empirical data. Therefore, Figure 8.1 presents a modified deterministic model of agility, illustrating the findings of the current research within the context of the earlier models (Figure 2.1). This model is not presented as being all-inclusive and other components from the constraints-led (Jeffreys, 2011) and ecological dynamics (Davids, Duarte, Vanda & Luis, 2013) theories will also influence reactive agility, although they were not specifically considered within this research project.
Figure 8.1: A modified deterministic model of reactive agility based on the findings of current research.
Firstly, the linear speed element is no longer included as a physical factor that influences reactive agility since, when reactive agility was narrowed down to the specific decision making and change of direction components, speed was largely unrelated to performance, which is consistent with earlier research (Little & Williams, 2005; Sheppard & Young, 2006). Secondly, although technique factors were not specifically examined, evidence from other research suggests the choice of agility technique will directly impact the time taken to change direction (Bradshaw, Young, Russell & Burge, 2010). In addition, technique could also indirectly influence the on-field success of the reactive agility manoeuvre based on the impact it has on an opponent’s response. For example, Bradshaw and colleagues (2010) observed that while the split-step was the slowest change of direction technique it produced the slowest response time by a defender, or put another way, produced the greatest advantage for the offensive player.

Thirdly, reactive strength appeared to have a limited association with reactive agility performance. Therefore, it is now questionable whether reactive strength should remain in this deterministic model. Nevertheless, given that this was the first study to examine this characteristic in a reactive agility context, it is premature to eliminate its contribution, especially given the large stretch-shortening cycle loads involved in agility. Consequently, more research is necessary before definitive conclusions can be made about the specific influence reactive strength (and other strength and power characteristics) has on reactive agility. This is particularly pertinent, given that asymmetries in reactive strength between the legs may influence the ability to turn off each leg, particularly the stronger leg, hence the addition of leg muscle symmetry into the model. Also, reactive agility is a dynamic full body activity, therefore it is somewhat simplistic to assume that leg muscle characteristics alone will be the sole muscular determinants of reactive agility performance. Accordingly, it was postulated that other global muscle characteristics such as dynamic balance, core strength and stability and inter- and intra-muscular coordination throughout the entire kinetic chain could play an important role in reactive agility performance. Therefore, global muscle characteristics are included as another theoretical factor potentially
responsible for agility performance, along with anthropometry and muscle fibre type (Jeffreys, 2011), that future research could consider.

From a perceptual and cognitive perspective, visual search behaviours (scanning) and pattern recognition remain important characteristics. The inclusion of the term "situation familiarity" reflects the finding that familiar, sport-specific stimuli are better able to detect differences in reactive agility than generic, or less familiar stimuli. Furthermore, successful anticipation, particularly of a deceptive movement, was identified as a potential source of advantage for defensive players that may overcome the typical advantage produced by a successful (attacking) feint. In addition, deceptive movements proved to be a factor that influenced reactive agility performance through decreases in both decision making accuracy and movement speed. Moreover, the impact of deceptive movements had a disproportionate impact on lesser standard players that was, in part, due to larger deteriorations in movement time. This was likely due to the increased physical demands of performing multiple high-intensity changes of direction. Therefore, deceptive movements also influence the task constraints by leading to multiple turns, which in turn will influence reactive agility performance. Accordingly, the model in Figure 8.1 begins to expose some of the many inter-relationships between these various components, although other interactions remain unexplored.

To extend this discussion beyond only the findings and collective trends of the data from the various studies within this thesis, Table 8.2 presents a summary of the main reactive agility performance times from each study. Only those that are directly comparable have been included; therefore, no feint trials were included, as all the other studies used only single-turn tasks. This table provides a direct comparison of the various agility component times across all the groups of trained and untrained participants (of different ages) used in these studies. This comparison allows an assessment of the stability of the results and may potentially give an insight into the range of normative data coaches can expect to see when conducting such testing.

While the trends in results outlined earlier are still apparent it is interesting to note that the total and movement times for the higher and
lower standard senior footballers in Chapter 5 were some of the slowest recorded. This seems counter-intuitive, given the higher performance group were the most experienced and well-trained participants in this research series. However, in this particular study, the trials were interspersed within other feint trials, and so each trial effectively had the potential for 5 outcomes, rather than 3 as was the case for the other studies.

**Table 8.2:** Mean (±SD) (non-feint) agility, decision, movement and total times (ms) from Chapters 4,5 and 7.

<table>
<thead>
<tr>
<th>Study</th>
<th>Group</th>
<th>Agility time</th>
<th>Decision time</th>
<th>Movement time</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chapter 4</strong></td>
<td>Higher performance adolescent Australian footballers</td>
<td>1493±76</td>
<td>309±38</td>
<td>1065±70</td>
<td>2224±136</td>
</tr>
<tr>
<td></td>
<td>Lower performance adolescent Australian footballers</td>
<td>1556±77</td>
<td>303±44</td>
<td>1095±80</td>
<td>2281±85</td>
</tr>
<tr>
<td></td>
<td>Trained adolescent non-footballers</td>
<td>1623±124</td>
<td>325±60</td>
<td>1134±88</td>
<td>2466±141</td>
</tr>
<tr>
<td><strong>Chapter 5</strong></td>
<td>Higher performance senior Australian footballers (non-feint trials only)</td>
<td>1490 ± 56</td>
<td>290 ± 54</td>
<td>1133 ± 66</td>
<td>2328±84</td>
</tr>
<tr>
<td></td>
<td>Lower performance senior Australian footballers (non-feint trials only)</td>
<td>1522 ± 78</td>
<td>331 ± 57</td>
<td>1105 ± 93</td>
<td>2335±82</td>
</tr>
<tr>
<td><strong>Chapter 7</strong></td>
<td>Current and recent Australian footballers</td>
<td>1480±70</td>
<td>262±80</td>
<td>1030±50</td>
<td>2276±104</td>
</tr>
</tbody>
</table>

Therefore, potentially this discrepancy may be due to increases in the information processing time since, as per Hick’s law (Hick, 1952), the time taken to respond should increase in accordance with the number of potential outcomes (Schmidt & Wrisberg, 2008). Indeed, this appears to be partly responsible for the slow performance in the lower standard group who exhibited the slowest decision time, but not for the higher standard group whose decision times were one of the fastest measured (although this may have been even faster had there been no feint trials). In fact, in the higher
standard group the major source of deficiency was in the movement time. Consequently, the possibility of a feint likely resulted in participants not fully committing to a turn until they were sure it was not a feint, thus slowing down their movement response compared to trials where no feint options were included.

Consequently, direct comparisons of the times from Chapter 5 with the other studies should be undertaken with some caution. However, given that the participants in Chapter 7 were mature, current and former Australian footballers, most of whom had competitive football backgrounds similar to the players in Chapter 5, it is reasonable to expect similar times if feint trials were not included. Nonetheless, comparing the data from the four remaining groups from Chapters 4 and 7 confirms the trends outlined earlier; that as skill and experience increases (e.g., non-players Chapter 4 → junior low performers Chapter 4 → junior high performers Chapter 4 → senior current and former footballers Chapter 7) agility, decision and movement times also improve (become faster).

Therefore, the combined results for this thesis confirm that reactive agility is an important characteristic in Australian football and that coaches should use tests such as the video-based reactive agility test to assess the overall agility capacity of their athletes as well as the source of any differences within the sub-components, as this can vary between athletes. Furthermore, when conducting such tests coaches should also consider using complex scenarios such as those involving feints, as these may be the best way of detecting strengths and weaknesses in all athletes, including the highly trained. When doing so, coaches should also be cognisant of the fact that overall results and those of the various sub-components cannot be directly compared to tests using single-turn tasks.
Finally, to complete the review of the results of this thesis the hypotheses developed in the first chapter will be reviewed.

Chapter 4 (Paper 1) - Validity of a reactive agility test for Australian football.

The specific aims of this study were to 1) determine the construct validity of the video-based method by comparing agility performance to a generic light-based test and another planned agility test, 2) determine whether a video reactive agility test can discriminate performance differences between three groups of participants differentiated by their level of involvement in Australian football, and 3) isolate the perceptual and physical sub-components of agility and examine their influence on overall performance and how this may vary between athletes playing at different competitive levels.

Accordingly, the first hypothesis stated that,

“Performance on both reactive agility tests will be slower than the planned test, while performance on the video test will in turn be slower than the light-based test, due to a longer decision time component related to the increased cognitive complexity of the video stimuli.”

This was accepted, since significant differences were observed in the agility time component between the planned test and both the reactive test modes. Also, although no significant differences were observed in agility and movement times between the reactive modes, decision time was significantly faster in the light-based test than the video-based test. Therefore, a simple light-based stimulus allows participants to make significantly faster decisions, likely due to the reduced cognitive demand in that protocol.

The second hypothesis stated that,

“Higher calibre footballers will demonstrate superior agility than lower calibre footballers, and both playing groups will perform better than non-players on all tests and these group differences will be greatest for the video-based protocol.”
This was accepted, since the higher standard group had a significantly faster agility time than the non-footballers on the video-based test. Also, although the effect sizes between the higher standard and lower standard groups on both the planned and light-based tests were not significant, the differences were largest on the video-based test. Therefore, there was a trend toward an increasing divergence in the ability of the different playing groups to respond to the increasing cognitive demand from the planned to the light to the video test.

The third hypothesis stated that,

“The primary source of the group differences will be in the decision time component rather than the physical component and the differences will be greatest in the video-based test.”

This was rejected, since no significant differences were observed in decision time between the participant groups on any test mode. Also, the larger differences in agility time between the non-footballers and the higher standard players were primarily due to differences in movement time.

Chapter 4A - Reliability of a reactive agility test for Australian football.

The specific aim of this study was to assess the test-retest and intra-rater reliability of a new video-based reactive agility test.

The hypothesis stated that,

“The new video-based reactive agility test will prove a reliable measure of reactive agility in Australian footballers.”

This was accepted, since the test-retest and intra-class correlation coefficients were acceptable for agility time ($r = 0.81$) and movement time ($r = 0.83$) but lower for total time ($r = 0.71$) and decision time ($r = 0.58$). Also, the coefficient of variation was low (<4%) for all variables except decision time, which was slightly larger (6.2%). However, movement time was improved during the second test session and as such coaches should ensure an interval of at least 8 weeks between repeat tests to minimise learning effects.
Further, intra-rater reliability was acceptable since a dependent t-test revealed no significant ($p=0.69$) difference between decision time from the first to the second assessments, a very strong correlation of $r = 0.99$ between these results and a coefficient of variation of 5.2%.

**Chapter 5 (Paper 2) - Effects of a feint on reactive agility performance.**

The aim of the second study was to firstly, use the new video-based reactive agility test, incorporating a mix of feint and non-feint trials, to examine the effects of deceptive movements on agility performance, and that of its sub-components. Secondly, this study investigated the relationships between feint and non-feint trials to determine whether the skills being measured are the same. Finally, whether the effects of a feint differ between different groups of Australian footballers was assessed to determine whether higher calibre players exhibited lower susceptibility to deceptive movements than their lower calibre counterparts.

Consequently, the first hypothesis stated that,

"*The inclusion of a feint in the stimulus video will decrease performance (increase time) of the “defensive” player through increases in both decision making and movement time components.*"

This was accepted, since when the skill groups were pooled, both agility ($p < 0.001; d = 3.06$) and movement times ($p = 0.002; d = 0.88$) were longer in the feint trials than the non-feint trials. Also, the first decision time was longer in the feint trials ($p = 0.02; d = 0.43$) than in the non-feint trials.

Further, the second hypothesis stated that,

"*There will be little relationship between the feint and non-feint trials due to the increased cognitive and physical complexity of the feint trials.*"

This was accepted, because the degree of association between the non-feint and feint trials for all the variables (agility, decision, movement and total times) were trivial to small ($r < 0.1$).
Finally, the third hypothesis stated that,

“The higher standard group will perform better across all agility trials but this advantage will increase with the inclusion of the feint and be manifested through slower decision and movement times in the lower standard group.”

This was partially accepted because, although the skill-group differences were small in all reactive agility tests, the effect sizes and qualitative interpretations of the confidence interval compared to the smallest worthwhile change revealed a trend for better agility times (feint: $p = 0.18; d = 0.52; 88/6/6$; likely beneficial; non-feint: $p = 0.22; d = 0.47; 74/22/4$; possibly beneficial) in the higher standard players. However, the primary source of the difference was in the movement time, since the inclusion of the feint resulted in a modest lengthening of movement time ($p = 0.23; d = 0.66; 81/13/6$; likely detrimental) for the higher standard group but a much larger deterioration for the lower standard group ($p = 0.002; d = 1.07; 100/0/0$; almost certainly detrimental).

Chapter 6 (Paper 3) - Decision making accuracy in reactive agility: Quantifying the cost of poor decisions.

This study sought to 1) examine the effect of the inclusion of feints on decision making accuracy by comparing the frequency of incorrect decisions in normal and feint trials, 2) compare differences in decision accuracy between higher and lower standard Australian footballers to assess whether the higher standard athletes maintain their level of accuracy due to a lower susceptibility to deception, and 3) compare the time-cost of response errors to successful trials to investigate whether decision making errors will lead to significant worsening in agility performance and identify which of the sub-components may be primarily responsible for this.

Therefore, the first hypothesis stated that,

“The introduction of feint movements will reduce decision accuracy, compared to non-feint trials.”
This was accepted since, with the skill groups pooled, decision accuracy at decision time 1 (94±7%) was higher ($p = 0.01; d = 0.69$) than at decision time 2 (83±20%).

The second hypothesis stated that,

“Higher calibre players will exhibit better decision making accuracy than lower calibre players. This superior level of accuracy will be maintained in the higher calibre group with the inclusion of a feint, but will decrease in the lower calibre players.”

This was partially accepted. The first part of the hypothesis was not supported since decision accuracy was similar between the playing groups at decision time 1 ($p = 0.6; d = 0.42$) and although the gap between the groups increased with the inclusion of the feint the difference in accuracy between the groups in the feint trials was not significant ($p = 0.08; d = 0.50$). However, the second part of the hypothesis was supported, since the decision accuracy with the inclusion of the feint was largely maintained in the higher standard group ($p = 0.2; d = 0.44$) while accuracy was significantly decreased in the lower performance players ($p = 0.02; d = 1.04$). Notwithstanding this larger decrease in accuracy, as noted above the between group differences in the feint trials was ultimately not significant.

The final hypothesis stated that,

“Decision making errors will lead to significant decreases in agility performance in the “pursuing” player.”

This was accepted, since in the non-feint trials, where initial responses were in the wrong direction, decision ($p = 0.004; d = 0.81$) and agility times ($p = 0.001; d = 1.13$) were longer than when players turned in the correct direction, whilst movement time was similar ($p = 0.12; d = 0.50$). Similarly, in feint trials where incorrect decisions were made at the second decision point, the resulting decision ($p < 0.001; d = 1.56$), agility ($p < 0.001; d = 1.76$) and movement times ($p < 0.001; d = 1.18$) were all longer than if the initial movement direction was correct. The source of these increases in response
time was a lengthening in both movement time (as movement direction was corrected) and decision time (due to confusion in response selection). Conversely, on feint trials where the first of the two reactions was incorrect, the agility ($p = 0.008; d = 0.92$) and movement times ($p = 0.002; d = 1.14$) were shorter, which seemingly contradicts the hypothesis. Potentially, this “error” at the first turn might be due to successful anticipation of the feint and so provides a unique insight into the potential benefit of effective anticipation that, if successful, may shift any advantage to the pursuing player.

Chapter 7 (Paper 4) - The relationship between reactive agility movement time and unilateral vertical, horizontal and lateral jumps.

The specific aims of this study were to 1) examine the relationship between unilateral vertical, horizontal and lateral jump performance, reactive strength and kinetic variables and reactive agility: in particular the movement phase of reactive agility; 2) compare agility and jump performance between the dominant and non-dominant legs to establish the presence of any asymmetries and investigate whether (due to greater similarity between the movements), lateral or horizontal jumps will be more sensitive to any differences in reactive agility performance between legs; 3) assess differences in jump performance between faster and slower reactive agility groups to clarify the relative influence of lateral, horizontal and vertical leg strength characteristics in producing faster agility movement.

Consequently, the first hypothesis stated that,

“A strong association between jump performance, kinetic variables and agility performance will be observed but the strongest association will be for the lateral jumps, and collectively these three jumps will explain the majority of the variance in agility performance.”

This was rejected, because correlations between the jumps and agility movement performance were weak, with the highest correlation of -0.33 ($p = 0.07$) between vertical jump height and movement time. Similarly, the association between pooled kinetic variables and movement time were
typically weak, with the highest negative correlation (e.g., as force output increased movement time decreased) between lateral jump mean lateral force output (Fx) ($r = -0.26$). Further, the total variance in agility movement performance explained by the lateral jump was $R^2 = 6\%$, $F(1, 29) = 1.92$, $p = 0.17$. Moreover, entering the vertical and horizontal jumps into the regression model only produced a 5% increase in the variance accounted for by the model, to a total of 11%, $F(3, 27) = 1.15$, $p = 0.35$. Therefore, collectively the jumps explain little of the total variance in reactive agility movement time.

Additionally, the second hypothesis stated that,

“Asymmetries between the legs during the jump tests will mirror functional differences in agility performance when pushing off each leg, and lateral jumps will demonstrate the greatest sensitivity due to the similarity between the movements (e.g., small differences in lateral jump ability will predict differences in agility time).”

This was accepted, because agility ($p < 0.001; d = 0.84$) and movement times ($p = 0.004; d = 0.86$) were significantly faster when turning off the dominant leg and participants also jumped significantly further ($p = 0.008; d = 0.35$), with a higher reactive strength index ($p = 0.03; d = 0.28$) using the dominant leg during lateral jumps. Therefore, it appears that there are some similar factors involved in jumping and turning laterally off the dominant leg. As such, unilateral lateral jumps could identify reactive strength or motor skill asymmetries which might have a meaningful impact on reactive agility performance using the dominant leg. Nonetheless, this association between lateral jumps and reactive agility using the dominant leg should be interpreted cautiously since asymmetries are considered common in jump assessments in normal athletic populations and so the similarity between lateral jump and agility asymmetries found here might simply be coincidental rather than functionally linked, a view supported by the weak correlations.

The third hypothesis stated that,

“After dividing the group into faster and slower groups (based on reactive agility movement times), differences in agility movement
performance between the groups will be accompanied by concomitant differences in jump ability on all jumps, but the greatest difference will be observed in the lateral jumps.”

This was rejected, since the faster sub-group had significantly faster movement times ($p < 0.001; d = 2.0$) than the slower group but there were no differences observed in performance or any kinetic variables in any jumps. Therefore, the lack of differences in reactive strength and kinetic variables between the faster and slower movement time groups indicates that factors other than reactive strength may be more involved and important in the movement component of reactive agility.

8.2 CONCLUSIONS AND PRACTICAL IMPLICATIONS

- Reactive and planned tests measure different characteristics and reactive tests are more sensitive to the differences between athletes competing at different competition standards of Australian football. As such, reactive agility tests should be preferred over historical planned agility tests when examining sport-specific agility ability.

- Reactive agility tests should use sport-specific stimuli, such as the video of another person changing direction, since the perceptual and cognitive elements, and the movement produced, are not as effectively examined using a generic light-based stimulus.

- The video-based reactive agility test introduced in this thesis is a valid and reliable method for discriminating Australian footballers from different skill groups. Coaches can use this test to identify the agility profile of their own teams and investigate the sub-components of agility to detect specific strengths and weaknesses. These results can then be used to assist in the development of appropriate training programs.

- When conducting repeated test sessions across a season to assess the effectiveness of agility training, coaches should ensure an interval of at least 8 weeks between tests to prevent a learning effect, which may influence the movement time measure.
• Linear speed contaminates agility performance when straight sprint segments form a large part of an agility test and consequently, linear sprinting should be eliminated from the agility measure where possible. Therefore, the agility time measure introduced in this thesis should be used in preference over the total time measure, as this removes the initial 3 m-approach sprint from the analysis.

• There is no discernable relationship between agility performance with and without a feint, thus agility in response to a feint appears to be a unique skill. Furthermore, feints typically reduce the agility performance of defensive players and provide offensive players with a practical time and distance advantage. However, if defensive players can recognise and anticipate feints the advantage can shift in their favour. Therefore, since the use of feints are common in sport, it is recommended that team sport participants devote specific training to this type of activity from both an offensive and defensive perspective, using context-specific scenarios common to their sport.

• The gap between higher and lower standard players is more pronounced as the complexity of the task increases, such as with the inclusion of feints and multiple turns. This is mainly due to a marked decrease in agility movement performance and decision making accuracy in lesser skilled athletes. Accordingly, simple single-stimuli/single-turn scenarios might not challenge more than the universal perceptual and cognitive skills common to many team-sport athletes and weaknesses in some higher performing athletes might only be uncovered during more complex tasks. Therefore, agility and a variety of other sport-specific testing and training should incorporate a variety of feint scenarios likely to be encountered during match-play, to expose potential weaknesses in more athletes.

• Reactive strength in the legs, as measured by unilateral drop jumps, has limited predictive value for assessing and comparing the motor component of reactive agility. Accordingly, reactive strength may not be an important contributor to agility movement performance, and other factors such as skill, balance, stability and coordination may play a larger role.
• Nevertheless, asymmetries in reactive agility performance are associated with a concomitant advantage in lateral jumping ability, and potentially the reactive strength in the dominant leg. Therefore, including single-leg jumps in a test battery could help coaches to identify reactive strength asymmetries, which might have a meaningful impact on both the motor component of reactive agility and overall performance. However, coaches should be cognisant of the fact that lateral jumps and agility asymmetries might be coincidental rather than functionally linked.

• It is unlikely that one single characteristic is responsible for overall reactive agility performance and that it will at different times, depending on the nature and complexity of the task and the athletes involved, be primarily influenced by either the cognitive and decision making factors or the motor component. Accordingly, the video-based reactive agility test introduced in this thesis provides coaches with a valid and effective tool with which to assess the various sub-components of agility and identify the specific strengths and weaknesses within the agility profiles of their athletes.

• Once the specific agility profiles and needs of players and teams are understood, coaches can then design agility training to maximise performance by improving weaknesses and exploiting strengths. However, rather than an isolated movement-based approach, a context-specific task-based approach to agility training would seem to offer the most potential for maximising sport-specific agility performance. This is because an isolated movement approach doesn’t consider the circumstances in which the movement occurs, the trigger upon which it is based (e.g., why and when the movement occurs) or the complex interpersonal interactions between players. Potentially, contextualisation of agility tasks may be achieved through video-based perceptual training using the protocol introduced here, but with different game-specific stimuli and scenarios. Additionally, escalating the cognitive and physical challenge over time by moving from relatively simple "one on one" activities to more complex multi-player and multi-movement scenarios and small-sided games might assist in maximising decision making speed and accuracy and minimise any
disadvantage caused via offensive feints and incorrect decisions. An approach such as this will also allow coaches to target specific task or movement goals or to modulate the complexity of the activity by altering the task and environmental constraints to maximise the learning outcome, in particular the transfer of practice to on-field performance.

8.3 Future research

Due to the embryonic nature of research into reactive agility, this topic remains fertile ground for future research. Until now, few studies had expanded the use of reactive agility to investigate the underlying mechanisms contributing to agility and the characteristics of agile athletes, in particular the specific post-response movement component. Nevertheless, since many of the concepts in this thesis are being investigated for the first time they are all areas that would benefit from follow-up research to confirm and strengthen (or perhaps dispute) the findings contained herein. Therefore, some areas future researchers should consider are:

• The current video-based reactive agility protocol should be directly compared to a real-person stimulus or emerging 3-D video technology to provide further insight into the impact of different types of sport-specific stimuli. This will also allow researchers to settle on a single type of stimulus, so that in future a consistent approach to testing is achieved using the most appropriate stimulus.

• This current research considered for the first time the influence of deceptive movements and feints and found that trials involving feints were able to identify differences in certain athletes that the single turn scenarios common to previous reactive agility research have not. Therefore, future research should include different types of deceptive movements such as those involving fake ball passes, plus accompanying multiple movements.

• This project identified that the movement component can play an important role in agility, especially in the more complex scenarios, but that reactive strength as measured by unilateral jumps did not show a
strong relationship to performance. Therefore, the role of other physical factors apart from reactive strength, such as dynamic balance, core strength and stability and coordination in agility performance should be investigated.

- However, given the high muscle loads involved in agility, future researchers should continue to investigate the role of different types of strength and power in agility. This could include maximum strength, eccentric strength and explosive power in various different movement planes and using one or two legs.

- Very little research has examined reactive agility training, but the limited amount thus far have recorded promising results and so further controlled trials using different types of context-specific agility training should be conducted. This could be in the form of video-based reactive agility training or small-sided games and multiple player drills. In addition, training that deconstructs the components of agility will provide a useful insight into the role of the various sub-components of agility. For example, strength and power training, particularly using lateral rather than vertical movements, would offer valuable additional information about the role of different types of strength, and the potential for specific strength and power training to augment traditional agility training regimes.


Appendix A - Ethics approval
Please be advised that ethical approval of the above project has been granted in accordance with the procedures of the Human Research Ethics Committee at the University of Western Australia.

It is the responsibility of the researcher to advise the Committee of any departure from the original protocol. The Committee requires that all Chief Investigators report immediately any adverse or unexpected events that might affect ethical approval of the project.

Approval should be sought in writing in advance from the Human Research Ethics Committee if any change to the procedures or the number of participants in the original application is envisaged. Should this change require amendments to an Information Sheet or Consent Form related to the project, the amended version of the forms should be submitted for review. The application for the amendment should give the rationale behind and justification for the amendment. You are also required to inform the Committee, giving reasons, if the research project is discontinued before the expected date of completion. Correspondence should be submitted to the Secretary, Human Research Ethics Committee, Research Services.

The Committee is bound by NHMRC Guidelines to monitor the progress of all approved projects until completion to ensure that they continue to conform to approved ethical standards. An Annual Report form will be sent to you twelve months after the initial approval date.

Please note that approval has been granted for a period of four years. Initial approval is for a period of one year, and, thereafter for future periods of one year at a time subject to the receipt of satisfactory annual reports. At the end of the four-year period you will be required to complete a new "Application to Undertake Research Involving Human Subjects" should you wish to continue with your research. However, in special circumstances, the Chair has the authority to extend the approval period in order to complete a project.

Please quote Project No RA/4/3/1114 on all correspondence associated with this study.

Yours sincerely,

KATE KIRK
Executive Officer
(Human Research Ethics Committee)

cc: Head of School
    Admin Officer
    Dr Sato Juniper

13 April 2007
Appendix B - Participant information letter and consent form Study 1 (Chapters 4 and 4A)
"Reliability and validity of a new test for reactive agility"

Purpose of the study

The purpose of this research is to assess a proposed new test to measure Reactive agility. You have been selected for this study because you are an active Colts Australian Rules Football player. Reactive agility requires an individual to sprint forward and then conduct an unplanned change direction in response to an external stimulus (such as an opponent or a bouncing ball in a game of football). This is in contrast to planned agility activities which may involve running around cones on pre-planned pathways, as is common in training and testing in football today. This type of planned agility however, rarely, if ever actually occurs on a football field and the continued use of this style of training and assessment is now being questioned. The test procedure will assess agility performance using no stimulus (planned agility), a complex stimulus (a video) or a simple stimulus (lights). Additionally, performance will be compared between elite and sub-elite junior Australian Rules footballers.

Procedure

All participants will be required attend the School of Human Movement at UWA on at least two occasions within one week where a number of speed and agility tests will be performed. In addition, some subjects will be asked to return again one week later for a third visit.

Day 1

- Height, weight and visual acuity test.
- Test 1: 10m Acceleration – 5 x 10m sprints with time recorded at 5m and 10m.
- Test 2: Light based reactive agility.

Day 2:

- Test 3: Video based reactive agility
- Test 4: Planned agility – measures agility on a 10m long pre-planned route around cones. Participants will complete 4 practice trials and 8 experimental trials.

Both of the reactive agility trials (light based and Video based) will involve straight sprint followed by an unplanned change of direction in response to an external stimulus (either a light or video). For both tests (tests 2 & 3) each participant will complete 5 practice trials followed by 12 real trials.

Day 3:

- The higher performance group returns one week later to repeat the video based reactive agility test.

Data Collection

For all tests the time to complete each experimental trial will be recorded using electronic timing gates and for tests 2, 3 and 4 video footage of each trial will also be captured. The video footage will later be analysed to calculate the change of direction time. Upon the completion of the research and thesis all confidential personal data will be destroyed.

Risks

Since the activities involve maximum intensity efforts and unanticipated change of direction tasks there is a small risk of soft tissue and/or joint injuries. However, all subjects will have experience in performing similar
activities during both the training and playing of Australian Rules football. Since activities of this nature are familiar to the participants it is envisaged that there will be little if any physical discomfort experienced at the completion of this test program.

**Benefits to the Participant**

Participants will gain valuable data on their 5m and 10m speed which are crucial performance measures in modern football. Additionally, detailed information about planned and reactive agility performance can be provided to the participants at the completion of the research. This information will be valuable in maximizing agility ability which is a critical component in team sport success.

**Time Commitments**

Two or three visits to the lab at UWA and each of the visits should take no longer than 120 mins.

Participants are free to withdraw at any time from the study without prejudice in any way. The participant need give no reason or justification for such a decision and in such cases the records for that individual will be destroyed unless otherwise agreed by that individual. Your participation in this study does not prejudice any right to compensation which you may have under statute or common law.

**Contact Details**

The researchers will be happy to answer any questions you may have regarding the procedures or details of the proposed research. The researchers may be contacted on:

Greg Henry (PhD Candidate)

c/- School of Human Movement and Exercise Science

Ph: 6488 7400

Ph: 0403 165 784

Email: greg.henry@bigpond.com

Prof. Brian Dawson (Principal Supervisor)

c/- School of Human Movement and Exercise Science

Ph: 6488 2361

bdawson@cylene.uwa.edu.au

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
CONSENT FORM

“Reliability and Validity of a new test for Reactive Agility”

Investigator Responsibilities - Participant Rights

1. As a subject you are free to withdraw your consent at any time without any prejudice. You do not need to give any reason or justification for your decision to withdraw and any records will be destroyed unless otherwise agreed.
2. The researcher will answer any queries about the study you may have at any time.

Any questions about the research can be directed to:
Researcher/Investigator: Greg Henry (PhD student) School of Sports Science, Exercise and Health University of WA Ph 0403 165 784 Email: henryg01@student.uwa.edu.au
Principal Supervisor: Prof Brian Davson School of Sports Science, Exercise and Health University of WA Ph 6488 2361

I (print your name), have read the information provided and any questions have been answered to my satisfaction. I agree to participate in this project and understand that I can withdraw my consent at any time without reason and without prejudice.

I understand that all information provided is treated as confidential and will not be released by the investigator. The only exception to this principle of confidentiality is if a court subpoena documentation. I have been advised as to what data is being collected, what the purpose is and what will be done with the data upon completion of the research. I also agree that any and all research data obtained during this project may be published providing my name and identifying details is not used.

Signature of Participant (parent/guardian if under 18 years of age) Date

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
Appendix C - Participant information letter and consent form Study 2 (Chapters 5 and 6)
"A comparison of the effect of deceptive movement on reactive agility performance"

**Purpose of the study**
The purpose of this research is to assess the effect that various different video stimuli has on reactive agility performance using a proposed new reactive agility test. You have been selected for this study because you are either an active WAFL or amateur Australian Rules Football player. Reactive agility requires an individual to sprint and undertake an unplanned change direction in response to an external stimulus (such as an opponent or a bouncing ball in a game of football). The test procedure will assess agility performance using the variety of complex video stimuli. Additionally, performance will be compared between sub-elite and amateur Australian Rules footballers.

**Procedure**
All participants will be required attend the School of Sports Science, Exercise and Health at UWA on a single occasion where a number of speed and agility tests will be performed.

Day 1
- Height, weight and visual acuity test.
- Test 1: 11m Acceleration – 5 x 11m sprints with time recorded at 4m and 11m.
- Test 2: Video based reactive agility using chase scenario

The reactive agility trials will involve a straight sprint followed by an unplanned change of direction in response to an external stimulus. Each participant will complete 9 practice trials followed by 14 real trials.

**Data Collection**
For the agility test the time to complete each experimental trial will be recorded using electronic timing gates and video footage of each trial will also be captured. The video footage will later be analysed to calculate the change of direction time. Upon the completion of the research and thesis all confidential data will be destroyed.

**Risks**
Since the activities involve maximum intensity efforts and unanticipated change of direction tasks there is a small risk of soft tissue and/or joint injuries. However, all subjects will have experience in performing similar activities during both the training and playing of Australian Rules football. Further, since activities of this nature are familiar to the participants it is envisaged that there will be little if any physical discomfort experienced at the completion of this test program.

**Benefits to the Participant**
Participants will gain valuable data on their 4m and 11m speed which are crucial performance measures in modern football. Additionally, detailed information about various types of reactive agility performance can be provided to the participants at the completion of the research. This information will be valuable in maximising agility ability which is a critical component in team sport success.
CONSENT FORM

“A comparison of the effect of deceptive movement on reactive agility performance”

Investigator Responsibilities – Participant Rights

1. As a subject you are free to withdraw your consent at any time without any prejudice. You do not need to give any reason or justification for your decision to withdraw and any records will be destroyed unless otherwise agreed.

2. The researcher will answer any queries about the study you may have at any time.

Any questions about the research can be directed to:

Greg Henry (PhD candidate)  Principal Supervisor:  Professor Brian Dawson
School of Sports Science, Exercise & Health  School of Sports Science, Exercise &
University of WA  Health
Ph 0403 165 794  University of WA
Email: henryg91@student.uwa.edu.au  Ph 6488 2301

I (print your name), ____________________________, have read the information provided and any questions have been answered to my satisfaction. I agree to participate in this project and understand that I can withdraw my consent at any time without reason and without prejudice.

I understand that all information provided is treated as confidential and will not be released by the investigator. The only exception to this principle of confidentiality is if a court subpoenas documentation. I have been advised as to what data is being collected, what the purpose is and what will be done with the data upon completion of the research. I also agree that any and all research data obtained during this project may be published providing my name and identifying details is not used.

Signature of Participant ____________________________  (parent/guardian if under 18 years of age)

Date ____________________________

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
Appendix D - Participant information letter and consent form Study 3 (Chapter 7)
INFORMATION SHEET

“The relationship between unilateral lateral, horizontal and vertical jump performance and reactive agility”

Purpose of the study
The purpose of this research is to assess the relationship between single leg jump performance and reactive agility performance. You have been selected for this study because you are a moderately trained male with a history of participation in Australian Rules Football. Reactive agility requires an individual to sprint and conduct an unplanned change direction in response to an external stimulus (such as an opponent in a game of football). The test procedure will assess agility performance using a variety of complex video stimuli. The jumps will involve jumping forward horizontally onto one leg on a force platform and then jumping as high, as far forward or as far laterally (45°) as possible.

Procedure
All participants will be required attend the School of Sport Science, Exercise and Health at UWA on two occasions separated by 7 days.

Day 1
- A thorough warm up.
- Measurement of height, weight and leg length.
- 3 x 10m sprints with time recorded at 4m and 10m.
- Explanation and demonstration of the jump protocols.
- 5-10 familiarization trials of each of the jumps.
- Explanation and demonstration of the Reactive agility test.
- 5-10 familiarization trials of the Reactive agility test.

Day 2:
- Thorough warm up.
- 5 practice trials of the jumps.
- 3 experimental trials of each of the jumps off each leg.
- 5 practice trials of the Reactive agility test.
- 12 experimental trials of the Reactive agility test.

The jump trials will involve a jump forward from a distance of 120% of your leg length onto one leg on a force platform and then either jump as high as possible or forward horizontally or laterally at an angle of 45° as far as possible.

The reactive agility trials will involve straight sprint followed by an unplanned change of direction in response to an external (video) stimulus.

Data Collection
For the jump trials video footage will be captured and data from a force platform will be recorded. During the Reactive agility test the time to complete each trial will be recorded using electronic timing gates and video footage captured. The video footage will later be analyzed to calculate the change of direction time and jump distance. Upon the completion of the research and thesis all confidential data will be destroyed.
Risks
Since the activities involve maximum intensity efforts and unanticipated change of direction tasks there is a small risk of soft tissue and/or joint injuries. Further, some participants may experience some transient low level delayed onset muscle soreness, which will pass within 48-72 hours. However, all subjects will have experience in performing similar activities during both the training and playing of Australian Rules football and as such any risk is considered minimal.

Benefits to the Participant
Participants will gain valuable data on their 4m and 10m speed, which are crucial performance measures in modern football. Additionally, detailed information about various types of reactive agility performance can be provided to the participants at the completion of the research. This information will be valuable in maximizing agility ability that is a critical component in team sport success. In addition, information about single leg jump ability in numerous planes will be gathered and any discrepancies between the legs will be determined which is also important for effective football performance.

Time Commitments
For the two performance test sessions each of the visits to the laboratory should take approximately 90 mins.

Participants are free to withdraw at any time from the study without prejudice in any way. The participant need give no reason or justification for such a decision and in such cases the records for that individual will be destroyed unless otherwise agreed by that individual. Your participation in this study does not prejudice any right to compensation which you may have under statute or common law.

Contact Details
The researchers will be happy to answer any questions you may have regarding the procedures or details of the proposed research. The researchers may be contacted on:

Greg Henry (PhD candidate)
c/o School of Sport Science, Exercise and Health
Ph: 6498 2361
Ph: 0403 165 784
Email: henryg01@student.uwa.edu.au

Winthrop Prof. Brian Dawson (Principal Supervisor)
c/o School of Sport Science, Exercise and Health
Ph: 6498 2361
bdawson@cyllene.uwa.edu.au

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
CONSENT FORM

“The relationship between unilateral single leg lateral, horizontal and vertical jump performance and reactive agility”

Investigator Responsibilities – Participant Rights
1. As a subject you are free to withdraw your consent at any time without any prejudice. You do not need to give any reason or justification for your decision to withdraw and any records will be destroyed unless otherwise agreed.
2. The researcher will answer any queries about the study you may have at any time.

Any questions about the research can be directed to:

Researcher/Investigator: Greg Henry (PhD candidate)  Principal Supervisor: Winthrop Professor Brian Dawson
School of Sports Science, Exercise & Health  School of Sports Science, Exercise & Health
University of WA  University of WA
Ph 0403 169 784  Ph 0488 2361
Email: henryg91@student.uwa.edu.au

I (print your name), ____________________________, have read the information provided and any questions have been answered to my satisfaction. I agree to participate in this project and understand that I can withdraw my consent at any time without reason and without prejudice.

I understand that all information provided is treated as confidential and will not be released by the investigator. The only exception to this principle of confidentiality is if a court subpoenas documentation. I have been advised as to what data is being collected, what the purpose is and what will be done with the data upon completion of the research. I also agree that any and all research data obtained during this project may be published providing my name and identifying details is not used.

Signature of Participant ____________________________
Date ____________________________

(parent/guardian if under 18 years of age)

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar’s Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 9289-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.
Appendix E - Raw data
### Raw data: Chapter 4

#### Linear speed and video-based reactive agility test (ms)

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*Repeat video-based reactive agility test for test-retest reliability analysis (ms)*

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Raw data: Chapter 6

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