

## A hierarchical model of factors influencing a battery of agility tests

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## **Abstract**

**Aims:** To investigate the hierarchical contributions of anthropometry, strength and cognition to a battery of prescriptive and reactive agility tests.

**Methods:** Nineteen participants (mean  $\pm$  S.D.; age:  $22.1 \pm 1.9$  years; height:  $182.9 \pm 5.5$  cm; body mass:  $77 \pm 4.9$  kg) completed four agility tests: a prescriptive linear sprint, a prescriptive change-of-direction sprint, a reactive change-of-direction sprint, and a reactive linear deceleration test. Anthropometric variables included body fat percentage and thigh girth. Strength was quantified as the peak eccentric hamstring torque at 180, 300, and  $60^\circ \cdot s^{-1}$ . Mean reaction time and accuracy in the Stroop word-colour test was used to assess perceptual and decision making factors.

**Results:** There was little evidence of inter-test correlation with the strongest relationship observed between 10m sprint and T-test performance ( $r^2 = 0.49$ ,  $P < 0.01$ ). Anthropometric measures were not strong predictors of agility, accounting for a maximum 23% ( $P = 0.12$ ) in the prescriptive change-of-direction test. Cognitive measures had a stronger correlation with the reactive (rather than prescriptive) agility tests, with a maximum 33% ( $P = 0.04$ ) of variance accounted for in the reactive change-of-direction test. Eccentric hamstring strength accounted for 62% ( $P = 0.01$ ) of the variance in the prescriptive change-of-direction test. Hierarchical ordering of the agility tests revealed that eccentric hamstring strength was the primary predictor in 3 of the 4 tests, with cognitive accuracy the next most common predictor.

**Conclusion:** There is little evidence of inter-test correlation across a battery of agility tests. Eccentric hamstring strength and decision making accuracy are the most common predictors of agility performance.

**Keywords:** agility, rehabilitation, isokinetic, hamstring, injury

## Introduction

Agility has been defined as a person's ability to change direction rapidly.<sup>1</sup> High speed cutting movements are commonly associated with a high risk of injury,<sup>2</sup> particularly when incorporating a rapid deceleration, and thus agility has a primary role in both performance enhancement and injury (p)rehabilitation. In the sporting context, a change of direction is often in response to a stimulus, and agility is considered to be dependent on two primary components: change of direction speed, and perceptual and decision making factors.<sup>3-5</sup> The myriad of factors influencing agility is reflected in the number and diversity of tests claiming to measure agility. The relationship between linear speed and change of direction speed has received considerable attention, with authors typically reporting weak inter-test relationships,<sup>6-12</sup> reflecting their differing physical and cognitive demands.

Research has advocated combining the physical and psychological components of agility,<sup>6</sup> but to date the physical strand of the Universal agility model<sup>3</sup> has received greater attention. Leg strength qualities have received the greatest attention,<sup>4,5,13,14</sup> highlighting the functional role of eccentric hamstring strength in enhancing the neuromuscular control of the contact phase to enhance agility.<sup>6</sup> Anthropometric variables have received less consideration, and where sport-specific test batteries have revealed better agility performance in individuals with lower body fat, this was not directly quantified.<sup>3</sup> In a rare multi-factorial investigation of the determinants of agility, body fat percentage and lower limb muscular performance variables were shown to account for ~45% of the variance in the predictive T-test and 5m shuttle run test,<sup>15</sup> which arguably include no cognitive demands.

The range of components influencing agility performance lends itself to a hierarchical ordering of factors. The aim of the present study is to consider both the physical and cognitive factors. The cognitive demands of agility have been afforded little attention, with many agility tests failing to present a reactive stimulus and involving only pre-planned, prescriptive movements. Anticipatory cues have been shown to distinguish between elite

and non-elite performers,<sup>16</sup> where the complexity of the stimulus will inevitably influence the information-processing demands of the task, and subsequently the response time.<sup>17</sup>

The myriad of factors influencing agility increases the complexity of test selection for the practitioner. In the present study it is hypothesised that inter-test correlations will be weak across a battery of agility tests, based on the multi-factorial nature of agility and the differing mechanical and cognitive demands of each test. Furthermore, it is likely that the hierarchical ordering of factors influencing agility are likely to be task-specific. In the present study the physical and cognitive profiling was designed to align to elements of the universal agility model,<sup>3</sup> including anthropometry, isokinetic dynamometry, and cognitive processing. In developing a hierarchical model of physical and cognitive factors for each agility test, it is hypothesised that cognitive elements will better predict reactive performance. Given the functional role of the hamstring musculature<sup>18</sup> it is hypothesised that eccentric hamstring strength will be the most common predictor of performance across the agility battery. A greater understanding of the factors influencing performance would enable the optimum design of functional (p)rehabilitation strategies.

## **Materials and Methods**

### ***Participants***

Nineteen male, university-level intermittent team sports players (mean  $\pm$  S.D.; age: 22.1  $\pm$  1.9 years; height: 182.9  $\pm$  5.5 cm; body mass: 77  $\pm$  4.9 kg) completed the study. Players were required to be injury free for three months preceding data collection, and provided written informed consent in partial fulfilment of gaining approval from departmental and faculty ethics committees. All testing was conducted between 14:00 – 16:00 hours in accord with regular competitive demands of these players, and to negate the influence of circadian effects on performance. Regular participation in intermittent team sports was set as an

inclusion criteria for the sample population such that all participants were familiar with the functional challenge posed by the test battery.

### ***Agility testing battery***

The agility test battery was designed to include both prescriptive and reactive tasks, linear and multi-directional speed, acceleration and deceleration. The testing battery comprised; a T-test, a 10m linear sprint, a reactive change of direction cutting task, and a reactive deceleration task. All agility tests were completed using commercially available photoelectric timing gates (Smartspeed, Fusion Sport, Australia), with participants instructed to complete each task to the best of their ability, requiring a maximal effort. Figure 1 provides a schematic representation of each test. Testing was preceded by a dynamic warm-up and a demonstration was conducted before each agility test.

**\*\* Insert Figure 1 near here \*\***

Participants were allowed a 1 metre rolling start from the first timing gate in order to replicate game type situations.<sup>19</sup> The T-test and 10m sprint were designed to test prescriptive agility, with the T-test incorporating a change in direction. Similarly, the cut and deceleration tasks were designed to test reactive agility. The reactive cut was performed at a 45° angle, with the sequencing of the light stimulus at point 'B' random to ensure a reactive stimulus. As the light flashing sequence was random each subject may have been required to run more than twice, but no more than four runs were conducted to avoid the cumulative influence of fatigue. Performance was quantified as the average of the first inversion and eversion sprint performed. The reactive deceleration task utilised the 10m Sprint set-up, with the final timing gate replaced by a light stimulus. A light stimulus was used to initiate a deceleration, no light meant the player continued to sprint through a second timing gate placed at 20m from 'A'.

Task performance was quantified as the distance from 'B' to the rearmost heel at the point where the player had become stationary and controlled.

### ***Physical and cognitive profiling***

All players completed a battery of physical and psychological profiling assessments within 2 weeks of the agility testing.

Anthropometric testing comprised a 7 site (biceps, triceps, subscapular, suprailiac, abdomen, mid-thigh, and gastrocnemius) skinfold assessment of body fat percentage.<sup>20</sup> All measures were taken using a Harpenden calliper (Lange, Cambridge, MA, USA) and averaged over three recordings. The mid-thigh location was also used to quantify a mid-thigh girth measurement

Isokinetic dynamometry (System 3, Biodex Medical Systems, Shirley, NY, USA) testing comprised eccentric knee flexor strength at angular velocities of 180, 300, and 60°·s<sup>-1</sup>.<sup>21</sup> Familiarisation trials were completed in each mode and at each speed, with data collection comprising 5 maximal<sup>22</sup> contractions at each speed. The recovery phase between maximal efforts was set as passive concentric knee flexion at 10°·s<sup>-1</sup>, requiring no exertion from the participant. There was an allocated 90 seconds rest between sets. Communication to each participant was restricted to informing them of the test speeds, no visual feedback was offered.

The cognitive component of agility was considered using a version of the Stroop Word-Colour test,<sup>23</sup> with response inhibition tasks providing a valid representation of the cognitive demands of reactive agility. The task comprised random assignment of five words (Red, Blue, Green, Yellow, and XXXX) presented in red, blue, green or yellow coloured font, resulting in a total of 20 different screens. The player was required to identify the font colour as quickly as possible, by pressing the appropriate colour-coded key on a standard keyboard. Each trial of the Stroop task comprised 36 responses, with performance quantified as the mean reaction time and accuracy (percentage of correct responses).

## **Statistical Analyses**

Performance to complete the 10m sprint, T-test and reactive cut were quantified as  $t_{10}$ ,  $t_T$  and  $t_{RC}$  respectively. The deceleration task was scored as the stopping distance  $d$ . Linear regression analysis was used to quantify the correlation coefficient between performance on each agility test.

Multiple linear regression analysis was used to correlate performance on each test with each of the anthropometric, isokinetic strength, and cognitive profiling parameters. The correlation coefficient was used to quantify the relative contribution of each factor to agility performance. To develop the hierarchical ordering of the anthropometric, strength and cognitive factors for each agility test, a forward stepwise regression was used.

## **Results**

Table 1 summarises the inter-test correlations for each agility test, providing the predictive regression equation and the correlation coefficient. The strongest correlation was observed between performance of the 10m sprint and T-test ( $r^2 = 0.49$ ,  $P < 0.01$ ), the two prescriptive tests. The weakest correlations were observed between the reactive cut and the T-test ( $r^2 = 0.03$ ,  $P = 0.48$ ), the change of directions tests, and between the reactive cut and the deceleration task ( $r^2 = 0.03$ ,  $P = 0.46$ ), the reactive tests.

**\*\* Insert Table 1 near here \*\***

Table 2 quantifies the strength of the linear correlation between agility test performance and each of the parameters determined from the cognitive, anthropometric, and strength profiling. For each agility test, the correlation is quantified for each factor and for the

summation of factors. For example, for the Stroop word colour test, each agility test is correlated with reaction time (RT) and accuracy (%) discretely, and then in a multiple linear regression against RT and %. The final row in Table 2 summarises the strength of the correlation when all factors from cognition, anthropometry and strength are included in a multiple linear regression. The greatest single correlation was observed between eccentric hamstring strength at  $180^{\circ}\cdot\text{s}^{-1}$  and T-test performance ( $r^2 = 0.61$ ,  $P = 0.01$ ). Anthropometric parameters were observed to have the least predictive power, the strongest correlation being with T-test performance ( $r^2 = 0.23$ ,  $P = 0.12$ ). Cognitive parameters were best able to account for variability in the reactive cut ( $r^2 = 0.33$ ,  $P = 0.04$ ). Eccentric hamstring strength matched this correlative strength in the deceleration task ( $r^2 = 0.33$ ,  $P = 0.10$ ), and showed the greatest predictive power in the T-test ( $r^2 = 0.62$ ,  $P = 0.01$ ). Agility performance was correlated against each parameter discretely, and against all parameters as a multiple linear regression. With all parameters included in a multiple regression model, the correlation coefficient ranged from  $r^2 = 0.39$  ( $P = 0.47$ ) for the 10m sprint to  $r^2 = 0.82$  ( $P < 0.01$ ) for the T-test..

**\*\* Insert Table 2 near here \*\***

A hierarchical model of each agility test was completed using a forward stepwise regression, as summarised in Table 3. The stepwise model includes additional parameters on the premise that the correlation coefficient is improved, and in 3 of the 4 tests only a single parameter was included. Eccentric hamstring strength at  $180^{\circ}\cdot\text{s}^{-1}$  was the primary predictor of both 10m sprint ( $r^2 = 0.23$ ,  $P = 0.24$ ) and T-test performance ( $r^2 = 0.61$ ,  $P < 0.01$ ), with peak torque at  $60^{\circ}\cdot\text{s}^{-1}$  best predicting deceleration task performance ( $r^2 = 0.32$ ,  $P = 0.01$ ). Cognitive accuracy was the primary predictor of reactive cut performance ( $r^2 = 0.29$ ,  $P = 0.02$ ), and was also observed as a secondary predictor in the T-test hierarchical model. No



anthropometric parameters were included in any of the agility test hierarchical models, and cognitive speed of response also failed to impact this analysis.

\*\* Insert Table 3 near here \*\*

## **Discussion**

The aim of the present study was to investigate the inter-test correlations across a battery of tests designed to evaluate aspects of agility performance, and to evaluate the hierarchical ordering of both cognitive and physical factors influencing agility performance.<sup>3</sup> Across the battery of agility tests there was generally weak inter-test correlation, supporting previous studies,<sup>6-12</sup> and reflecting the myriad of factors which might influence performance on each task. The present study used a more comprehensive testing battery than previous literature, incorporating both linear and directional change tasks, characterised as both prescriptive and reactive. The strongest correlation ( $r = 0.79$ ) was evident between the 10m sprint and T-test, whose common element is their prescriptive nature. In contrast, the two reactive tasks shared a correlation accounting for only 3% of the variation, reflecting the greater complexity in these tasks.

The reactive element of agility highlights the dependence on decision making, part of the psychological strand defined in the Universal model of agility,<sup>3</sup> and quantified using a decision making task characterised by inhibition of the response.<sup>23</sup> In all agility tests, the accuracy in decision making was more important than the speed of decision making. The predictive strength of the accuracy in cognition was greatest in the reactive cut sprint, a task which is enhanced by a quick response but fundamentally requires an accurate response. It is better to make an accurate decision slower, than an erroneous decision quickly as the necessary correction will increase the time taken to complete the task.

The physical strand of the Universal model of agility<sup>3</sup> was defined using anthropometric measures and eccentric hamstring strength. Anthropometry was quantified as the percentage body fat and girth of the mid-thigh, given the functional role of the thigh musculature in speed and agility tasks.<sup>6,15</sup> In all tests body fat percentage was a greater predictor of agility performance than thigh girth, but did not appear in the deterministic regression model for any test. Body fat % contributed most to the T-test ( $r = 0.48$ ) and deceleration ( $r = 0.42$ ) tests. This correlation is in line with, but of smaller magnitude, than previous studies using male soccer and basketball players.<sup>15,24</sup> Common to both the T-test and deceleration test is the necessity to decelerate quickly and under control. The negative linear relationship between body fat and performance therefore most likely relates to the greater mechanical effort in decelerating a body mass with a higher fat percentage to arrest momentum.

The T-test and deceleration test were also observed to have the greatest predictive relationship with eccentric hamstring strength, reflecting the function of the hamstrings in deceleration. The combined eccentric hamstring profile was able to account for 62% and 33% of the variance in the T-test and deceleration test respectively, the greater value in the T-test potentially attributable to the multiple actions performed in this test. Peak torque at the mid-range speed of  $180^\circ \cdot s^{-1}$  was the primary predictor of performance in the 10m sprint ( $r^2 = 0.23$ ) and T-test ( $r^2 = 0.61$ ), whereas peak torque at  $60^\circ \cdot s^{-1}$  was the biggest contributor to deceleration ability ( $r^2 = 0.32$ ). Previous studies considering the correlation between agility and isokinetic strength measures have used only the slowest testing speed of  $60^\circ \cdot s^{-1}$ .<sup>6,15</sup> The present study highlights the varying contribution from strength at different test speeds, with the slowest speed most affecting deceleration performance, and the moderate speed affecting those tasks emphasising acceleration. This highlights the different functional demands of strength, and the necessity for a range of speeds when conducting isokinetic evaluations. The test that showed no relationship with eccentric hamstring strength was the reactive cut, where the information processing model<sup>17</sup> suggests potentially insufficient time

to generate muscle force. The greater relative contribution to predictive change of direction speed is in line with previous work, where eccentric hamstring strength was able to discriminate between the best and worst T-test performers.<sup>15</sup>

The hierarchical modelling of factors affecting different agility tasks has practical implications in training and (p)rehabilitation. The common inclusion of eccentric hamstring strength as a predictor of performance is likely to relate to the functional role of the hamstrings in neuromuscular control during the ground contact phase,<sup>6</sup> enhancing stride frequency, and ultimately task performance. The anatomy of the hamstrings musculature enhances their functionality in both linear and directional change tasks,<sup>25</sup> helping to maintain hip extensor torque, assisting dynamic trunk stabilisation, and controlling knee flexion.<sup>6</sup> The force-velocity relationship warrants greater consideration in conditioning, training the hamstring musculature at a speed with functional relevance to the task.

The multiple linear regression model comprising all parameters from cognition, anthropometry and strength, was able to account for between 39-82% of the variability in performance. The greater predictive capacity for the T-test perhaps reflects the greater functional demands of this test, requiring elements of the other tests in linear acceleration, deceleration, and change of direction. The T-test therefore replicates the discrete performance objective of each of the other tests. The variability in task performance not explained by the multi-factorial approach used in the present study ranged from 18% in the T-test to 61% in the 10m linear sprint. This highlights the complexity in determining those factors affecting agility, and future research might further explore additional elements of the universal model.<sup>3</sup> The 'perceptual and decision-making factors' are most likely to further explain variability in reactive agility, whereas the 'change of direction speed' pathway has opportunities particularly in the analysis of technique. The nature and size of the population used in the present study also limits generalisation.

## Conclusions

Across a battery of tests designed to emphasise different components of 'agility' performance, there was little evidence of inter-test correlation as hypothesised. Each agility test produced a unique deterministic model from a selection of multi-factorial parameters. In particular there was disparity between prescriptive and reactive agility tasks. The most frequent predictor of agility performance was eccentric hamstring strength, particularly in tasks involving prescriptive change of direction, and reflective of their kinesiological function. Whilst observations cannot be generalised beyond the particular participant group used in the present study, the task-specific dependence on isokinetic test speed has implications for training and (p)rehabilitation strategies.

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## Legends to Figures & Tables

Figure 1. The agility testing battery.

Table 1. Inter-test correlation across the battery of agility tests.

Table 2. Correlation strength between each test and each predictive factor from cognition, anthropometry and strength.

Table 3. A hierarchical forward stepwise model of factors influencing each test.

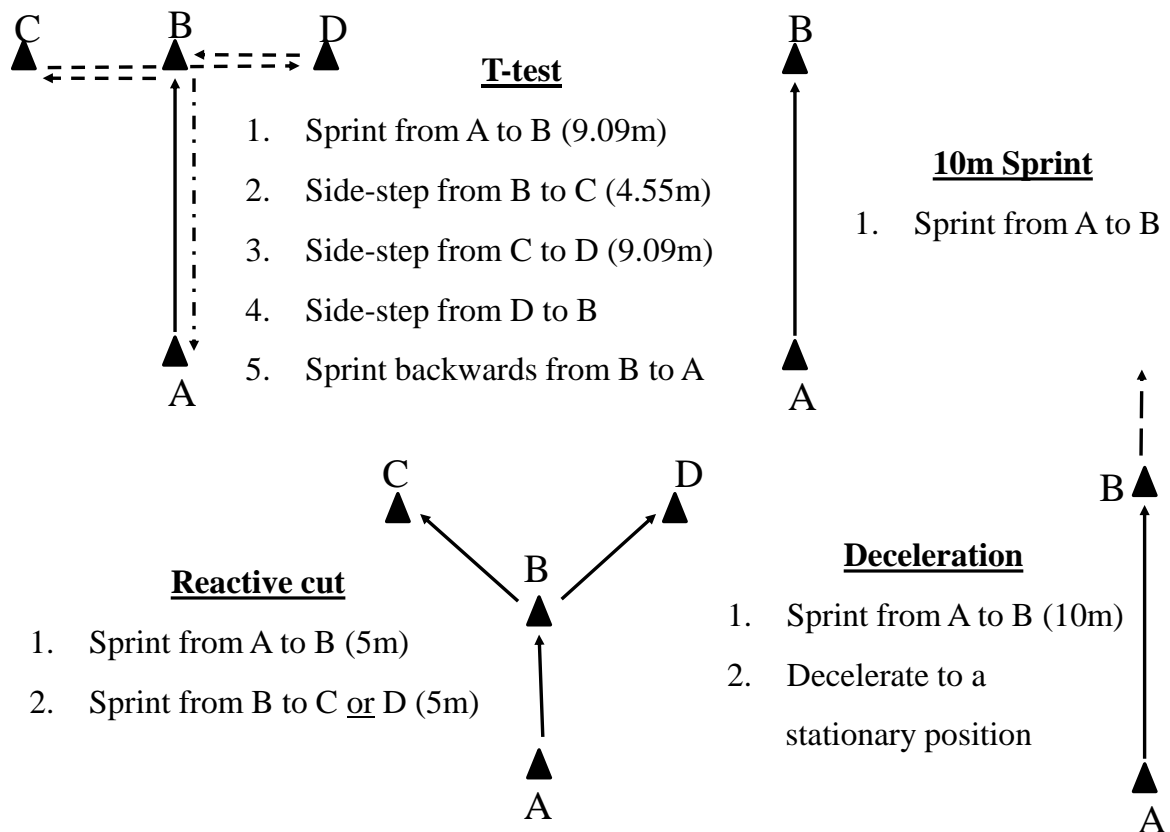


Figure 1. The agility testing battery.

Table 1. Inter-test correlation across the battery of agility tests.

	<b>10m Sprint</b> <b>t<sub>10</sub> (sec)</b>	<b>T-test</b> <b>t<sub>T</sub> (sec)</b>	<b>Reactive Cut</b> <b>t<sub>RC</sub> (sec)</b>	<b>Deceleration</b> <b>d (m)</b>
<b>t<sub>10</sub></b>		= 4.74 + 3.41(t <sub>10</sub> )	= 1.31 + 0.78(t <sub>10</sub> )	= 3.11 + 1.40(t <sub>10</sub> )
<b>t<sub>T</sub></b>	r <sup>2</sup> = 0.49 P < 0.01		= 2.15 + 0.05(t <sub>T</sub> )	= 1.34 + 0.39(t <sub>T</sub> )
<b>t<sub>RC</sub></b>	r <sup>2</sup> = 0.32 P = 0.01	r <sup>2</sup> = 0.03 P = 0.48		= 4.38 + 0.45(t <sub>RC</sub> )
<b>d</b>	r <sup>2</sup> = 0.16 P = 0.09	r <sup>2</sup> = 0.31 P = 0.01	r <sup>2</sup> = 0.03 P = 0.46	



Table 2. Correlation strength between each test and each predictive factor from cognition, anthropometry and strength.

	<b>10m Sprint</b> $t_{10}$	<b>T-test</b> $t_T$	<b>Reactive Cut</b> $t_{RC}$	<b>Deceleration</b> $d$
<b><i>Stroop word colour task, f(Reaction time RT, Accuracy %)</i></b>				
<b>RT</b>	$r^2 = 0.02$ P = 0.54	$r^2 = 0.04$ P = 0.42	$r^2 = 0.01$ P = 0.67	$r^2 = 0.01$ P = 0.74
<b>%</b>	$r^2 = 0.05$ P = 0.38	$r^2 = 0.16$ P = 0.09	$r^2 = 0.29$ P = 0.02	$r^2 = 0.09$ P = 0.22
<b>RT, %</b>	$r^2 = 0.06$ P = 0.62	$r^2 = 0.18$ P = 0.21	$r^2 = 0.33$ P = 0.04	$r^2 = 0.09$ P = 0.48
<b><i>Anthropometry, f(Body fat %, Mid-thigh girth)</i></b>				
<b>Fat %</b>	$r^2 = 0.08$ P = 0.24	$r^2 = 0.23$ P = 0.04	$r^2 < 0.01$ P = 0.94	$r^2 = 0.16$ P = 0.09
<b>Girth</b>	$r^2 = 0.04$ P = 0.44	$r^2 < 0.01$ P = 0.82	$r^2 = 0.01$ P = 0.95	$r^2 = 0.08$ P = 0.72
<b>%, Girth</b>	$r^2 = 0.10$ P = 0.42	$r^2 = 0.23$ P = 0.12	$r^2 = 0.10$ P = 0.10	$r^2 = 0.18$ P = 0.20
<b><i>Eccentric hamstring peak torque, f(60, 180 and 300°·s<sup>-1</sup>)</i></b>				
<b>T<sub>60</sub></b>	$r^2 = 0.11$ P = 0.16	$r^2 = 0.32$ P < 0.01	$r^2 = 0.01$ P = 0.99	$r^2 = 0.32$ P = 0.01
<b>T<sub>180</sub></b>	$r^2 = 0.23$ P = 0.04	$r^2 = 0.61$ P = 0.01	$r^2 = 0.02$ P = 0.62	$r^2 = 0.21$ P = 0.05
<b>T<sub>300</sub></b>	$r^2 = 0.21$ P = 0.05	$r^2 = 0.42$ P < 0.01	$r^2 = 0.02$ P = 0.59	$r^2 = 0.23$ P = 0.04
<b>T<sub>60,180,300</sub></b>	$r^2 = 0.27$ P = 0.19	$r^2 = 0.62$ P = 0.01	$r^2 = 0.05$ P = 0.87	$r^2 = 0.33$ P = 0.10
<b><i>All parameters, f(Cognition, Anthropometry, Strength)</i></b>				
<b>Σ</b>	$r^2 = 0.39$ P = 0.47	$r^2 = 0.82$ P < 0.01	$r^2 = 0.41$ P = 0.43	$r^2 = 0.45$ P = 0.33

Table 3. A hierarchical forward stepwise model of factors influencing each test.

	<b>Step 1</b>	<b>Step 2</b>
10m Sprint	Eccentric Hamstring T <sub>180</sub> r <sup>2</sup> = 0.23 P = 0.04	
T-test	Eccentric Hamstring T <sub>180</sub> r <sup>2</sup> = 0.61 P < 0.01	Stroop Accuracy % r <sup>2</sup> = 0.70 P = 0.05
Reactive Cut	Stroop Accuracy % r <sup>2</sup> = 0.29 P = 0.02	
Deceleration	Eccentric Hamstring T <sub>60</sub> r <sup>2</sup> = 0.32 P = 0.01	