Reliability and Generality of Measures of Acceleration, Planned Agility, and Reactive Agility

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Purpose: The purpose of the current study was to assess the reliability of a new protocol that examines different components of agility using commercially available timing gates. Methods: Seventeen physically active males completed four trials of a new protocol, which consisted of a number of 10-m sprints. Sprints were completed in a straight line or with a change of direction after 5 m. The change of direction was either planned or reactive, with participants reacting to a visual light stimulus. Results: There was no systematic bias in any of the measures, although random variation was reduced in the straight acceleration and planned agility when considering only the final pair of trials, with mean coefficients of variation (CV) of 1.6% (95%CI, 1.2% to 2.4%) and 1.1% (0.8% to 1.7%), respectively. Reliability of reactive agility remained consistent throughout with mean CVs of approximately 3%. Analyses revealed a high degree of common variance between acceleration times and both planned ($r^2 = .93$) and reactive ($r^2 = .83$) agility, as well as between the two agility protocols ($r^2 = .87$). Conclusion: Both planned and reactive agility could be measured reliably. Protocol design and use of a light stimulus in the reactive test emphasize physical abilities comparable with other test measures. Therefore, inclusion of a reactive light stimulus does not appear to require any additional perceptual qualities.

Keywords: linear sprint, change of direction, visual stimulus, commonality

The ability to rapidly change direction and react to different stimuli is a requisite of many sports, particularly team and racket sports.1 When examining a variety of anthropometric, physiological, psychological, and skill components of elite and subelite youth soccer players, it has been reported that agility is the most discriminating factor.2 Similarly, tests of agility have been shown to distinguish between playing standards in Australian rules football3 and netball,4 as well as between different age groups and standards of play in rugby league.5,6

An understanding of the various definitions of agility is important when considering the merits of different protocols. The traditional definition of the ability to rapidly change direction has been redefined as change of direction speed,3,4,7 or planned agility.4 The term planned agility denotes the fact that participants are aware of the exact movement pattern required before the start of a test. This allows...
the distinction with a more recent definition of agility as a whole-body movement with a change of velocity or direction in response to a stimulus. This latter definition has been termed reactive agility, reflecting the requirement for participants to change direction in response to a given stimulus mid-test.

The type of stimulus presented during a reactive test needs to be considered. Besier et al. instruct participants to perform a cutting action in response to a flashing light stimulus, although the reliability and validity of this protocol were not reported. Other authors have incorporated sport-specific stimuli into reactive agility protocols. Construct validity has been supported by the ability of these reactive agility tests to distinguish between team players of differing standards. Farrow et al. used life-size images projected onto a wall to provide a sport-specific stimulus, a protocol that may be difficult for others to re-create. In contrast, Sheppard et al. described a method whereby participants reacted to a real-life opponent, with movement patterns that were very specific to defensive movement patterns in Australian rules football. Recently, commercially available timing gates have been developed that incorporate a function to provide a non-sport specific light stimulus, allowing the possibility for test protocols that measure a generic ability to react to a stimulus.

Currently, it is not clear whether different components of agility exist as general or specific qualities. When two measures share a common variance of >50%, they are thought to represent one general quality, whereas a common variance of <50% reflects the fact that both variables measure independent and specific qualities. Currently, the association between different components of agility is not well described. Commonality between measures of planned and reactive agility have been reported to be as high as 50% or as low as 10%. The aim of the current study was to assess the reliability of a new agility test that used commercially available timing gates to measure straight acceleration as well as planned and reactive agility while running forward (with participants reacting to a flashing light stimulus). A further aim was to assess the level of association between linear and planned and reactive agility sprints to determine whether each component represented a specific or general quality.

**Method**

**Subjects**

Seventeen male sports students from a variety of backgrounds (rugby, hockey, football, athletics, racket sports) volunteered to participate in the study. Mean age (± SD) of the participants was 20.3 (0.7) y; stature, 179.4 (8.2) cm; and body mass, 81.5 (12.5) kg. The institutional ethics committee approved the project, and all participants provided written informed consent.

**Experimental Approach to the Problem**

This study examined the between-day reliability of measures of acceleration and agility across multiple trials, while also examining the level of association between the different performance components. The use of multiple trials allowed for the examination of any possible learning effects, with all testing conducted at the
same time of day and with 3 to 4 d between test sessions. Reliability was assessed by examining the change in the mean between trials and calculating the coefficient of variation, which together can be considered the most important reliability statistics.11 Participants completed four trials of a test battery that measured times to complete a 10-m linear sprint, a 10-m planned agility sprint that included one change in direction, and a 10-m reactive agility sprint that also included one change in direction. All testing was performed in an indoor sports hall. Commercially available timing gates were used to provide a flashing light as a generic stimulus for the reactive test (Smartspeed, Fusion Sports, Australia). The relationship between different performance measures was used to examine whether each variable measured a specific or general performance quality.

**Agility Protocol**

A diagram of the setup of the agility protocol is provided in Figure 1. Participants started all sprints from a position 30 cm behind the first timing gate. Sprint times were recorded using photoelectric timing gates (Smartspeed). The timing instrumentation in the middle of the course was placed outside foam barriers, which were placed 1 m apart (Figure 1). The physical barriers were used to keep participants in a central position through the middle section of the course and to protect the timing equipment. Exit gates were placed at the left and right end of the test course for the agility sprints, the center point of each gate was visually placed perpendicular to the intended line of running. Sprint times were recorded telemetry, with all data transmitted to a personal digital assistant (PDA).

Each session began with a 10-min dynamic warm-up followed by the experimental protocol. Participants completed a number of sprints in the following order: two trials of a straight 10-m sprint, two trials (one to the left and one to the right) of a planned agility sprint, and repeated trials of a reactive agility sprint until either the participant had completed two sprints to either side or a total of eight sprints, whichever occurred first. As the change in direction in the reactive agility sprints was not under the control of the researcher, this approach meant there was a <1% chance that all reactive sprints would be in the same direction. In the planned agility run, participants were instructed which way to turn at the midpoint of test course before commencing each sprint. In the reactive agility test, the timing gate system dictated the direction in which participants proceeded having completed the first 5 m of the course. Upon breaking the beam of the timing gate in the middle of the course, lights on either the left or right exit gate flashed. Participants were required to react to this stimulus and sprint as quickly as possible through the illuminated timing gate. The delay time between breaking the beam in the middle timing gate and a stimulus light flashing was ~40 to 45 ms. During the reactive agility sprints, participants were instructed not to try to predict which exit gate they would be required to sprint through; to ensure that this did not occur, the investigator visually monitored technique and compared reactive performance times to planned sprint times.

The best single effort from the straight 10-m sprint was used for analysis. The mean of the efforts to the left and right was used as a measure of planned agility. For the reactive agility, the best two efforts to each side were taken, or when this was not possible either a single effort or no result was recorded to a particular
Reactive agility results were then considered as the overall mean, the mean to both the left and the right, and the best effort to both the left and right.

**Statistical Analyses**

All participants completed four trials of the test procedures. Any systematic bias in test scores over the repeated trials was tested for using a repeated-measures ANOVA, with results for each trial presented as the mean ± SD. If the assumptions of sphericity were violated, a Greenhouse–Geisser adjustment was used. A Bonferroni post hoc test was used to identify significant differences between pairs of trials. Random variation in the test variables was expressed as a mean coefficient of variation (CV) across repeated trials. The mean CV was calculated using a two-way ANOVA on the log-transformed raw data with participants and test

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**Figure 1** — Diagram of the experimental setup for measuring straight, planned agility, and reactive agility sprint speed.

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trials as effects. The antilog of the root mean square error (RMSE) term was substituted into the following equation:

\[
\text{Mean CV} = 100 \left( e^{\text{RMSE}} - 1 \right)
\]

The possibility of any learning effects reducing random variation was analyzed by calculating the mean CV over consecutive sets of subsequent repeated trials (trials 1 to 4, trials 2 to 4, and trials 3 to 4). The 95% confidence intervals were calculated for all mean CVs. To assist with interpreting reliability results, the smallest worthwhile effect was calculated by pooling data across all trials and using 0.2 of the between-participant standard deviation. To compare differences and relationships between performance in the different tests, data were averaged across all four trials (to provide values closer to each participants “true” score). A one-way repeated-measures ANOVA was used to test for significant differences between different performance measures using the same procedures previously described. The level of association between test measures was assessed using Pearson’s correlation coefficient, and the typical error of estimate (TEE%) was also calculated. For all tests, significance was set at the \( P \leq .05 \) level.

**Results**

All variables were found to be reliable with minimal systematic bias and low levels of random variation. Mean sprint times in each trial are reported in Table 1. Although there were small improvements in straight and planned agility sprint times across the four trials, no significant between-trial differences were found for any variable. When examining data averaged over all trials, participants took significantly longer in agility tasks compared with straight sprinting and significantly longer when having to react compared with preplanned agility (all \( P > .001 \)). Compared with the 10-m straight sprint, sprint times were 6.1 ± 1.4% longer in the planned agility run and 39.7 ± 3.0% longer in the reactive agility sprint. Based on standard deviations, the straight sprint, mean planned, and mean reactive agility sprints all showed a smallest worthwhile effect for a change in performance of 1.1%.

Reliability of the various performance variables are reported in Table 2. Variability in straight and planned agility sprint times was reduced when only considering the final pair of trials. This finding was not reflected in the reactive agility sprints, with mean CV values remaining consistent irrespective of which trials were considered. Results were more reliable for agility protocols when considered as a mean rather than movements to either the left or right. Mean CVs to the

<table>
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<tr>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
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<tbody>
<tr>
<td>Straight (s)</td>
<td>1.84 ± 0.11</td>
<td>1.84 ± 0.11</td>
<td>1.81 ± 0.09</td>
</tr>
<tr>
<td>Planned (s)</td>
<td>1.95 ± 0.14</td>
<td>1.96 ± 0.13</td>
<td>1.91 ± 0.08</td>
</tr>
<tr>
<td>Reactive (s)</td>
<td>2.53 ± 0.15</td>
<td>2.55 ± 0.15</td>
<td>2.54 ± 0.12</td>
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right and left during the planned task were 2.4% (95% CI, 1.8% to 3.7%) and 1.2% (0.9% to 1.8%), respectively. Mean CVs across all trials were approximately 4% during the reactive agility sprints when considering only the best sprint to the right (4.3, 3.6% to 5.3%) or left (4.0, 3.3% to 5.0%), or the mean sprint performance to the right (4.3, 3.6% to 5.4%) or left (3.8, 3.1% to 4.7%).

Ten-meter straight sprint time was found to be a strong predictor of both planned and reactive agility sprint times (Figure 2). A significant relationship of $r^2 = .87$ ($P < .001$) was also found between planned and reactive agility performance. When considering participants involved in team sports only ($n = 12$) the strength of relationships remained largely unchanged, with relationships of $r^2 = .93$, 0.83, and 0.85 between straight and planned, straight and reactive, and planned and reactive sprint times, respectively. The same was true when analyzing a more homogenous group containing only rugby players ($n = 8$) with relationships of $r^2 = .96$, 0.86, and 0.81 between straight and planned, straight and reactive, and

<table>
<thead>
<tr>
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<th>Trials 1–4</th>
<th>Trials 2–4</th>
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<tbody>
<tr>
<td><strong>Straight</strong></td>
<td>2.5 (2.1–3.1)</td>
<td>2.6 (2.1–3.4)</td>
<td>1.6 (1.2–2.4)</td>
</tr>
<tr>
<td><strong>Planned</strong></td>
<td>3.3 (2.7–4.1)</td>
<td>3.1 (2.5–4.1)</td>
<td>1.1 (0.8–1.7)</td>
</tr>
<tr>
<td><strong>Reactive</strong></td>
<td>3.0 (2.5–3.7)</td>
<td>2.7 (2.2–3.6)</td>
<td>3.3 (2.5–5.0)</td>
</tr>
</tbody>
</table>

**Figure 2** — Relationship between straight 10-m sprint time and both 10-m planned agility (□) and 10-m reactive agility (△) sprint times.
planned and reactive sprint times, respectively. In all instances, the TEE% was \( \leq 2.2\% \) when considering pairs of data.

**Discussion**

The current study investigated the reliability of and commonality between different measures of speed and agility using a commercially available timing gate system. To the authors’ knowledge, this is the first study to report reliability of reactive agility over multiple trials. Results showed that familiarization sessions are not required when using the protocol described to measure reactive agility, with no systematic bias and no improvement in random variation when discounting earlier trials. The mean CV of 3.0% for the reactive agility test is in good agreement with the value of 2.8% reported by Gabbett et al\(^9\) following two trials of an agility test involving a sport-specific cue. Reliability of straight and planned agility sprints were also similar to previous research,\(^9\) although random variation was improved when only the latter pair of trials were considered. While familiarization may improve reliability, reporting the mean value of more trials represents an alternative option.\(^15\)

Practically, it is important to determine whether a given test has sufficient accuracy to detect small but important changes in performance. Coincidentally, straight sprinting and both planned and reactive agility sprints all showed a smallest worthwhile effect of 1.1% based on the results obtained for the sample population. The low random variation in the straight sprint and planned agility should allow the smallest worthwhile effects to be accurately detected. While there is more random variation inherent to the reactive agility test, it is still low enough to allow for a reasonable prediction of whether small changes in performance are in fact “real.”

When comparing an 8-m sprint to agility sprints over the same distance but with one change in direction, Young et al\(^1\) reported that sprint times increased by \( \sim 7\% \) with a 40° turn. Similarly, results of the current study showed an increase of \( \sim 6\% \) in sprint time when comparing planned agility and the straight sprint. The planned agility run required participants to turn at an angle of 37°, and this was used to reflect a moderate turning angle and to provide a test area that could easily be measured, set out, and replicated by others. The protocol was also designed to test the ability of participants to perform a quick and agile movement while running forward, which has been suggested to be one of the most common types of agile movement.\(^16\)

The reactive protocol substantially slowed participants with sprint times \( \sim 0.7 \) s longer than the straight sprint and \( \sim 0.6 \) s longer than the planned agility sprint. The increases in sprint times when reacting to a stimulus could be attributed to two factors: first, the increased distance covered as a result of a less than ideal movement pattern and second, the need to detect and react to a stimulus. Not performing the cut until 6 m would increase the overall sprint distance by 0.24 m and not performing the cut until 7 m would increase overall distance by 0.61 m. Performing a late cut would also increase the cutting angle to 45° and 56°, respectively, in the previous examples. While an increase in cutting angle will increase sprint time, such an increase has previously been reported to be only 18% with a
planned 60° cut.\textsuperscript{1} Therefore, the increased time during the reactive agility sprint can be considered to be due to the combined effects of detecting and reacting to the stimulus presented and the subsequent impact on total distance covered and cutting angle. These results are in contrast to the findings of Sheppard et al.\textsuperscript{3} who reported that high-performance athletes were able to complete a reactive agility task faster than a planned agility test over the same course. This finding may be explained by the use of a sport-specific cue in the study of Sheppard et al.\textsuperscript{3} with participants able to use visual cues and anticipation when reacting to a real-life opponent. Previous research has shown that visual cues may be used to anticipate the need for a general motor response\textsuperscript{17} or a more sport-specific motor response,\textsuperscript{18} with more skilled sports participants better able to recognize and respond to movement-pattern information to reduce their response time.\textsuperscript{18}

Previous research is equivocal regarding the relationship between agility and linear sprinting.\textsuperscript{3,9,19,20} Although there were significant differences in straight and agility sprint performance, straight sprint times accounted for $\geq 83\%$ of the variance in agility performance. This association remained even when the sample size was reduced to produce more homogenous sample groups. Furthermore, all performance variables could be well predicted from one another with typical error of estimates of $\leq 2.2\%$. The strong association found between a linear sprint and agility measures in the current study suggests that all variables measure a general performance quality. Protocol design is likely to influence the level of association between different linear and agile movements, particularly whether straight sprints measure speed or acceleration and the complexity and demands of an agility test. Previous research has shown that the strength of the relationship between linear sprint speed and planned agility is reduced with greater changes in direction.\textsuperscript{21} In the current study, participants were required to perform a single agile movement with a moderate cutting angle while running forward, which can be considered a relatively simple agility task.

The reported relationships between reactive agility and both linear acceleration and planned agility are considerably stronger than has previously been reported for protocols utilizing a sport-specific stimulus.\textsuperscript{3,4,9} Gabbett et al.\textsuperscript{9} found significant relationships between reactive agility and a number of planned agility tasks as well as linear sprinting; however, common variance was $\leq 34\%$, suggesting little generality in the different measures. Differences in the findings of the current study when compared with previous research might be the result of the protocol design (discussed above) or the stimulus used. Participants were required to react to a flashing light in the current study, a method that is being routinely used in an applied setting using commercially available timing gates. Reacting to a flashing light will increase the external loading on the knee when performing a cutting movement,\textsuperscript{8} while participants will also be required to adjust their body position to produce this cutting movement. These factors will contribute to the overall increase in movement time observed during the reactive test. However, the generality observed between test measures suggests that the reactive test still focused on common physical abilities and required limited perceptual abilities. For example, the determining factor in the reactive test may be the ability to accelerate both at the start of and again midway through the test rather than the ability to detect and change body position in response to the light stimulus. The use of sport-specific cues would require perceptual factors, such as visual scanning,
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anticipation, and pattern recognition, to be used to minimize movement time. The low common variance reported in the literature between reactive protocols using a sport-specific stimulus and planned agility supports the notion that the perceptual requirements of such tests reflects a specific performance quality, and this cannot be replicated with a generic light stimulus.

Practical Applications

The use of multiple trials showed that no familiarization period is necessary when measuring reactive agility using the protocol described (which had a mean CV of 3%). With low levels of measurement error, the new protocol could be used to establish and monitor an agility profile of an individual, providing a description of some of the component parts of agility (acceleration, ability to change direction, and ability to react to a stimulus). However, all of these tests will predominantly measure a shared general physical ability with limited perceptual requirements during the reactive test. Therefore, coaches and sport scientists may need to develop agility tasks with more demanding movement patterns or sport-specific cues (for reactive tests), to isolate different components of agility. Expanding the present protocol to also include a reactive component with a sport-specific stimulus could be one option to increase ecological validity.

Conclusion

To the authors’ knowledge, this is the first study to report reliability of a reactive agility test using commercially available timing gates with an in-built light stimulus. Straight acceleration, planned agility, and reactive agility could all be reliably measured with sufficient accuracy to detect worthwhile changes in performance. However, the strong relationships and low typical error of estimates between all test variables reflect the fact that linear and agile sprints were measuring a general performance quality. The high levels of common variance are suggested to be a result of the relative simple design of the agility task, which required only one change in direction while running forward, and the use of a generic light stimulus in the reactive test. These tasks emphasize physical qualities during agility testing while minimizing the need for higher level perceptual abilities.

References