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Is muscle power related to running speed with changes of direction?

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Background. **The purpose of this study was to identify the relationships between leg muscle power and sprinting speed with changes of direction.**
Methods. **Experimental design: the study was designed to describe relationships between physical qualities and a component of sports performance. Setting: testing was conducted in an indoor sports hall and a biomechanics laboratory. Participants: 15 male participants were required to be free of injury and have recent experience competing in sports involving sprints with changes of direction. Measures: subjects were timed in 8 m sprints in a straight line and with various changes of direction. They were also tested for bilateral and unilateral leg extensor muscle concentric power output by an isokinetic squat and reactive strength by a drop jump.**
Results. **The correlations between concentric power and straight sprinting speed were non-significant whereas the relationships between reactive strength and straight speed were statistically significant. Correlations between muscle power and speed while changing direction were generally low and non-significant for concentric leg power with some moderate and significant ($p<0.05$) coefficients found for reactive strength. The participants who turned faster to one side tended to have a reactive strength dominance in the leg responsible for the push-off action.**
Conclusions. **The relationships between leg muscle power and change-of-direction speed were not consistent. Reactive strength as measured by the drop jump appears to have some importance for lateral change-of-direction speed, possibly because of similar push-off actions. It was concluded that reactive strength of the leg extensor muscles has some importance in change-of-direction performance but the other technical and perceptual factors than influence agility performance should also be considered.**

KEY WORDS: Muscle, skeletal, physiology - Motor skills - Exercise, physiology.

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Sprinting over various distances is an important quality in many sports. There are many instances in team or racquet sports where the demands of sprinting are characterised more by rapid changes of direction rather than running in a straight line.[1,2] These change-of-direction movements, often described as agility, may be initiated to either evade or pursue an opponent, or to react to a moving ball. When reacting, it has been shown that the nature of the stimulus (timing and location) influences performance in agility tasks, and therefore perceptual factors are significant for agility performance.[3-5]

There is a lack of research describing running technique in team or racquet sports. However it has been suggested that in contrast to straight sprinting as demonstrated by track and field athletes, a team sport athlete runs with a relatively lower centre of gravity (C of G), more forward lean/slouched upper body, less knee flexion during leg recovery and a lower knee lift.[6] A lower C of G would seem to be advantageous for quickly producing lateral forces to the ground to evoke opposite ground reaction forces for sideways movements. The medio-lateral forces produced in "cutting" movements by professional basketball players have been reported to be moderate (equal to bodyweight), however these were produced after only a 4 step approach run in a laboratory, and may be expected to be greater in a competitive game.[7]

When the foot is planted to one side of the body to change direction to the other side, the leg extensor muscles would be expected to initially lengthen. Then an active push-off or leg extension would follow due to shortening of the same muscles. To produce a fast change of direction, it would be desirable to achieve a relatively short ground contact time and small flexion at the hip, knee and ankle joints. Therefore it may be expected that good change-of-direction performance is associated with a rapid stretch-shortening cycle of the leg extensors. This quality of quickly attenuating an eccentric action to produce a powerful concentric action has been termed reactive strength,[8] and may be important for change-of-direction speed. However one study that investigated the relationship between strength qualities (including reactive strength) and 20 m time with 3×90° changes of direction in Australian Rules footballers,[9] reported non-significant correlations. The authors suggested that this relatively complex agility task could be influenced more by motor control factors than the strength qualities of the muscles.

Other studies that have correlated tests of agility with various measures of leg muscle power have reported statistically significant but moderate coefficients between 0.38 and 0.65.[10-12] Research on female soccer players by Djevalikian [12] indicated a statistically significant correlation between the Boomerang agility test (4×90° turns and 3×180° turns) and drop jump performance (r=-0.42), but a non-significant correlation (-0.15) for a 15 sec continuous vertical jump test. The authors suggested that the drop jump, which was performed from a drop height of approximately 0.5 m, was a more specific test of leg power than the vertical jumps for change-of-direction running. However this study did not find a relationship between asymmetry in leg power and speed while turning. The main purpose of the present study was to determine the relationships between the power and reactive strength of the leg extensor muscles and 8 m sprint performance for straight and various change-of-direction sprints. The strength of these relationships may provide insights into the relative importance of strength requirements for agility. Another purpose was to determine whether imbalances in leg muscle power were related to imbalances in speed when turning. If left-right imbalances were related to running speed requiring turning, training directed at reducing imbalances could potentially improve agility performance.

In an attempt to elucidate the potential factors that influence agility performance, we have proposed a deterministic model of agility (Fig. 1). This is intended to indicate the main factors that determine agility, and can be applied to sports involving fast changes of direction such as most team and racquet sports. It highlights that the strength qualities of the leg muscles have potential to influence agility performance, along with several other factors.

Materials and methods

Subjects

Fifteen males aged 18-28 years with a mean ± standard deviation height and body mass of 1.75±0.08 m and 74.6±12.6 kg respectively, volunteered to participate in this study. The participants were required to be free of any injury that might influence their performance and to have been involved competitively in a sport requiring changes of direction in the past 12 months. The group consisted of soccer, basketball, Australian football and tennis players who played at club level.

All subjects were required to participate in 3 sessions involving tests of sprints that included changes of direction and leg muscle power. The first session required the participants to practice all the tests to become familiar with the procedures. The second and third sessions involved the sprint and muscle power tests, respectively. A 2-4 day recovery period was provided between each of the 3 sessions.

Sprint tests

All sprints were performed over an 8 m distance in an indoor sport facility and comprised the following (Fig. 2):

1) straight sprint;
2) single change of direction of 20° to the left;
3) single change of direction of 20° to the right;
4) single change of direction of 40° to the left;
5) single change of direction of 40° to the right;
6) single change of direction of 60° to the left;
7) single change of direction of 60° to the right;

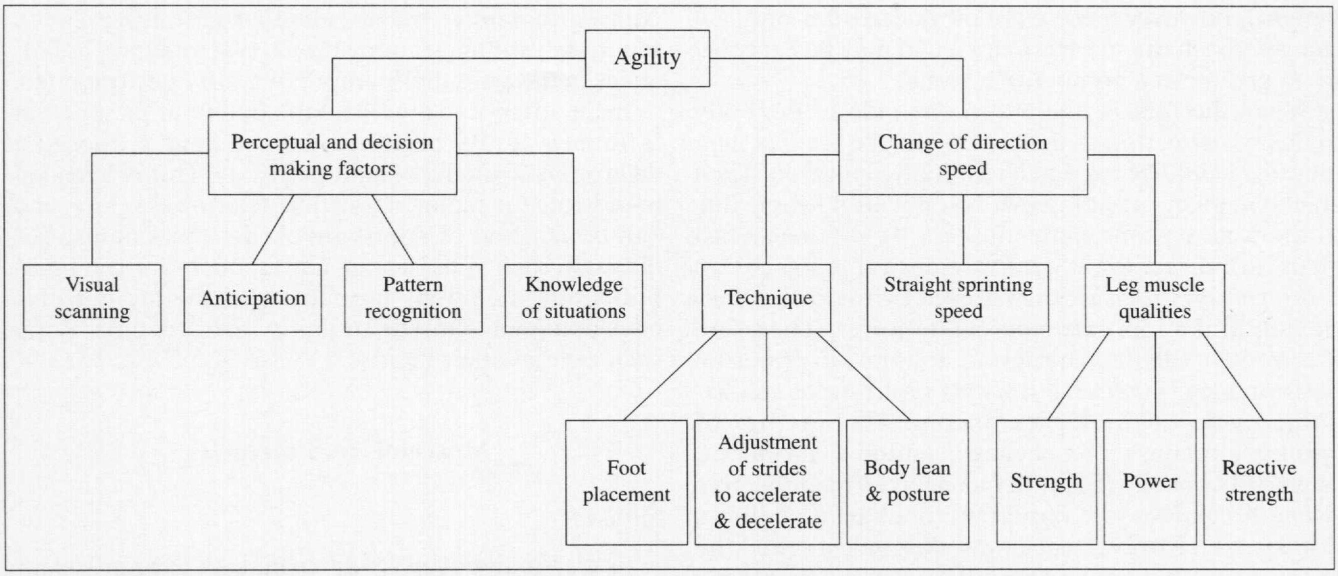

Fig. 1.—Model indicating the main factors determining agility. *Agility*: running speed with at least one change of direction performed in a competitive game. This may include being in possession of a ball or piece of equipment; *visual scanning*: ability to process visual information in competitive game; *anticipation*: prediction of an event in a game that influences the movements of a player in a game; *pattern recognition*: the ability to recognise patterns of play by an opposing team or player; *knowledge of situations*: knowledge of the probable movements of other players, based on previous experience of the game.

8) 4 changes of direction of 60°, 2 to the left and 2 to the right.

The various tests were included to determine if the relationships with muscle power altered as the sprints required sharper changes of direction (tests 1-7), and more changes of direction (test 8). It could be rationalised that muscle power becomes more important as directional changes are sharper, due to a need to apply greater medio-lateral forces to the ground. However it could also be argued that the technical demands of the sprints increase from tests 1 to 8 and therefore the role of muscle power could diminish. Therefore the various conditions were included to provide insights into these relationships.

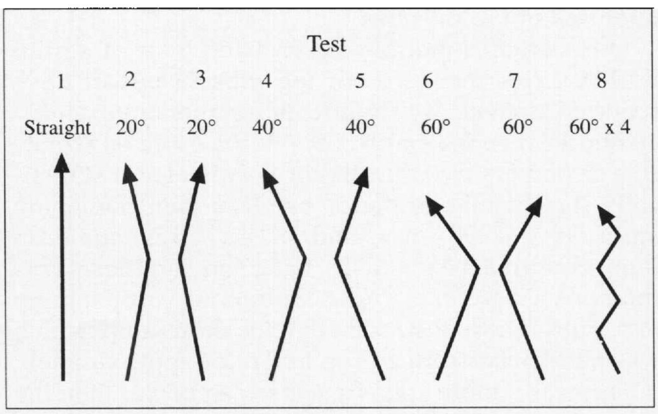

Fig. 2.—Eight metre straight and change-of-direction sprint tests.

The order of performing the 8 sprint tests was ascending for 8 of the subjects and descending for the remaining 7 participants. A random order was not used due to difficulty of precisely setting up the testing equipment. Sprint times were recorded to a resolution of 0.01 sec by a Swift dual beam infra-red timing system (Lismore, Australia). The system requires both beams to be broken simultaneously to trigger the start or finish of timing, and is designed to capture the trunk movement rather than a false trigger from a limb. The lower beam was set at approximately 0.8 m above the floor, which was typically around hip level. Each subject adopted a standing start with the toe of the preferred leg in line with the start gate, and was not permitted to commence with a "rolling" start. A pole approximately 1 m high was used as an obstacle for the change-of-direction sprints, which subjects were not allowed to touch as they ran around it.

Two trials were performed for each test with at least 2 min rest provided between all efforts. The subjects were instructed to sprint when ready with maximum effort through the finish gate, which stopped the timing, and the best time was retained for further analysis. The participants were instructed to wear indoor sport shoes and use the same shoes for all sprint tests.

Muscle power tests

To assess the explosive force qualities of the leg extensor muscles, 2 tests were conducted for both bilateral and unilateral muscle power in a random order:

Concentric leg extension power.—The subjects adopted a squat position under a Computerised Exercise System 5000 Multi-Function machine (Ariel Dynamics, Trabuco Canyon, CA). Using the isokinetic mode at a set speed of $40°\cdot sec^{-1}$ to produce the maximum power output,[13] the subject first squatted to a position that corresponded to a 100° angle at the knees, as measured by a manual goniometer. The participants were allowed to adopt a squat position that was comfortable for them, so the hip and ankle angles were not specified and controlled. This position was held statically for a count of 2 sec and then the subject extended the legs as fast as possible until standing on the balls of the feet. This procedure was also conducted with the left leg and right leg separately. During these unilateral tests, the subject was required to lift the non-support leg off the floor and maintain its position throughout the leg extension to eliminate any contribution from this leg to the power output recorded. The speed used for the unilateral test was $70°\cdot sec^{-1}$ and was faster than the bilateral test because pilot testing indicated this speed produced the greatest power output across a range of speeds. The power output was divided by body mass and the resulting value expressed in W/kg was used in the statistical analyses.

Reactive strength.—The reactive strength of the leg extensors was assessed by a drop jump test that required the subject to rebound for maximum height and minimum ground contact time, with the objective of maximising the height/time.[14] These instructions require the subject to quickly reverse the downward motion of the body to an upward movement produced by stretch-shortening cycle muscle actions of the leg extensors, and have previously been found to produce a relatively small knee flexion and contact times shorter than 0.2 sec.[14] The reactive strength score was measured as the jump height (cm) divided by the contact time (sec), and the test was conducted according to procedures previously reported for bilateral leg muscle power [14] using a drop height of 0.3 m. Jump height and contact times were measured by a Swift contact mat system (Lismore, Australia). The procedures were modified for this study to allow assessment of unilateral muscle power. The subject dropped from a 0.15 m high box and was instructed to rebound for maximum height and minimum ground contact time with out assistance from the non-support leg. Since the eccentric loading is influenced by the drop height, a lower drop height was deemed necessary for the single leg jumps.

Three trials were allowed for all muscle power tests with a 0.5-1.0 min rest between efforts, and the best result was retained. All sprint and muscle power testing sessions were preceded by a standardised warm-up consisting of 5 min of jogging and 10 min of static stretching of the muscles of the lower extremity. Three sub-maximum warm-up/practice trials were performed before the maximum efforts for each test.

Statistics

The relationships between the sprint tests and leg muscle power were determined by Pearson correlations. The percentage common or shared variance between variables ($r^2\times100$) was also considered. The differences between left and right sprint and leg power results were analysed by paired "t"-tests, and the statistical significance of all tests was set at $p<0.05$.

Results

The mean ± standard deviation results for all tests are indicated in Table I. The times taken to complete the 8 m sprints increased as the change of direction became sharper and the number of changes increased from 1 to 4 (Fig. 3). The correlation coefficients describing the relationships between the sprint tests and the bilateral as well as unilateral muscle power tests are shown in Tables II and III.

Further insights into the potential role of muscle power to change-of-direction performance may be seen by exploring differences in times to turn to the left and right and between left and right legs in the muscle power tests. The entire group turned slightly faster to the left (1.5%, $p>0.05$) for the 120° turns.

TABLE I.—*Results for sprints and leg muscle power.*

Tests	Mean	Standard deviation
Sprint tests over 8 m		
Straight sprint (sec)	1.65	0.09
Single change 20° to left (sec)	1.68	0.06
Single change 20° to right (sec)	1.68	0.06
Single change 40° to left (sec)	1.75	0.10
Single change 40° to right (sec)	1.77	0.08
Single change 60° to left (sec)	1.94	0.10
Single change 60° to right (sec)	1.97	0.09
Four changes 60° (sec)	2.85	0.16
Leg muscle power		
Concentric leg power, bilateral (W/kg)	2.15	0.47
Concentric leg power, left (W/kg)	1.29	0.28
Concentric leg power, right (W/kg)	1.25	0.24
Reactive strength, bilateral (cm/sec)	195	46
Reactive strength, left (cm/sec)	77	14
Reactive strength, right (cm/sec)	82	14

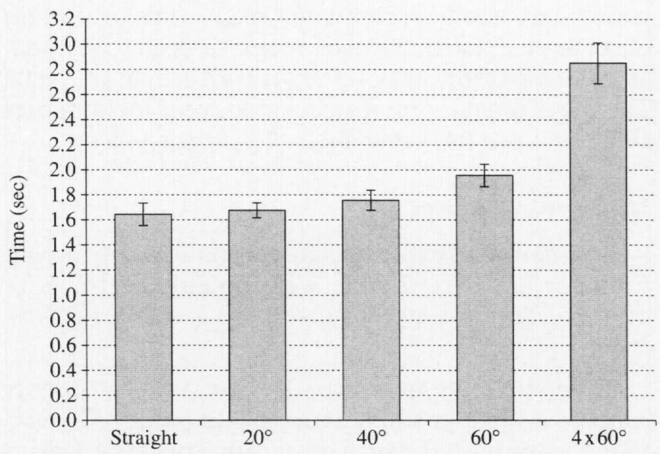

Fig. 3.—Mean times for straight and directional change sprints. The 20°, 40° and 60° values are the mean of left and right scores.

There was also a significant right leg dominance (6.5%, $p<0.05$) as indicated by the drop jump test. Because a significant effort to push laterally to change direction for the 40° and 60° turns was observed, but not for the 20° turn, the left/right turn imbalances in the former tests were averaged. There were 5 subjects who were faster in turning to the left by 3% or more. All of these subjects exhibited a right leg dominance based on the drop jump test, which averaged 13%. When viewed another way, the reactive strength imbalance was greater than 20% for 3 subjects (right leg dominance of 24% on average). These individuals all turned faster to the left, with the mean performance being 4% better than the turn to the right.

TABLE II.—*Correlations between bilateral leg muscle power and sprint tests.*

Tests	Concentric power	Reactive strength
Straight	0.27	-0.55*
Single change 20° to left	0.38	-0.50
Single change 20° to right	0.10	-0.65*
Single change 40° to left	0.33	-0.40
Single change 40° to right	0.54*	-0.53*
Single change 60° to left	0.30	-0.31
Single change 60° to right	0.46	-0.35
Four changes 60°	0.29	-0.54*

* $p<0.05$.

TABLE III.—*Correlations between unilateral leg muscle power and sprint tests.*

Tests	Concentric power		Reactive strength	
	Left	Right	Left	Right
Straight	-0.33	-0.07	-0.45	-0.61*
Single change 20° to left	-0.22	0.10	-0.29	-0.51
Single change 20° to right	-0.45	-0.24	-0.50	-0.71*
Single change 40° to left	-0.15	0.06	-0.29	-0.51
Single change 40° to right	-0.18	0.10	-0.28	-0.44
Single change 60° to left	0.07	0.26	-0.23	-0.46
Single change 60° to right	-0.19	0.07	-0.39	-0.43
Four changes 60°	-0.22	0.04	-0.54*	-0.59*

* $p<0.05$.

Discussion and conclusions

The mean times taken to complete the various sprint tasks indicated that as the change in direction increased from the straight sprint by 20° to 40° to 60°, the times to cover 8 m increased (Table I). When 4 rather than one 60° changes of direction were produced, the time was increased further by 45%. These results are likely to be due to the time lost decelerating and re-accelerating and producing lateral force to the ground to change direction. While running technique was not specifically analysed, it appeared that the subjects only made minor adjustments to their straight running movements for the 20° turn which resulted in only a 1.8% increase in 8 m time, but more obvious alterations to manoeuvre around the 40° and 60° turns.

The bilateral tests of muscle power were moderately correlated to the sprint tests (Table II). For concentric leg extension power, all the coefficients were in the positive direction, indicating that the more powerful subjects produced the slower times. While this was surprising, the relationships were generally nonsignificant. It was expected that the straight sprint would be significantly related to concentric power since this has been previously shown with relatively long sprints.[15-17] However since these studies used different methods for assessing concentric power, this may indicate that power expressed in an isokinetic squat over a 100° range of motion of the knee has little relevance to short sprinting.

In contrast to the concentric power test, reactive strength was significantly and negatively related to the straight sprint and some of the change-of-direction tests, indicating some relevance of this form of muscle power to the sprint tests. Some characteristics common to the sprints and the drop jump test that might explain these results were a relatively small leg extension range of motion, relatively short contact times and a muscle power involving stretch-shortening cycle actions. These results are consistent with previous research [12] which reported a low and non-significant correlation between an agility test with vertical jumping, but a higher and significant correlation with a drop jump test involving greater eccentric loading.

None of the unilateral concentric tests of leg power correlated significantly with any of the sprint tests (Table III). This further suggests the irrelevance of this test for the sprint tasks. As with the bilateral tests, some of the correlations between unilateral reactive strength and speed in changing direction were statistically significant. However even the highest correlation indicated a shared variance of only 50%, indicating other factors besides muscle power (Fig. 1) are likely to contribute to change-of-direction speed. Perhaps this should be expected given that many of the running strides that were performed over the 8 m distance were directed in a straight line to accelerate or decelerate, whereas relatively few strides were performed with a clear lateral push-off action to change direction. It was thought that the correlation coefficients might increase or decrease as the sharpness of the change of direction increased. There was a tendency for the correlations to diminish from sprint tests 2 through to 7, but the relationships tended to increase for the test 8 involving 4 changes of direction. Therefore the role of muscle qualities as a function of change of direction complexity was unclear. It is possible that the strategies used by individuals to sprint around the markers varied, which might partly explain the inconsistent correlations. A biomechanical examination of running patterns during turning should be conducted in future research.

If leg muscle power was important for change-of-direction speed, it would be expected that the "outside" leg would exert more influence than the "inside" leg in a turning movement if that movement required a clear lateral push-off action. Therefore it would be expected that the correlation for the right leg would be greater than the left leg muscle power with a turn to the left, and *viceversa*. The results indicate that for the single changes of direction, the right leg reactive strength correlated more strongly than the left leg with performance in turning to the left. However the reverse was not true; that is, left leg reactive strength did not correlate more strongly than the right leg with performance in turning to the right. It is possible that this discrepancy could be due to the finding that the majority of the subjects performed better in turning to the left and there was a statistically significant right leg dominance in reactive strength (observed in 13 of the 15 subjects). It may be that muscle power (reactive strength) only exerted some influence from the dominant right leg in turning to the left. The right leg dominance may have also contributed to the significant relationship between right leg reactive strength and straight sprint performance. This explanation is speculative and the above evidence for the role of leg muscle power in performance in changing direction is equivocal.

Perhaps the most compelling evidence in favour of the contribution of muscle power to change-of-direction performance was the finding that the 5 individuals who demonstrated at least a 3% advantage in turning to one side (left), all had a reactive strength dominance in the "outside" (right) leg, averaging 13%. Further, 3 participants demonstrated a relatively high reactive strength imbalance (right leg at least 20% better than left), which was associated with a 4% greater performance in turning to the left. It is therefore possible that the role of leg muscle power is significant only when imbalances are apparent.

The reason for an individual possessing a turning imbalance or a reactive strength dominance in one leg is not clear. It is possible that a dominance in one leg causes a superior turning performance to the opposite side. However it is also possible that an individual who develops a preference to turn to one side might, with repetition of this movement, develop a muscle imbalance. Whatever the causal relationships, such turning or muscle imbalances may be viewed as undesirable for a athlete who may enhance on-field performance by being equally proficient in turning to both sides.

In summary, the results of the present study indicate that concentric leg extension power was not significantly related to performance in change-of-direction sprints over 8 m. However there were some moderate and significant relationships between leg reactive strength and change-of-direction performance, most likely due to the similarity in the push-off mechanism used to change direction. There was some association between turning speed to one side and significant leg muscle imbalances.

The findings from this research do not conclusively indicate the relative importance of leg muscle power for change-of-direction speed, and therefore the value of training designed to increase leg muscle power to enhance agility in sports remains unclear. A longitudinal study designed to observe such training effects is warranted. Plyometric training methods that target reactive strength particularly with lateral movements that are biomechanically similar to a specific sport, and resistance training aimed at reducing muscle imbalances would seem worthy of experimentation. A holistic approach to the development of agility that considers all the muscle strength qualities, technique, and perceptual factors related to performance (Fig. 1) would be expected to be fruitful.

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