Relationship Between Strength, Power, Speed, and Change of Direction Performance of Female Softball Players

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Abstract

Nimphius, S, McGuigan, MR, and Newton, RU. Relationship between strength, power, speed and change of direction performance of female softball players. *J Strength Cond Res* 24(4): 885–895, 2010—The purpose of this study was to investigate (a) the cross-sectional relationship of strength, power, and performance variables in trained female athletes and (b) determine if the relationship between these variables changes over the course of a season. Ten female softball players (age = 18.1 ± 1.6 years, height = 166.5 ± 8.9 cm, and weight = 72.4 ± 10.8 kg) from a state Australian Institute of Sport softball team were tested for maximal lower body strength (one repetition maximum [1RM]), peak force (PF), peak velocity (PV), and peak power (PP) during jump squats unloaded and loaded, unloaded countermovement vertical jump height (VJH) 1 base and 2 base sprint performance and change of direction performance on dominant and nondominant sides. The testing sessions occurred pre, mid, and post a 20-week training period. Relationship between body weight (BW), relative strength (1RM/BW), VJH, relative PP, relative PF, PV, speed, and change of direction variables were assessed by Pearson product–moment correlation coefficient at each testing session. Significant relationships were found across all time points with BW, speed, and change of direction measures ($r = 0.70$–0.93) and relative strength and measures of speed and change of direction ability ($r = -0.73 - 0.85$). There were no significant relationships between VJH and any measure of performance at any time point. In conclusion, BW and relative strength have strong to very strong correlations with speed and change of direction ability, and these correlations remain consistent over the course of the season. However, it seems as if many relationships vary with time, and their relationships should therefore be investigated longitudinally to better determine if these cross-sectional relationships truly reflect a deterministic relationship.

Key Words fastpitch, women, agility, correlation, relative strength

Introduction

The emphasis of most strength and conditioning programs is to improve strength, power, speed, and change of direction ability in athletes. Most coaches and sport scientists prescribe programs to improve muscular strength and power in an effort to translate these improvements into decreases in sprint and change of direction times. Strong correlations between measures of strength and speed have been shown in previous research (2,19,29,30). Further, relationships between measures of strength and change of direction performance have also been demonstrated (20,28). However, many studies have also shown that measures of strength, speed, and change of direction are not significantly correlated (2,4,24). The difficulty in finding a consensus on whether relationships exist between strength, power, and performance is a result of a number of factors.

The relationship between measures of strength, power, and performance assessed by performing a correlation only demonstrates a cross-sectional relationship that is often wrongly interpreted as causation. Therefore, to determine if a relationship is causative, one must investigate changes longitudinally (5). Secondly, the level of correlation between 2 variables will change based on a number of factors, such as training age, level of athlete, gender, and time in the training season that could explain why many studies have found differing results when comparing the level of relationship between strength, power, and performance (2,4,8,28). There is very limited research in the area of strength, speed, and change of direction ability longitudinally in female athletes (5). Further, of the research available, it seems the relationship between strength, power, speed, and change of direction performance in trained female athletes is different when

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compared with trained male athletes (8). Therefore, the purpose of this study was to investigate (a) the cross-sectional relationship of strength, power, and performance variables in trained female athletes and (b) determine if the correlation of these variables changes over the course of a season.

Methods

Experimental Approach to the Problem

To investigate the relationship between strength, power, speed, and change of direction in female softball players, athletes were assessed on multiple criterion measures. Further, to investigate if the relationship between strength, power, and performance variables varies over time, athletes were measured at 3 different points (pre, mid, and post), their preseason and in-season training period lasting 20 weeks.

Subjects

Ten female softball players (age = 18.1 ± 1.6 years, height = 166.48 ± 8.9 cm, and weight = 72.43 ± 10.82 kg) from a state Australian Institute of Sport softball team were recruited for this study. All subjects had been involved in supervised resistance training and softball-specific training at the institute of sport level for at least 1 year before participation in the study. The skill level of players selected for an institute of sport program would be considered high because it forms the pool where players are selected for the national softball team. All participants received an information sheet explaining the nature of the study, including the potential risks, and benefits of participation. The study was approved by the institutional ethics committee, and written consent was obtained from each participant before commencement of testing.

Maximal Strength Testing

Maximal lower body strength was assessed by a 3 repetition maximum (3RM) free-weight back squat as required by testing guidelines for athletes at the institute of sport. The 3RM protocol was modified from a similar 1RM protocol (16). Subjects performed a number of warm-up trials at percentages of approximately 30, 50, and 90% of their estimated 3RM, based on previous testing and training records. Subjects then attempted a weight at their estimated 3RM. Upon successful completion of 3 repetitions, the testing ceased, and additional weight was applied. Subjects were allowed adequate rest (3–5 minutes) between subsequent 3RM attempts until a weight was reached where failure occurred on the fourth repetition. A repetition was deemed successful only if the subject lowered the bar to an elastic cord at a height that equated to a horizontal thigh position. The 1RM was estimated using a prediction equation by Mayhew et al. (15). All data are presented relative to body weight (BW); therefore, relative maximal strength (1RM/BW) was calculated as estimated 1RM divided by BW.

Jump Squat Testing

Subjects performed several practice jumps during the general preparation period for familiarization before the pretraining session and were previously familiar with jump squats from training programs of previous years. Subjects performed all jump squats (JS) while standing on a force plate (400 Series Performance Plate; Fitness Technologies, Adelaide, South Australia, Australia) and holding either a fiberglass pole (for body mass jumps) or the bar (24.5 kg) of a standard Smith Machine with a position transducer (PT9510; Celesco, Canoga Park, CA, USA) attached. Data were sampled at 200 Hz, and force and displacement measures were interfaced with computer software (Ballistic Measurement System; Fitness Technology) for calculation of peak force (PF), peak velocity (PV), and peak power (PP) (7). Two jumps were performed at the following loads: body mass (JS_{BM}), BM + Bar (24.5 kg) (JS_{Bar}), BM + 40% of 1RM (JS_{40}), BM + 60% of 1RM (JS_{60}), and BM + 80% of 1RM (JS_{80}). Vertical jump height (VJH) was also assessed during the JS_{BM}. Subjects were instructed to lower to a self-selected depth and accelerate as rapidly as possible with the intent of jumping for maximal height during all loads. One-minute rest was provided between jumps and 5–7 minutes of rest between loads. The test–retest reliability of JS_{BM} has been previously reported in a similar population in our laboratory: intraclass correlation coefficient (ICC) ≥ 0.96 and CV < 3% (18). Further, the loaded jump squat (JS_{bar}, JS_{40}, JS_{60}, and JS_{80}) reliability for PF (ICC: 0.88–0.98; coefficient of variation (CV): 1.2–2.8%), PV (ICC: 0.87–0.94; CV: 2.7–4.0%), and PP (ICC: 0.93–0.98; CV: 2.1–3.9%) measures were calculated using previously described methods (10).

Sprint and Change of Direction Testing

All speed and change of direction times were measured using dual beam timing lights (Swift Performance, Lismore, Australia) to an accuracy of 1/100 th of a second. Sprint performances over the distances of a sprint to first base (1B, 17.9 m),

Table 1. Correlation between BW and performance variables during pre, mid, and posttesting.*

	Relationship to BW		
	Pre	Mid	Post
VJH	−0.53	−0.57	−0.32
1RM/BW	−0.83†	−0.89†	−0.83‡
505 ND	0.93†	0.74‡	0.82†
505 D	0.71‡	0.71‡	0.70‡
1B split 10 m	0.83†	0.93†	0.73‡
1B sprint	0.89†	0.90†	0.82‡
2B sprint	0.86†	0.78‡	0.80‡

*VJH = vertical jump height; 1RM = 1 repetition maximum; BW = body weight; ND = nondominant; D = dominant; 1B = first base; and 2B = second base.
†Correlation is significant ($p < 0.01$) (2-tailed).
‡Correlation is significant ($p < 0.05$) (2-tailed).

TABLE 2. Correlation between VJH and performance variables during pre, mid, and posttesting.*

	Relationship to VJH		
	Pre	Mid	Post
1RM/BW	0.36	0.38	0.16
505 ND	−0.23	−0.45	−0.30
505 D	−0.35	−0.31	−0.48
1B split 10 m	−0.36	−0.58	−0.21
1B sprint	−0.25	−0.36	−0.27
2B sprint	−0.23	−0.48	−0.25

*1RM = 1 repetition maximum; BW = body weight; ND = nondominant; D = dominant; 1B = first base; 2B = second base; VJH = vertical jump height. There were no significant correlations.

including a split time at 10 m and during a sprint to second base (2B, 35.8 m), were assessed on the field as a performance measure for softball players, similar to that for baseball players (17). After a 5-minute warm-up jog followed by stretching and submaximal warm-up sprints, participants performed 2 sprints for maximum effort at each distance. The best time was recorded for each. Subjects began in a stationary split-stance position, 30 cm behind home plate in the right side batters' box. Timing began when the athlete crossed the infrared beam setup at home plate and stopped when the athlete crossed the infrared lights at the 10-m split, first, or second base. No provisions were made for athletes who normally bat from the left side of the box.

Change of direction performance was assessed by the 505 agility test on a grass surface outdoors (6). All subjects began the test 30 cm behind the first set of timing lights in

TABLE 3. Correlation between relative maximal strength and performance variables during pre, mid, and posttesting.*

	Relationship to relative maximal strength (1RM/BW)		
	Pre	Mid	Post
505 ND	−0.75†	−0.73†	−0.85†
505 D	−0.50	−0.75†	−0.60
1B split 10 m	−0.87‡	−0.85‡	−0.75†
1B sprint	−0.84‡	−0.84‡	−0.80†
2B sprint	−0.84‡	−0.79†	−0.83†

*ND = nondominant; D = dominant; 1B = first base; 2B = second base.
†Correlation is significant ($p < 0.05$) (2-tailed).
‡Correlation is significant ($p < 0.01$) (2-tailed)

TABLE 4. Correlation between speed and change of direction performance during pre, mid, and posttesting.*

	Pre					Mid					Post				
	505 ND	505 D	1B split 10 m	1B sprint	2B sprint	505 ND	505 D	1B split 10 m	1B sprint	2B sprint	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
505 ND	1.00					1.00					1.00				
505 D	0.73†	1.00				0.89‡	1.00				0.66	1.00			
1B split 10 m	0.76†	0.55	1.00			0.76†	0.81‡	1.00			0.96‡	0.53	1.00		
1B sprint	0.86‡	0.66	0.96‡	1.00		0.76†	0.88‡	0.92‡	1.00		0.96‡	0.55	0.98‡	1.00	
2B Sprint	0.87‡	0.58	0.93‡	0.98‡	1.00	0.89‡	0.94‡	0.90‡	0.88‡	1.00	0.99‡	0.59	0.98‡	0.98‡	1.00

*ND = nondominant; D = dominant; 1B = first base; and 2B = second base.
†Correlation is significant ($p < 0.05$) (2-tailed).
‡Correlation is significant ($p < 0.01$) (2-tailed).

TABLE 5. Correlation between relative peak force and performance variables during pre, mid, and posttesting.*

	Pre							Mid						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} Rel PF	0.21	0.741†	−0.64	−0.33	−0.58	−0.61	−0.63	−0.06	0.70†	−0.57	−0.74†	−0.58	−0.83‡	−0.66
JS_{Bar} Rel PF	0.42	0.80‡	−0.87‡	−0.46	−0.78†	−0.83‡	−0.88‡	0.49	0.79†	−0.83‡	−0.88‡	−0.80‡	−0.88‡	−0.86‡
JS_{40} Rel PF	0.32	0.92‡	−0.85‡	−0.60	−0.79†	−0.84‡	−0.88‡	0.18	0.79†	−0.66	−0.73†	−0.71†	−0.88‡	−0.74†
JS_{60} Rel PF	0.44	0.95‡	−0.79†	−0.58	−0.89‡	−0.88‡	−0.89‡	0.21	0.87‡	−0.83‡	−0.90‡	−0.82‡	−0.94‡	−0.88‡
JS_{80} Rel PF	0.44	0.92‡	−0.88‡	−0.66	−0.82‡	−0.86‡	−0.89‡	0.68†	0.89†	−0.60	−0.64	−0.82‡	−0.75†	−0.734†

	Post						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} Rel PF	0.48	0.68	−0.39	−0.56	−0.44	−0.55	−0.40
JS_{Bar} Rel PF	0.47	0.85‡	−0.69	−0.74	−0.60	−0.71	−0.63
JS_{40} Rel PF	0.43	0.88‡	−0.79†	−0.84†	−0.68	−0.76†	−0.74
JS_{60} Rel PF	0.34	0.89‡	−0.85†	−0.84†	−0.77†	−0.85†	−0.81†
JS_{80} Rel PF	0.35	0.92‡	−0.82†	−0.79†	−0.73	−0.82†	−0.79†

*JS = jump squat; Rel PF = relative peak force; VJH = vertical jump height; 1RM = one repetition maximum; BW = body weight; ND = nondominant; D = dominant; 1B = first base; 2B = second base.

†Correlation is significant ($p < 0.05$) (2-tailed).

‡Correlation is significant ($p < 0.01$) (2-tailed).

Table 6. Correlation between relative PP and performance variables during pre, mid, and posttesting.*

	Pre							Mid						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} Rel PP	0.12	0.67†	−0.33	−0.14	−0.49	−0.44	−0.47	0.61	0.88‡	−0.66	−0.73†	−0.77†	−0.76†	−0.79†
JS_{Bar} Rel PP	0.09	0.56	−0.56	−0.49	−0.44	−0.56	−0.62	0.43	0.79†	−0.72†	−0.90‡	−0.90‡	−0.97‡	−0.89‡
JS_{40} Rel PP	0.20	0.58	−0.59	−0.53	−0.48	−0.59	−0.668†	0.42	0.84‡	−0.76†	−0.89‡	−0.90‡	−0.97‡	−0.92‡
JS_{60} Rel PP	0.18	0.50	−0.39	−0.48	−0.34	−0.43	−0.50	0.46	0.83‡	−0.68†	−0.85‡	−0.91‡	−0.92‡	−0.91‡
JS_{80} Rel PP	0.20	0.41	−0.49	−0.54	−0.34	−0.49	−0.57	0.47	0.82‡	−0.75†	−0.88‡	−0.96‡	−0.97‡	−0.92‡

	Post						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} Rel PP	0.64†	0.70†	−0.41	−0.56	−0.47	−0.50	−0.40
JS_{Bar} Rel PP	0.34	0.86‡	−0.76†	−0.61	−0.73	−0.80†	−0.76†
JS_{40} Rel PP	0.29	0.81†	−0.83†	−0.74	−0.81†	−0.88‡	−0.84†
JS_{60} Rel PP	0.23	0.79†	−0.85†	−0.72	−0.86†	−0.91‡	−0.84†
JS_{80} Rel PP	0.17	0.74†	−0.76†	−0.68	−0.76†	−0.83†	−0.78†

*JS = jump squat; Rel PP = relative peak power; VJH = vertical jump height; 1RM = one repetition maximum; BW = body weight; ND = nondominant; D = dominant; 1B = first base; B = second base.

†Correlation is significant ($p < 0.05$) (2-tailed).

‡Correlation is significant ($p < 0.01$) (2-tailed).

Table 7. Correlation between PV and performance variables during pre, mid, and posttesting.*

	Pre							Mid						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} PV	0.24	0.53	−0.27	−0.29	−0.37	−0.35	−0.39	0.75†	0.34	−0.06	−0.08	−0.40	−0.12	−0.28
JS_{Bar} PV	0.05	0.13	0.36	0.27	−0.06	0.01	−0.05	0.07	0.42	−0.26	−0.61	−0.63	−0.71†	−0.57
JS_{40} PV	−0.08	−0.03	−0.12	−0.26	0.11	−0.03	−0.11	0.32	0.52	−0.54	−0.80‡	−0.79†	−0.82‡	−0.79†
JS_{60} PV	−0.27	−0.34	0.25	−0.04	0.43	0.31	0.24	0.20	0.39	−0.30	−0.62	−0.62	−0.68†	−0.62
JS_{80} PV	−0.30	−0.46	0.19	−0.02	0.38	0.23	0.16	0.23	0.32	−0.38	−0.66	−0.65	−0.74†	−0.60

	Post						
	VJH	1RM/BW	505 ND	505 D	1B split 10 m	1B sprint	2B sprint
JS_{BM} PV	0.47	0.36	0.14	−0.43	0.26	0.29	0.21
JS_{Bar} PV	0.45	0.57	−0.52	−0.51	−0.53	−0.53	−0.51
JS_{40} PV	0.19	−0.10	−0.16	−0.15	−0.26	−0.26	−0.19
JS_{60} PV	0.21	−0.13	−0.28	−0.31	−0.40	−0.38	−0.29
JS_{80} PV	0.04	−0.22	−0.20	−0.33	−0.31	−0.31	−0.23

*JS = jump squat; PV = peak velocity; VJH = vertical jump height; 1RM = 1 repetition maximum; BW = body weight; ND = nondominant; D = dominant; 1B = first base; 2B = second base.

†Correlation is significant ($p < 0.05$) (2-tailed).

‡Correlation is significant ($p < 0.01$) (2-tailed).

a stationary split-stance position. The second set of timing lights was at the 10-m mark, and a set of cones was set 15 m from the start position. Subjects were instructed to sprint to the cones, placing either their right or left foot on the line, pivot and sprint through the finish (timing lights at the 10-m mark). The time from the 10-m gate to the 15-m cones and back to the 10-m gate was recorded for the 505 agility time for either a left or right pivot. Two trials were completed for each pivot foot and the best of each used for analysis. Data are presented as dominant (D) or nondominant (ND) side, based upon batting stance where right hand batters would be right-foot dominant and left foot batters left-foot dominant. The test–retest reliability of 505 agility measures was: ICC $\geq$ 0.93, CV $\geq$ 1.9%, showing high reliability with specified plant-foot instructions.

Statistical Analyses

SPSS Version 16.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Data were log-transformed and the relationship between all variables was assessed by Pearson product–moment correlation coefficient. Magnitude of effect for the correlations was based on the following scale. trivial: $<$0.10, small: $\leq$0.10–0.29, moderate: 0.30–0.49, large: 0.50–0.69, very large: 0.70–0.89, and nearly perfect: $\geq$0.90 (11). An α level of $p \leq 0.05$ was used as the criterion for statistical significance.

Results

The correlation between BW, 1RM/BW, VJH, speed, and change of direction during pre, mid, and posttesting sessions are shown in Tables 1–3, respectively. Significant relationships explaining at least 50% of the variance between variables were found across all time points between BW, speed, and change of direction measures (r = 0.70–0.93). Similarly, relative strength and measures of speed and change of direction ability of the ND side were very strongly correlated ($r = -0.73$ to -0.85) across all time points. There were no significant relationships between VJH and any measure of performance at any time point.

The relationship between speed and change of direction performance during pre, mid, and posttesting sessions are presented in Table 4. All variables except for 505 D were very strongly and significantly correlated (r = 0.73–0.98) with each other at all time points. Only during midtesting did 505 D performance significantly and very strongly correlate with measures of speed (r = 0.81–0.94).

The relationships between relative PF, relative PP, and PV and performance variables during pre, mid, and posttesting sessions are displayed in Tables 5–7, respectively. There were very strong relationships between relative PF at all loads and relative strength at all time points (r = 0.70–0.95) except during JS_{BM} post, which still displayed a strong and nearly significant relationship ($r = 0.69$; $p = 0.06$). All loaded relative PF values at pre and midtesting correlated very strongly and significantly with all speed measures ($r = -0.71$ to -0.94). However, these very strong correlations decreased by the post time point, where only the JS_{60} and JS_{80} relative PF values correlated significantly with all speed measures ($r = -0.73$ to -0.85). Relative PF at all loads greater than BM, correlated very strongly and significantly with 505 ND performance for all time points ($r = -0.79$ to -0.92); however, the relationship with 505 D performance was varied and only significant at some loads at mid and posttesting ($r = -0.46$ to -0.90).

Relative PP and relative strength for all loads at mid and post–time points were very strongly and significantly correlated (r = 0.70–0.88). However, relative PP and relative strength was only significant and strongly correlated for JS_{bm} during pretesting ($r = 0.67$; $p = 0.03$). Relative PP at all loads was significant and very strongly correlated to all speed measures at midtesting ($r = -0.76$ to -0.97) and showed a very strong relationship with relative PP at all loads greater than JS_{BM} at posttesting ($r = -0.73$ to -0.91). Relative PP for loads greater than JS_{BM} also showed strong to very strong relationships with both 505 D and 505 ND performance ($r = -0.61$ to -0.90). Relative PV was not significantly or very strongly correlated with any performance measures at any loads during the pre and posttesting sessions. During midtesting, relative PV at JS_{BM} was significantly correlated with VJH, and loads above JS_{BM} were not always significant but strongly to very strongly correlated with speed performance ($r = -0.57$ to -0.79).

Discussion

The primary findings of this study are that (a) BW and relative strength have strong to very strong correlations with speed and change of direction ability, and these correlations remain consistent over the course of the season and (b) some relationships vary with time and should be investigated over longer time periods to better determine if these cross-sectional relationships actually reflect a deterministic relationship. Further, it appears the strength of these relationships differ from previously reported relationships in male athletes. This study provides evidence that cross-sectional relationships between variables should be evaluated cautiously. Changes in strength of the relationship of performance variables over time indicates that one measure may change, whereas another remains stagnant or even changes at a different rate, therefore, affecting the strength of correlation. This reinforces that cross-sectional correlations do not represent causation for the performance. If the 2 variables were directly linear in their relationship and actually causative, cross-sectional correlations would remain constant over time as the 2 variables would have a similar relative rate of change.

The sample size of this study was small (n = 10), and therefore, relationships may have reached significance with larger numbers because of increased power. The inherent nature of following a team at an institute of sport level limits subject numbers, and this should be taken into consideration for the importance of the information and the limitations of the results. Additionally, the findings of this research is limited to the small population of female softball players with similar training experience, but the unique results of this study highlights the importance of investigating groups with limited research in the literature.

There were very strong and significant negative correlations between BW and relative strength ($r = -0.83$ to -0.89) but only nonsignificant negative correlations to VJH ($r = -0.32$ to -0.57) at pre, mid, and posttesting (Table 1). Further, there were also strong to very strong positive correlations between BW and change of direction and speed times at pre, mid, and posttesting ($r = 0.70$–0.93) (Table 1). The level of correlation varied only slightly from pre, mid to post values. However, at the post measurement, only BW and 505 ND performances were correlated to a significance level of $p < 0.01$, but all measures other than VJH were still significant to a level of $p < 0.05$. The strongest relationships seem to occur at midtesting (Table 1). Although the strength of the relationship between BW varies during the season, it can still be concluded that the smaller-sized athletes excel in the variables of speed, change of direction, and relative strength. However, this should not be interpreted as smaller-sized athletes will perform better in the sport of softball.

It is important to note that the nature of softball causes many athletes to be selected for speed and change of direction ability, whereas others rely on maximal hitting power for their performance, which is positively correlated to lean body mass (26). Therefore, athletes of higher body mass are often termed "power hitters" and do not rely on maximal speed to increase their on-base percentage or contribution to the game. Therefore, even in a highly trained squad, a strong correlation may exist between BW, speed, and change of direction performance, but this correlation should be fully examined with other performance characteristics, such as throwing velocity, bat velocity, and batted ball velocity before drawing conclusions on the importance of having lower BW in these athletes.

Several studies have found significant relationships between VJH and a measure of sprint performance in male and female athletes (4,8,28–30). However, similar to Maulder et al. (14), this study did not result in significant correlations between VJH and any measure of running speed at any point in the season, nor did any correlation reach a level deemed very large and could explain at least 50% of the variance in the 2 measures (Table 2). There are 3 major justifications for the difference in the findings of this investigation. First, VJ performance in softball players does not comprise a significant part of their game or skill practice, especially when VJ performance is measured without the use of an arm action. Yet, in many sports, jumping is a more common aspect of performance or training. For example, track and field athletes regularly perform lower body plyometric exercises, and soccer athletes regularly jump to head the ball. Therefore, a strong correlation between VJ performance (even without the use of an arm swing) and sprint speed in these athletes may be because of a trained ability in the VJ. Further, a transfer of learning may occur in their ballistic leg-performance during running (8,28,29). However, Maulder and colleagues did not find a significant correlation ($r = -0.13$) between 10-m sprint performance in male track athletes and countermovement jump height (without the use of an arm swing). Therefore, when considering the relationship between VJ performance and sprint performance, one must consider the influence of the type of VJ performed (arm swing or no arm swing) and the effect of transfer of learning opportunities during training for the athletes. Second, level (high school vs. collegiate) of the athletes may result in varying degrees of correlation between VJ and sprint speed. Previous studies involving female athletes investigated high school and college-age female athletes (8,23,28). The correlation between VJH and measures of sprint performance varied ($r = -0.49$ to -0.64) in high-school track and soccer female athletes and stronger correlations were found ($r = -0.61$ to -0.79) among mixed female collegiate athletes (8,23,28). Vescovi and McGuigan (28) found correlations that explained more than 50% of the variance between countermovement jump height (without the use of arm swing) and sprint speed (18.3, 27.4, and 36.6-m times) in collegiate soccer and lacrosse players; however, the findings of this study did not show correlations near this strength ($r = -0.21$ to -0.58). This variability may also be attributed to the sporting background of the athletes.

Finally, justification for the difference in the findings of this study may be the time in the training cycle at which the testing occurred. This study is the first to our knowledge to track the correlations in strength, power, speed, and change of direction relationships through a competitive season. When observing the relationship between VJ and sprint performance, it is interesting to note that the relationships in this study are low ($r = -0.21$ to -0.36) at the pre and posttesting but are higher during midtesting where improved moderate relationships ($r = -0.36$ to -0.58) occurred. Therefore, the point in a training cycle (off season, midseason, and postseason) may be a confounding factor that can alter the relationship of these 2 or many variables because of factors such as accumulated fatigue or focus for improvement in the macrocycle of training.

In conclusion, one may assume VJH capability is a function of coordination and jump training practice rather than a measure that explains sprint performance in these female softball players. However, VJH measured inclusive of an arm swing during the jump may result in different findings. Young or untrained individuals are probably more homogenous in their athletic abilities; where those who excel in one aspect of athletic performance may excel at most aspects, which may explain the strong correlations in other studies (8,28), while those of a greater training age begin to differentiate their athletic skills. A similar hypothesis may be made about female athletes as well; however, more research is needed to support this hypothesis. In conclusion, it is critical to understand that the cross-sectional relationship between VJH and sprint performance changes with training over time and other measures within the VJ such as PF in the first 100 meters during a jump performance may better explain sprint performance (30).

Countermovement jump height and change of direction performance has not displayed significant correlations or a relationship strong enough to explain more than 50% of the variance in the measures in previous studies (3,24,28). These studies included investigations of female athletes and therefore support the findings of the current research that displayed only small to moderate correlations (−0.229 to −0.484) between VJH and 505 ND, and 505 D change of direction ability (Table 2). Therefore, at any point in the season, it should be deemed that VJH performance and change of direction tests measure separate athletic qualities in female softball athletes.

Relative strength showed significant and more importantly, consistent correlations with sprint speed at pre, mid, and posttesting sessions (Table 3). The correlation between relative 1RM and 10-m split time was significantly correlated at pre (−0.87; $p = 0.002$) and mid (−0.85; $p = 0.01$) testing but displayed a slightly smaller but still significant relationship post (−0.75; $p = 0.05$). As these female athletes became more trained (later in their season), relative strength, although still explaining a majority of the variance in 10-m sprint performance began to slightly decrease its role in 10-m sprint performance. Even with a decreasing correlation between 10-m sprint performance and relative strength, the relationship seems to be far greater than that displayed by well-trained male athletes between relative strength and 10-m performance ($r = -0.39$) (2).

The 10-m sprint performance is often considered a measure of acceleration ability in field sport athletes, and distances beyond 30 m are more a measure of maximal velocity (2,30). The 1B-sprint is still a short distance (17.9 m), mostly dependent upon acceleration ability. Therefore, it is expected that the results of this study show a consistently similar correlation between relative strength and 10-m sprint performance at pre (−0.87; $p = 0.002$), mid (−0.85; $p = 0.004$), and post (−0.75; $p = 0.05$) testing and relative strength and 1B-sprint performance at pre (−0.84; $p = 0.005$), mid (−0.84; $p = 0.004$), and post (−0.80; $p = 0.03$) testing. This indicates that for this group of athletes, relative strength has a very strong relationship to performance at both these distances. Further, the relationship between relative strength and 2B-sprint performance (35.8 m) remained strong and constant throughout the season, displaying significant relationships at pre (−0.84; $p = 0.004$), mid (−0.79; $p = 0.01$), and post (−0.83; $p = 0.02$) measures.

These findings are similar but stronger than the significant relationship found by Baker and Nance (2) between relative strength and 40-m sprint performance ($r = -0.66$; $p < 0.05$). Another study of both trained and nontrained female sprinters revealed a similar relationship as the current study between relative strength and a measure of maximal velocity (100-m sprint time, $r = -0.88$; $p < 0.001$) (19). The 2B sprint in softball does have a minor change of direction component and therefore is specific to the sport, requiring a skill level that modifies the degree to which relative strength may predict performance. This may explain the slightly lower mean correlation over all time points in the current study of female athletes (mean $r = -0.82$) compared with the study by Meckel et al. ($r = -0.88$) (19).

A review by Sheppard and Young came to the conclusion that most research does not find concentric strength to be a strong predictor of change of direction speed (24). However, in research involving mixed gender but untrained subjects, strong and significant relationships have been found between a measure of change of direction ability and both relative and absolute isokinetic squat strength (12,20). A study involving college female volleyball players also failed to find a significant correlation between isokinetic leg extensor PF and change of direction performance ($r = -0.37$) (3). However, in a study of female collegiate athletes from multiple sports, a strong correlation between relative strength and change of direction performance ($r = -0.63$) was found (23). This correlation was much stronger than that displayed by the male collegiate athletes ($r = -0.33$) (23). The ability to accelerate, decelerate, and change direction, as is typically required in a measure of change of direction ability would only logically be more dependent on one's ability to move their body mass. Although absolute strength has been shown to have a relationship with change of direction ability (12), it does not take into account the fact that athletes are only required to produce enough force to accelerate and decelerate their BW. Therefore relative strength should be a stronger indicator of change of direction performance.

In this study, there was a very strong and significant relationship at pre ($r = -0.75$; $p = 0.02$), mid ($r = -0.73$; $p = 0.03$), and post ($r = -0.85$; $p = 0.02$) measures between relative strength and 505 ND performance, showing consistency over time that would indicate these measures have a consistent, longitudinal relationship. However, a strong and significant relationship at the midtesting session between relative strength and 505 D performance ($r = -0.75$; $p = 0.02$) occurred despite a nonsignificant relationship at pre and posttesting between relative strength and 505 D performance (Table 3). This may indicate bilateral strength deficits, common in softball athletes, may impact the relationship between a bilateral test of strength (1RM/BW) and unilateral strength use in change of direction ability (21). A study by Hoffman et al. investigating the effect of a bilateral power deficit on direction-specific movement, found low to moderate and significant correlations between ND leg and performance to both sides (9). The change of direction test involved in the study by Hoffman et al. was relatively complex and longer than a 505 change of direction test (9). This may have allowed for the dominant leg to compensate over time for the lower ND performance. In the future, the ability for a given change of direction test to differentiate between dominant and ND legs should be investigated.

It has been suggested the determinants of first step quickness, acceleration, maximal speed, and change of direction ability are different components of athletic ability (4,13,24). This has been supported by the results of many investigations where the correlation between measures have shown only small to moderate correlations, where less than 50% of the variance can be explained by a variable, indicating they are specific or somewhat independent of one another (27). However, in studies with female subjects, strong to very strong and significant relationships between measures of CODS and straight sprinting performance have been shown (22,28). In research where the change of direction task involves a large component of straight sprinting, it would be expected that relationships would be stronger than when the change of direction task requires more directional changes over shorter distances (24).

In this study, only change of direction ability on the ND side (505 ND) correlated significantly and consistently with measures of speed at pre, mid, and post–time points (Table 4). These athletes displayed significant and strong to very strong correlations (r = 0.88–0.98; $p > 0.01$) between 10-m sprint performance, 1B sprint (17.9 m) performance and 2B sprint (35.8 m). This was similar to the research by Cronin and Hansen (4) where correlations between 5-, 10-, and 30-m sprint performance were significant and very strong (r = 0.73–0.92). The variability of relationship between measures of speed and COD performance on the dominant leg over time indicates another factor may influence this relationship. The very strong to nearly perfect relationship between 2B performance and 505 ND at all time points (r = 0.87–0.99) may be related to 2B base sprinting occurring with a change of direction to the left with an attempted left foot plant on 1B which is the ND foot for most athletes in this sport.

Almost all measures of relative PF (Table 5) at all loads greater than BM correlated strong to very strongly with measures of performance ($r = -0.46$ to -0.89; 0.79–0.95) except VJH (r = 0.18–0.68). However, the level of correlation varied through the season and seemed to decrease slightly during postmeasures. Only relative PF, relative strength, and 505 ND performance maintained a consistent strong to very strong relationship with at all loads greater than BM ($r = -0.66$ to -0.95) over all 3 time periods. Therefore, the relationship of relative PF and performance needs further investigation. It seems that only relative strength and relative PF at all loads are strongly and consistently correlated, but all other performance variables seem to have an inconsistent relationship.

The relationship between relative PP and performance (Table 6) showed a lack of significant relationships between measures at any load and performance measures during pretesting (with the exception of relative PP at JS_{BM} and relative strength and relative PP at JS_{40} and 2B sprint). However, relative PP and relative strength for all loads at mid and post–time points were very strongly and significantly correlated (r = 0.70–0.88). These findings are similar to that of Baker and Nance where strong and significant relationships between relative PP at multiple loads and 40-m sprint performance when testing athletes at their "peak condition" were shown (2). The "peak condition" refers to a time in the middle a training cycle when an athlete would be considered optimal in both their conditioning status and skill ability. Other research has also shown that 2.5- and 5-m sprint performance significantly correlate to loaded jumps relative PP (25,30). Therefore, it can be concluded that relative PP during the JS at loads greater than BM may explain a large amount of variance in both speed performance (r^2 = 0.53–0.94) and change of direction performance (r^2 = 0.37–0.81) but only when athletes are at "peak condition."

As shown in Table 7, PV does not seem to consistently correlate to performance measures through the season. However, during midtesting, relative PV at JS_{BM} was significantly correlated with VJH and loads above JS_{BM} were not always significant but strongly to very strongly correlated with speed performance ($r = -0.57$ to -0.79). The variability between pre, mid, and postmeasures may indicate the training state of the athlete influences the measures of PV during jumping performance and may not be a reliable predictor of performance in these athletes. Therefore, in this investigation, only measures of relative PP (at mid and post) seem to have strong to very strong and consistent relationships to measures of performance. At these time periods, the athletes would be considered in "peak condition" where an athlete has both improved in power capability and has been afforded adequate time to effectively use this power during measures of performance. Relative PF has strong to very strong relationships with relative strength, but the decrease in the strength of its relationship with other measures of performance shows the consistency as a predictor of performance questionable in this population. It may be that relative PP is the best predictor because it is the result of force and velocity with optimal timing. Relative PF and PV may occur at time points not beneficial for maximizing power and hence their measures having greater variability with relationship to performance measures.

The results of this study show that cross-sectional relationships may vary through the season, and therefore, cross-sectional results should be interpreted with caution. Further, this study has demonstrated how these relationships change over time and the need for investigations to monitor changes longitudinally to be able to determine characteristics that are truly determinants of performance. Finally, this research indicates that performance in these trained female softball athletes displays strong to very strong relationships to relative strength of a higher magnitude than those measured in trained male athletes (1). In addition, the level of correlation between different measures of speed (acceleration versus maximal velocity) may be more highly correlated in these female athletes than the correlation found in male athletes (4).

Practical Applications

It is important to understand the limitations of investigating cross-sectional relationships of performance and drawing conclusions about deterministic properties. This investigation provides an insight for the sports scientist and strength and conditioning professional that correlations change because of a number of factors, including time in the season, gender, and level or training age of the athlete. Therefore, when determining if a test is a measure of a certain aspect of athletic performance one must be critical in choice and interpretation of the measure. Determining the appropriate test to evaluate specific athletic qualities should include assessment of whether changes occur simultaneously in two measures, showing their dependent relationship. Additional research in the area of longitudinal changes in strength, power, and performance is necessary to successfully understand causative relationships instead of only determining cross-sectional relationships. Finally, the practical implications of a very strong and consistent correlation between speed and change of direction performance measures and relative strength may indicate that in female athletes, improvements in relative strength may result in significant improvements in speed and change of direction performance longitudinally.

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