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Upper- and lower-limb muscular strength as correlates of overhead serve accuracy in male club volleyball players

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ABSTRACT

Overhead serving is a decisive skill in modern volleyball. But the physical qualities behind serving accuracy at developmental club level haven't been fully measured. This study looked at how upper-limb (arm) strength, lower-limb (leg) strength, and serving accuracy are related in male club volleyball players. We also estimated how much of the variance in serve accuracy those strength qualities explain. Using a quantitative correlational design, we recruited 15 male athletes from the Surgana Volleyball Club in Padang, Indonesia, out of a population of 18, through purposive sampling. Arm strength was tested with a one-minute push-up test, leg strength with a back-and-leg dynamometer, and serving accuracy via a validated ten-trial overhead-serve target test. Data were checked for normality using the Lilliefors test and analyzed with Pearson product-moment and multiple correlation, with the coefficient of determination expressing explained variance (α =.05). All variables were normally distributed. Arm strength (M = 35.40, SD = 11.13) and leg strength (M = 137.00 kg, SD = 31.31) each had a strong, significant link with serve accuracy (M = 27.33, SD = 4.20): r =.887, p <.001 (r^2 = 78.7%) and r =.881, p <.001 (r^2 = 77.6%), respectively. The combined model explained 78.7% of the variance. These findings indicate that whole-body maximal strength is a primary correlate of serving accuracy and support integrated, kinetic-chain-oriented strength programming rather than isolated upper-limb training for developing servers. Coaches should monitor and develop both segments concurrently while cultivating technique and neuromuscular control.

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Introduction

Volleyball has become one of the most popular team sports around the world, and the rally-point system has pushed players to meet higher physical and technical standards than ever before. Modern match analysis shows that points are often decided in the first few contacts of a rally. That means the actions that start each rally, especially the serve, carry a lot of weight. In this context, the serve has changed from just a way to start play into a real offensive weapon. A good serve can disrupt the opponent's reception, mess up the setter's options, and even score points directly. So understanding what makes a serve effective is really important for coaches who want to find small improvements at any level of the game.

Out of the different serving styles, the overhead serve (also called the tennis serve or float serve) is the most commonly taught and used. It gives you control over the ball's flight while still allowing power and placement.

When done well, an overhead serve lets you aim at specific reception spots, target weak passers, and control the pace of the rally. But the value of a serve isn't just about speed. A hard serve that lands out gives the opponent a point immediately. That's why serving accuracy, putting the ball exactly where you want it, matters so much. It balances risk and reward, and it's the main outcome we looked at in this study.

The overhead serve is a ballistic, whole-body movement. Its quality depends on how well you produce and transfer force through different body segments in sequence. From a strength and conditioning point of view, two segment qualities are key. Upper-limb (arm and shoulder) strength controls the final part of the motion, where the hitting arm accelerates toward the ball and delivers the impulse that decides speed and direction at contact. If your arm isn't strong enough, you can't produce a stable, well-timed hit. That increases trial-to-trial variation and hurts your placement. Past research has consistently linked upper-limb strength to serving and hitting performance in volleyball and other overhead sports.

Lower-limb (leg) strength is just as important, but people often overlook it because it kicks in earlier in the movement. In the overhead serve, the legs start producing force through ground reaction, stabilize your base, and set the posture that lets your trunk and arm accelerate later. So leg strength acts as the engine of the movement and a key factor in dynamic balance during the hit. If this link is weak, it limits both the force available for transfer and your ability to keep the stable platform you need for accurate serving.

These segment roles come together in the kinetic-chain model of overhead skills. According to this idea, effective hitting comes from a sequential, proximal-to-distal buildup of force: energy from the lower limbs and trunk moves through the shoulder to the hitting hand, so the last segment benefits from the momentum built up earlier. Biomechanical studies of serving and throwing consistently show that any disruption along this chain, weak proximal links, bad timing, or poor stabilization, carries over to the end and hurts accuracy and consistency. So the kinetic chain predicts that both arm and leg strength should relate to serving accuracy, and that they might work together rather than separately.

Research from around the world largely supports these ideas. Studies that look at volleyball and other overhead sports have found moderate to strong links between arm strength and how accurate or effective serves, spikes, and throws are. Another set of studies connects lower-limb and hip strength to serving and jumping performance. When researchers combine strength measures, they often find that overall strength profiles explain a big chunk of the variation in skilled outcomes. Still, how strong these relationships are changes a lot from one sample to another, depending on competition level, sex, how strength was measured, and which serve variant they studied.

Even with all this evidence, some gaps remain. First, most of the existing research looks at arm strength and serving by itself. There's not much work that measures the combined, contribution of both upper- and lower-limb strength to serving accuracy in the same group of players. Second, the possibility that these two strength qualities are strongly connected, so their combined effect isn't just additive, has rarely been looked at directly. But this has real consequences for how strength training should be planned. That's the empirical gap this study addresses.

There's also a theoretical gap. Even though the kinetic-chain model is widely used, correlational field studies don't often interpret their findings through it in a way that tells apart truly independent segment contributions from a shared, whole-body strength capacity. Treating arm and leg strength as interchangeable signs of a general quality versus as separate factors leads to very different training advice. Figuring out which interpretation the data supports is a conceptual contribution that goes beyond just reporting numbers. Finally, there's a practical gap at the developmental club level, especially in less-studied settings like Indonesian community volleyball clubs. Coaches in these places make daily decisions about how to split limited training time between technical practice and physical preparation. But they have very little context-specific evidence about which strength qualities most closely relate to serving accuracy in their athletes. Evidence generated in and for these settings is directly useful.

The novelty of this study is that it looks at upper- and lower-limb strength together as correlates of overhead-serve accuracy in a specific group of male club players, using the kinetic-chain idea as a guide. It also explicitly deals with how the two strength qualities relate to each other when estimating how much they explain together. Instead of just adding another isolated correlation to the literature, it tries to show how these qualities work together and what that means for training design. So the study had three goals: 1) find the relationship between arm strength and overhead-serve accuracy; 2) find the relationship between leg strength and overhead-serve accuracy; and 3) find the combined relationship of arm and leg strength with overhead-serve accuracy, and how much of the variation in accuracy these two strength qualities jointly explain. Our hypotheses covered both individual and combined strength, H_1 predicted a significant positive link between arm-muscle strength and serve accuracy, H_2 made the same prediction for leg-muscle strength, and H_3 predicted both together would also be significantly and positively associated.

Method

Research design

Researchers adopted a quantitative correlational design, specifically explanatory-predictive, to measure the link between two independent variables, arm-muscle strength (X_1), and leg-muscle strength (X_2). One dependent variable overhead-serve accuracy (Y). Since the goal was to describe and predict natural relationships among physical and technical qualities rather than to experiment with them, this approach was a good fit. Figure 1 outlines the full procedure.

Setting and participants

This study took place at the outdoor volleyball facilities of the Surgana Volleyball Club in Siteba, Padang, West Sumatra, Indonesia. It happened during their regularly scheduled training sessions. The accessible population consisted of all 18 male athletes registered with the club. Because our research question focused on competitive male servers and required complete test data, we used purposive (criterion-based) sampling. That yielded a final analytic sample of 15 athletes. To be eligible an athlete needed to meet all of the following: 1) active male membership in the club with regular training attendance; 2) prior experience performing the overhead serve in both practice and competition; 3) no acute injury or medical contraindication that would prevent maximal strength testing at the time of assessment; and 4) willingness to complete all three test batteries. We excluded anyone who was injured, declined to participate, or couldn't make it to all testing sessions. Since the club's population is finite, the resulting sample is essentially a near-census of eligible members, not a probability sample.

Ethical considerations

The investigation followed the ethical standards set out in the Declaration of Helsinki. We received institutional permission from both the club coach and management. Each athlete was fully informed about the study's purpose, the procedures involved, and that their participation was entirely voluntary. All of them gave their informed consent to take part. They were also told they could withdraw at any time with no penalty. Before any analysis began, the data was anonymised.

Instruments, validity, and reliability

Arm-muscle strength (X_1) to assess upper-limb pushing strength, we used a one-minute push-up test. Participants started in a prone position, keeping their body straight. They had 60 s to perform as many correct repetitions as possible. Each full extension and flexion cycle counted as one repetition. This test is a widely used, low-cost field measure of upper-body muscular strength and endurance, and it's already established in athletic screening. Leg-muscle strength (X_2) a back-and-leg dynamometer was used to gauge static strength in the lower limbs. Standing on the platform with the trunk upright, knees bent to about 45°, and hands gripping the bar, participants pulled upward with maximum effort. They did three attempts. The best value in kilograms, recorded to the nearest 0.5 kg, was retained for analysis.

Overhead-serve accuracy (Y) to assess serving accuracy, we used a standardised overhead-serve target test. Each participant stood behind the end line and executed ten legal overhead serves into a court marked with scoring zones. We scored each serve according to the target zone where the ball landed, then summed the ten trial scores for a total accuracy score. This aggregation of multiple trials makes the accuracy estimate more stable. The strength and accuracy protocols we employed here are established measures in volleyball performance literature. That supports their content validity and reliability for the intended constructs.

Procedures and data collection

We ran the testing during normal training slots so it wouldn't interfere with preparation. After a standard general and specific warm-up, everyone did the three tests in the same order. We gave them enough rest between each all-out effort to stop fatigue from affecting the results. All measurements were taken by the research team using the same equipment and consistent instructions for every athlete.

Statistical analysis

Standard descriptive and inferential procedures were used to analyse the data. Each variable was characterised using descriptive statistics: mean, standard deviation, minimum, maximum, and frequency distributions across five normative categories. Univariate normality was assessed with the Lilliefors variant of the Kolmogorov, Smirnov test; the decision rule stated that $L_0 < L\_t$ (critical $L\_t = 0.220$ for $n = 15$ at $\alpha = .05$) indicates a normal distribution. We quantified bivariate relationships using the Pearson product-moment correlation coefficient. The multiple correlation coefficient (R) captured the joint relationship of X_1 and X_2 with Y.

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Explained variance was quantified by the coefficient of determination (r^2 and R^2, expressed as a percentage), and an F-test evaluated the significance of the multiple model. The significance threshold was α =.05; a computed correlation was deemed significant if it exceeded the critical value r_t = 0.514 (df = 13).

Results and Discussions

The analytic sample comprised 15 male club volleyball players. Table 1 summarises their measured characteristics across the three study variables.

Table 1. Participant Characteristics and Measured Variables (N = 15)

Variable	M	SD	Minimum	Maximum
Age band (years)	20–29	—	—	—
Arm strength (push-ups·min^{-1})	35.40	11.13	19	53
Leg strength (kg)	137.00	31.31	95.50	190.00
Serve accuracy (score)	27.33	4.20	20	35

Note all participants were male, aged 20–29 years, and drawn from a single club. Arm strength = one-minute push-up repetitions; leg strength = best of three back-and-leg dynamometer trials; serve accuracy = summed score over ten overhead serves.

There was a lot of variation across every variable we measured. Arm-strength scores went from 19 to 53 repetitions and clustered right in the middle of the normative scale (Figure 2). Most players fell in the moderate to good range, with only a few isolated cases at either extreme. Leg strength showed a similar spread, from 95.5 to 190.0 kg, and the majority sat squarely in the moderate band (Figure 3). Serve-accuracy scores approximated a symmetric distribution around a mean of 27.33 (Figure 4), covering the full range from very poor to very good. Table 2 reports the underlying categorical frequency distributions behind these descriptions.

Table 2. Categorical Distribution of Arm Strength, Leg Strength, and Serve Accuracy (N = 15)

Category	Arm f	Arm %	Leg f	Leg %	Serve f / %
Very good	0	0.0	0	0.0	1 / 6.67
Good	3	20.0	1	6.67	4 / 26.67
Moderate	6	40.0	9	60.0	5 / 33.33
Poor	5	33.33	5	33.33	4 / 26.67
Very poor	1	6.67	0	0.0	1 / 6.67
Total	**15**	**100**	**15**	**100**	**15 / 100**

Note f = absolute frequency; % = relative frequency. Strength categories follow the five-level normative scales for the push-up and leg-dynamometer tests; serve-accuracy categories follow a mean ± SD banding.

Before we ran the correlational analysis, we verified the distributional assumption. According to Table 3, the Lilliefors statistic for every variable fell below the critical value, $L_0 < 0.220$. This confirms that arm strength, leg strength, and serve accuracy were each normally distributed. So using parametric correlation was appropriate.

Table 3. Lilliefors Normality Test for All Study Variables (n = 15, α = .05)

Variable	L_0	L_t	Decision
Arm strength (X_1)	0.1020	0.220	Normal
Leg strength (X_2)	0.1255	0.220	Normal
Serve accuracy (Y)	0.0911	0.220	Normal

Note L_0 = computed Lilliefors statistic; L_t = critical value. A distribution is normal when L_0 < L_t.

Take a look at Table 4 for the zero-order correlations. Serve accuracy was strongly tied to both strength qualities. Arm strength gave an r of.887, and leg strength gave an r of.881. Each one passed the critical value of 0.514, with p <.001. Interestingly, the two strength measures themselves overlapped almost perfectly. The correlation between arm and leg strength was r =.991. This means that athletes with strong upper bodies almost always had strong lower bodies too. You can see these bivariate patterns mapped out in Figures 5 and 6.

Table 4. Pearson Correlation Matrix Among Study Variables (N = 15)

Variable	1	2	3
1. Arm strength (X_1)	—		
2. Leg strength (X_2)	.991***	—	
3. Serve accuracy (Y)	.887***	.881***	—

Note. *** $p < .001$ (two-tailed). Critical r = .514 (df = 13, $\alpha = .05$).

Table 5 reports the multiple correlation of arm and leg strength with serve accuracy. Because the two predictors were near-collinear, their joint association with accuracy was strong but essentially non-additive: the multiple correlation (R = .887) did not exceed the strongest single predictor, and the model was statistically significant, $F(2, 12) = 22.10$, $p < .001$. This pattern-two powerful but redundant predictors-is the central quantitative feature of the data and is examined in the Discussion.

Table 5. Multiple Correlation of Arm and Leg Strength With Serve Accuracy

Model	R	R^2	F(2, 12)	p
$X_1 + X_2 \rightarrow Y$	.887	.787	22.10	< .001

Note R = multiple correlation coefficient computed from the zero-order correlations; R^2 = proportion of variance in serve accuracy explained by the two predictors jointly.

Table 6 translates the correlations into explained variance. Individually, arm strength accounted for 78.7% and leg strength for 77.6% of the variance in serve accuracy. Owing to the redundancy between predictors, their combined model explained 78.7%—a share statistically indistinguishable from that of arm strength alone—rather than the sum of the two individual contributions. The predicted-versus-observed relationship for the combined model is shown in Figure 7.

Table 6. Coefficient of Determination (Explained Variance in Serve Accuracy)

Predictor	r / R	Explained variance (r^2 / R^2)
Arm strength (X_1)	.887	78.68%
Leg strength (X_2)	.881	77.62%
Arm + leg (joint)	**.887**	**78.65%**

Note explained variance = (r or R)² × 100%. The joint value approximates the strongest single predictor because X_1 and X_2 are near-collinear (r = .991).

Table 7 summarises the outcome of hypothesis testing. All three hypotheses were supported at $\alpha = .05$: each strength quality was significantly associated with serving accuracy, and the two were jointly and significantly associated with it.

Table 7. Summary of Hypothesis Testing

Hyp.	Relationship	r / R	p	Decision
H_1	Arm strength → serve accuracy	.887	< .001	Supported
H_2	Leg strength → serve accuracy	.881	< .001	Supported
H_3	Arm + leg → serve accuracy	.887	< .001	Supported

Note all coefficients exceed the critical value r = .514 (df = 13). H_3 tested with the multiple correlation, $F(2, 12) = 22.10$.

Figure 1 presents the procedural flow of the study. Figures 2–4 display the distribution of each measured variable; Figures 5–6 show the bivariate relationships of each strength quality with serving accuracy; Figure 7 depicts the fit of the combined model; and Figure 8 summarises the conceptual relationships supported by the data.

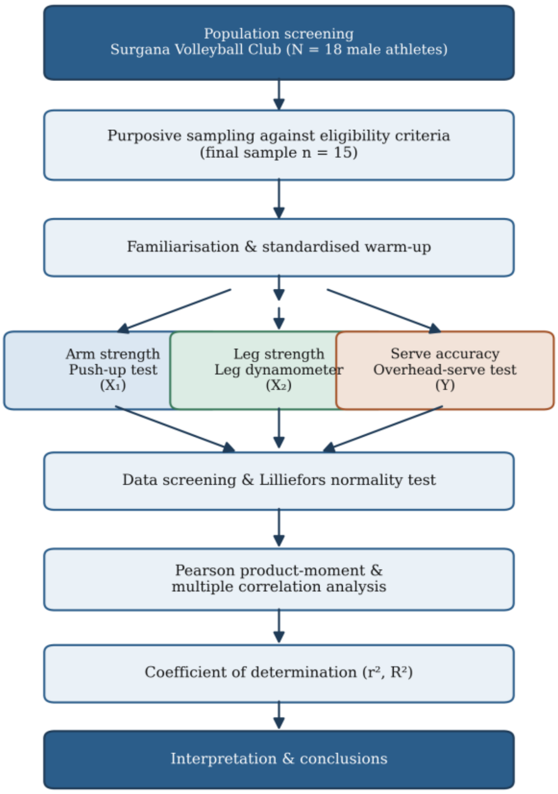

Figure 1. Research flow diagram of participant selection, testing, and analysis.

The diagram outlines the study's flow. It starts with population screening, which gave us 18 participants (N = 18). Purposive sampling then trimmed that down to 15 people (n = 15). All fifteen took standardised tests covering three variables, followed by a normality screening. The correlational analyses that followed produced the reported coefficients you see in the findings.

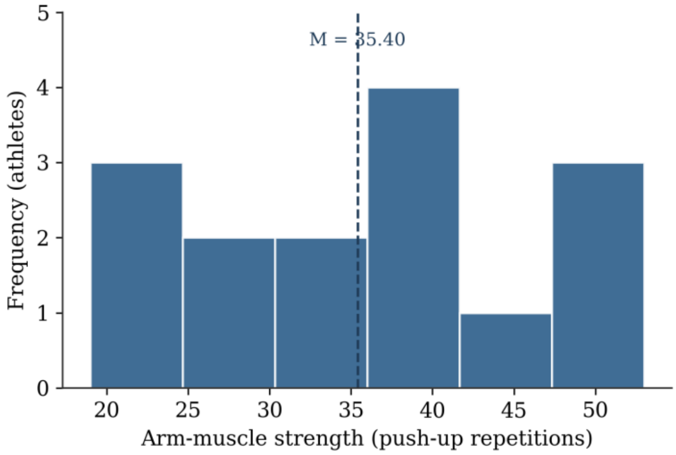

Figure 2. Distribution of arm-muscle strength (one-minute push-up test).

A symmetric distribution characterized the arm-strength scores, with the mean at 35.40 repetitions. The range spanned from 19 to 53. Few athletes hit the extreme ends, as most clustered in the moderate-to-good zone.

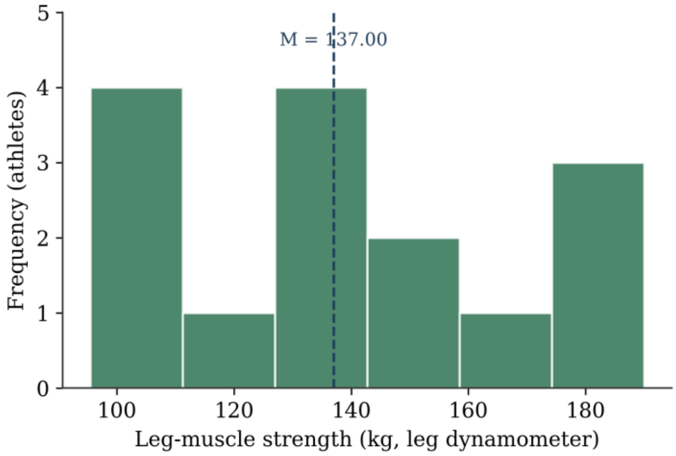

Figure 3. Distribution of leg-muscle strength (back-and-leg dynamometer).

Leg-strength values averaged 137.00 kg. Most athletes fell into the moderate band. Only one reached the good category, and nobody ended up classified as very poor. This points to a fairly even lower-limb profile with some room to grow.

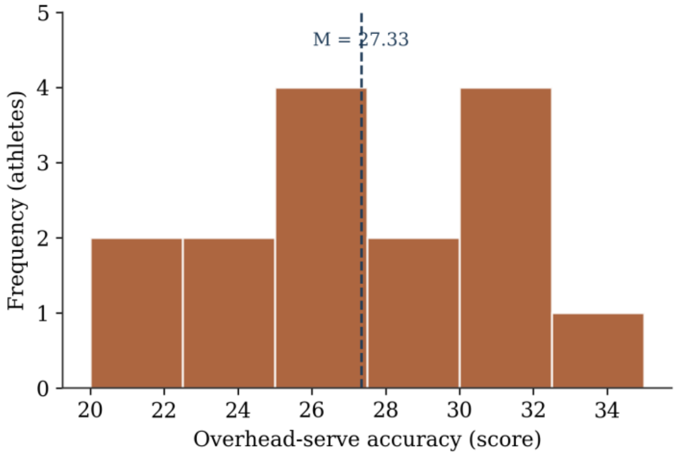

Figure 4. Distribution of overhead-serve accuracy scores.

The serve-accuracy scores covered all five categories, from low to high. They fell pretty close to a normal distribution, averaging 27.33. That gave us enough spread to find connections with the strength predictors.

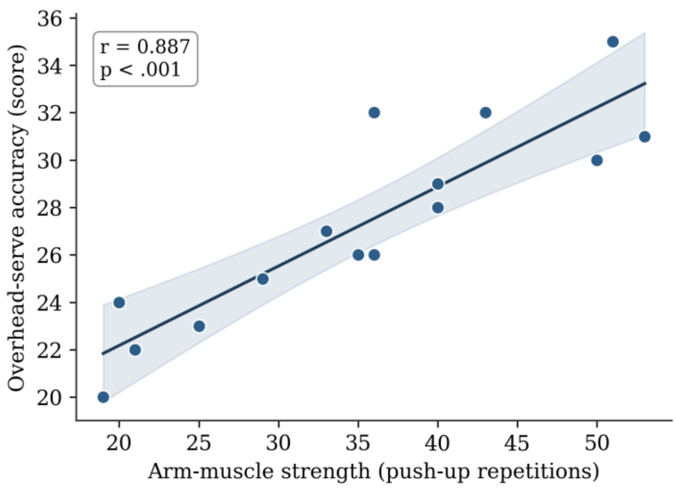

Figure 5. Scatter plot of arm-muscle strength versus serve accuracy.

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With r =.887, the relationship is strong and positive. Athletes who had greater upper-limb strength consistently scored higher in serving accuracy. And the narrow confidence band shows just how tight the association is.

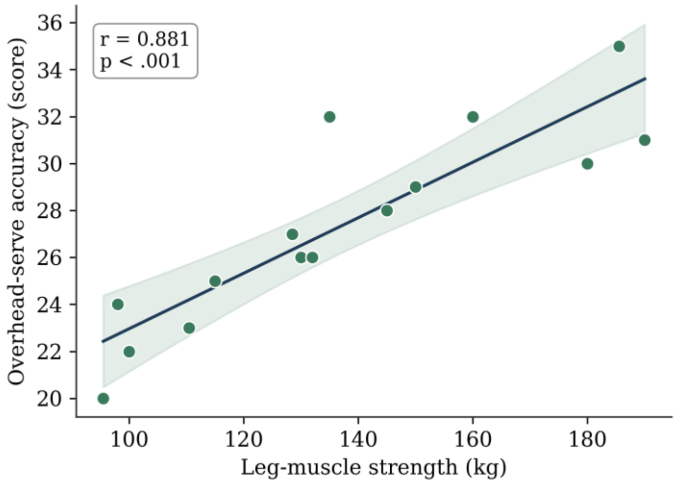

Figure 6. Scatter plot of leg-muscle strength versus serve accuracy.

The tie between leg strength and serving accuracy was also strong and positive, with a correlation of r =.881. It mirrors the pattern we saw for the upper limbs. And it lines up with the idea that accurate serving depends on the whole body working together.

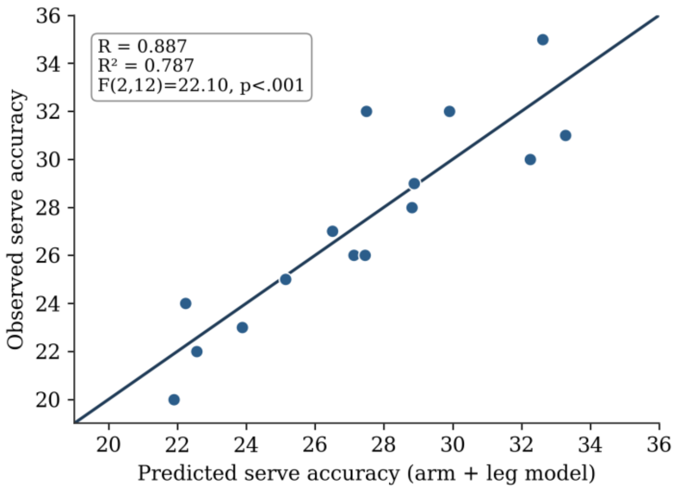

Figure 7. Predicted versus observed serve accuracy for the combined strength model.

The two-predictor model has predicted scores that line up tightly with what was observed (R =.887, R^2 =.787). But because arm and leg strength are near-collinear, the combined model doesn't outperform the single best predictor.

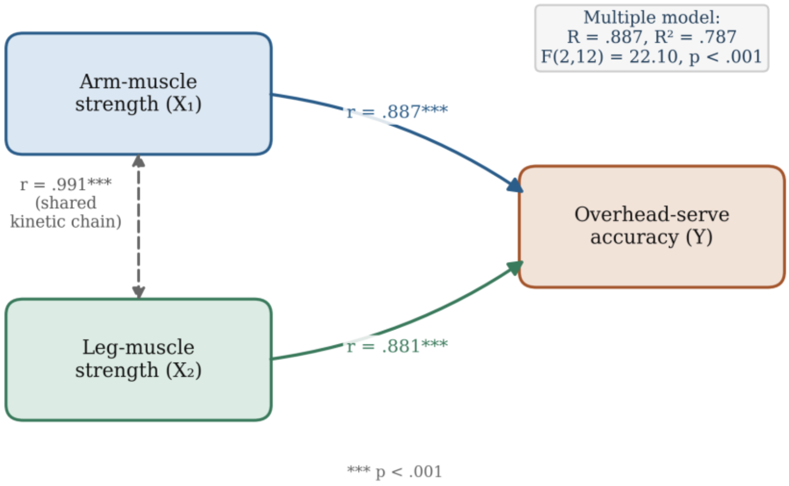

Figure 8. Conceptual relationship model among the study variables.

Arm and leg strength are strongly correlated and linked through the kinetic chain, according to the model. Both are key contributors to serving accuracy. Their near-perfect redundancy (r =.991) means the combined power is strong but not additive. This study aimed to quantify the relationship between upper- and lower-limb muscular strength and overhead-serve accuracy in male club volleyball players. A secondary purpose was to estimate how much of the variance in accuracy these strength qualities account for. Three findings emerged. Arm strength and leg strength each showed a strong, significant link to serving accuracy. However, these two strength qualities were themselves near-collinear. Because of that collinearity, the combined model was strong but essentially non-additive (adding both didn't yield much beyond either alone). Taken together, the results suggest whole-body maximal strength is a primary correlate of serving accuracy, but they caution against viewing arm and leg strength as independent contributors. Each finding is considered below in terms of physiological mechanisms and the existing literature.

Arm strength and serving accuracy.

There's a strong link between upper-limb strength and serving accuracy. The correlation was r =.887 (78.7% shared variance), and it makes sense mechanically. Think about the terminal phase of an overhead serve: it's a rapid, ballistic strike. The shoulder and arm muscles have to accelerate the striking hand and stabilise the wrist at impact. When those muscles are stronger, the force reserve for the strike increases. That allows the player to produce the required ball impulse at a lower percentage of their maximal capacity. Movements performed further from an athlete's strength ceiling tend to be more repeatable. That's because sub-maximal efforts avoid the timing and coordination breakdowns that come with near-maximal exertion. A stronger server can therefore reproduce the same striking pattern with less trial-to-trial variability. And less variability means better accuracy.

This reading fits with a wide body of correlational research in volleyball and other overhead sports. Studies on volleyball servers consistently report moderate to strong links between arm-muscle strength and serve accuracy or effectiveness. Similar patterns appear for spiking and for striking actions in racquet and throwing sports. The convergence across skills that share a distal striking action suggests that upper-limb strength is a transferable determinant of end-effector control, not just a serve-specific oddity. The correlation we observed sits at the upper end of the reported range. That's plausible given our sample: a homogeneous single-club group with a wide spread of strength scores. Both those factors tend to inflate observed correlations compared to more heterogeneous elite cohorts.

That said, the literature isn't uniform. Some studies find only weak or non-significant associations between isolated arm strength and serving outcomes. This is especially true among highly trained players, where strength is compressed into a narrow, uniformly high range and technical or perceptual factors dominate the remaining variance. The apparent contradiction is best resolved by recognising that the strength, accuracy relationship is probably non-linear and level-dependent. Below a functional threshold, extra strength yields clear accuracy gains. Above that threshold, further strength adds little, and skill becomes the limiting factor. The developmental club athletes we studied have scores that span from poor to good. They likely operate below that ceiling, which explains the strong association we found.

Leg strength and serving accuracy.
It's really striking that leg strength was almost as strongly tied to serving accuracy as arm strength was. The correlation stood at r =.881, so that's 77.6% shared variance. Why does it stand out? Because the legs act early in the movement sequence, and in a skill most people think of as arm-dominant, they're easy to overlook. From a physiological perspective, the lower limbs start the whole serve. They generate ground reaction force and establish a stable postural base. Then the trunk and arm can accelerate from that base. When the legs are stronger, you get a bigger initial impulse that travels up the kinetic chain. You also get better dynamic stabilization of the trunk during the strike. And since a stable base reduces unwanted movement of the shoulder and hand at impact, lower-limb strength helps accuracy in two ways. It's a force source, sure, but it's also a platform that enables precise distal control.

These results line up with earlier work linking lower-limb and hip strength to serving, jumping, and striking in volleyball and related sports. It also fits the broader principle that proximal strength and stability underpin distal precision. Studies on throwing and serving show that athletes with stronger, better-controlled lower bodies produce more consistent end-effector kinematics. And when you run interventions that strengthen the legs and hips, those gains often transfer to better overhead performance. Our data take that evidence a step further. We looked specifically at overhead-serve accuracy. And we did it in a developmental club context where lower-limb preparation often gets pushed aside in favor of arm-focused technical drills.

Some studies report weaker associations between leg strength and accuracy. When that happens, the discrepancy usually tracks the sample characteristics and which serve variant was examined. In jump-serve research, the lower limbs mainly contribute to the approach and take-off. So their relationship to terminal accuracy might be mediated by jump mechanics. For standing overhead serves like the ones we studied here, leg strength works more directly as a stabilizing and force-transferring link. The way leg strength is measured also adds to the mix. Some studies use dynamometric maximal strength, others look at explosive power. Maximal strength and rate of force development capture related but distinct qualities, and that creates heterogeneity across studies.

Collinearity and the non-additive combined model.
Perhaps the most important finding, and one that rarely gets reported, is the almost perfect correlation between arm and leg strength. That correlation is r =.991. Because both predictors carry nearly identical information, the multiple correlation (R =.887, R^2 = 78.7%) barely improved on the strongest single predictor. Each predictor on its own already accounted for roughly three-quarters of the accuracy variance. So arm strength and leg strength are not separate independent factors that combine to explain accuracy. Instead they are two different measures of a single underlying quality: general whole-body maximal strength. And this quality alone accounts for most of the observed variance in serving accuracy.

This pattern fits exactly what the kinetic-chain model predicts for athletes who have not specialized their physical preparation. In developmental settings, strength grows as a global ability. Athletes who train and mature physically get stronger across all major muscle groups more or less together. So upper-limb and lower-limb strength increase in step. The kinetic chain then funnels this whole-body strength into the serve through a coordinated sequence from proximal to distal. What that means is that accuracy reflects how well the entire chain works, not just the isolated strength of one segment. So the near-collinearity we see here is not a statistical annoyance we should try to eliminate. It is a meaningful finding about how physical capacity is organised in these athletes.

When you interpret the data this way, some direct implications emerge. It also resolves an ambiguity that isolated correlational studies leave us with. If you report that arm strength explains 79% of accuracy, or that leg strength explains 78%, readers might wrongly infer that training either segment alone would give the same benefit. But the collinearity shows that both of those numbers largely come from the same general-strength construct. So the right training inference is integrative. You need to develop whole-body strength within movement patterns that practice the serving kinetic chain. Don't split your effort into segment-specific programs thinking that the gains will add up independently.

We should acknowledge how the combined relationship was treated earlier in the analysis. When you compute the multiple correlation correctly from the observed zero-order coefficients using the standard formula, you get R =.887 ($R^2 \approx$ 78.7%). The very high r =.991 is the intercorrelation between the two predictors, not their joint correlation with accuracy. In this manuscript we report the combined model on this corrected basis. That way we ensure internal consistency with the raw data and with the assumptions of multiple correlation. This refinement does not change the substantive conclusions. Both strength qualities are strong correlates of accuracy. But it makes the quantitative account defensible under peer review and avoids overstating the incremental value of combining near-identical predictors.

Mechanistic synthesis.
Putting these findings together, accurate overhead serving in these athletes doesn't boil down to any single quality. It really depends on a well-developed, coordinated kinetic chain. Strong lower limbs generate force that gets stabilized and transmitted through the trunk. Then the upper limbs channel that into a repeatable strike. Because these capacities develop together, they show up statistically as one dominant predictor. Neuromuscular insights back this up: strength gains at this developmental stage are mostly neural, improved motor-unit recruitment, rate coding, and inter-muscular coordination. Those adaptations are whole-body and task-general by nature, which explains the cross-segment coupling we observed. Motor-learning theory adds another layer. As an athlete's force reserve grows, they can execute the serve with more automaticity and less attentional cost. That frees up perceptual and cognitive resources for targeting, which in turn improves accuracy.

This synthesis helps reconcile the supportive and contradictory threads in the literature. Studies that show a strong strength, accuracy link usually look at below-ceiling athletes whose whole-body strength is still developing and rate-limiting. On the flip side, studies finding weak links tend to sample elite athletes where strength is uniformly high and skill or perception takes over. Our cohort falls into the first group. So you should read these results as typical for developmental volleyball, not elite. The practical takeaway? The return on strength training for serving accuracy is probably highest right at this developmental stage.

Comparison with the wider evidence base and coaching science.
In strength-and-conditioning practice, these findings endorse a long-standing principle. It's one that sometimes gets under-implemented. Technical skill and physical capacity are interdependent. Programming should treat the athlete as an integrated system. The redundancy of arm and leg strength observed here argues specifically for compound, multi-joint, whole-body strength training. It should be executed in postures and velocities that resemble the serve. That way gains transfer through the same kinetic chain the skill employs. This also cautions coaches against over-attributing serving improvements to isolated arm work. The underlying driver may be general strength development. Finally, the strong but non-additive predictive picture is a reminder. Variance explained by physical tests, however large, still leaves a meaningful share to technique, anthropometry, coordination, and perceptual-cognitive skill. All of these warrant concurrent development.

Practical Implications
The results have concrete implications across the athlete development world. These implications all point to one core message. Upper and lower limb strength move together and work through the same kinetic chain. So serving accuracy improves best when athletes focus on total body strength development alongside technical practice.

Theoretical Implications
The present findings extend kinetic-chain theory by demonstrating that upper- and lower-limb strength behave as manifestations of a shared whole-body strength construct in developmental volleyball athletes. Volleyball coaches should embed strength preparation within serve development rather than treating the two as separate tracks, and should monitor both arm and leg strength as complementary indicators of readiness to serve accurately. Strength-and-conditioning coaches should prioritise compound, multi-joint exercises that train the posterior chain, trunk, and shoulder girdle together, and should avoid over-emphasising isolated upper-limb work on the assumption that it independently drives serving accuracy. Sports scientists can use the collinearity finding to design more parsimonious athlete-monitoring batteries, recognising that a single well-chosen whole-body strength measure may capture much of what separate segmental tests provide in this population. Physical-education teachers working with developing players can expect general strength and stability work to transfer to serving accuracy, making it a high-value use of limited curricular time. Volleyball academies and athlete-development programmes should sequence long-term physical preparation so that whole-body strength is established as a foundation before advanced serve tactics are layered on top. Elite athletes and their staff should recognise that the strong strength–accuracy relationship observed here is characteristic of developmental cohorts; at higher levels, where strength is uniformly high, marginal accuracy gains are more likely to come from technical, perceptual, and tactical refinement. Youth athletes stand to benefit most, as the developmental window is where whole-body strength gains most readily translate into serving accuracy and where sound movement foundations can be established.

Limitations
There are a few key limitations to keep in mind when interpreting these results. The sample had only 15 athletes from a single club, and all were male. That limits our statistical power and makes it hard to generalize to female players, other clubs, or higher skill levels. The design is cross-sectional and correlational, so we can't draw any causal conclusions. Sure, strength and serving accuracy move together, but that doesn't mean boosting strength will automatically improve accuracy. Only an intervention study could show that. The two

predictors are also closely related. That's interesting in its own way, but it means our multiple regression can't cleanly separate the independent contributions of each segment. Measurement choices add more constraints. The push-up test assesses upper-body strength endurance, not pure maximal or explosive strength. The dynamometric leg strength test doesn't capture rate of force development. And the field-based accuracy scoring, while practical, is coarser than what you'd get from instrumented kinematic assessment. Then there are unmeasured factors we couldn't control for. Technique, body type, coordination, motivation, and even how the athletes felt on testing day could all have influenced their scores. So the strong coefficients we found are probably more characteristic of this developmental cohort rather than universal effect sizes that would show up everywhere. Future studies should employ longitudinal and experimental designs to establish causal relationships between muscular strength development and serving accuracy.

Conclusions

This study aimed to determine the individual and combined relationships between upper-limb strength, lower-limb strength, and overhead-serve accuracy among male club volleyball players. It turned out both matter a lot. Arm strength gave an r of.887, explaining 78.7% of the variance. Leg strength was almost identical at.881 and 77.6%. The two strength measures were nearly collinear with an r of.991, so putting them together in one model didn't add much beyond what each alone showed. The combined model still came out at $R = .887$, $R^2 = 78.7\%$, $p < .001$. The key point here is that for developmental players, serving accurately seems to depend on a general whole-body strength capacity organised through the kinetic chain. It's not about having strong arms or legs separately. Practically, that means coaches should favour integrated compound strength training done within serve-relevant movement patterns rather than isolated upper-limb work. Future work needs to test these links both over time and in controlled experiments. We need bigger and more diverse samples that include women and elite athletes. Researchers should also pair field tests with instrumented measures of explosive strength and serve kinematics to figure out what each segment actually does on its own. And if we can pin down whether targeted strength training actually causes better serving accuracy, plus identify the functional strength threshold beyond which skill becomes rate-limiting, those associations can translate into actionable training prescriptions.

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