CORRELATION BETWEEN CORE STRENGTH AND POWER, AND SERVE VELOCITY IN COLLEGIATE VOLLEYBALL PLAYERS

A THESIS

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THESIS APPROVAL

Graduate Athletic Training Education

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INTRODUCTION

There are many factors that can influence and enhance athletic performance. One idea gaining popularity is that core strength and power can improve athletic performance. There are many aspects of any sport that can contribute to an increase in athletic performance. Within the sport of volleyball, there are many skills that can help to determine the success of a team or player.[1] One skill that is required of each position is the serve.

The serve in a volleyball match is one of the most important attack actions because it is the first chance a team has for an offensive play within the match. A successful volleyball player must master an effective serve. Therefore, coaches and players should focus on this fundamental action.[1,2] Silva et al. studied 24 matches for a total of 90 sets and 24,670 separate actions from the 2010 FIVB Men's World Championships; they found the skills that discriminate in favor of victory are both the serve point and blocking errors.[3] As such, it can be understood that the serve is one of the most critical components during a volleyball game, and therefore emphasis should be placed upon this skill during training.[1]

The core is an area of the body that essential to both activities of daily living, as well as athletic performance. Core strength is important to everyday living as the body must maintain balance during every day activities such as walking, running, or sitting.[4] However, during athletics, the core musculature can have more demands placed upon it. The core is the connection point for both the upper and lower extremities. Core strength is a pivotal component in almost every athletic activity.[5] Core strength can be perceived as an arbitrary term, as there is no set definition. However, core strength and power has been defined as the ability of the core musculature to stabilize the lumbar spine and or generate and maintain a force.[6,7] Core proprioception has been defined as the ability of the lumbopelvic-hip structures and musculature to withstand compressive forces on the spine and return the body to equilibrium.[8]

The three muscles thought to have the most profound effect on athletic performance are the lumbar multifundus, transverse abdominis, and quadratus lumborum muscles.[9] Sports that require overhead movements rely heavily on core musculature as this musculature appears to produce torque during athletic performance.[10]

Research has found there are many different ways to measure core strength and power. Recently, Zazulak et. al. found that decreased core proprioception is a predictor for injury by utilizing muscle latency tests.[11] Muscle latency was measured by utilizing an apparatus that passively moved the participant into lumbar extension of 20 degrees where a weight was dropped, and the participant actively moved into hip neutral.[11] Muscles fire in groups to produce a task-specific pattern providing core strength; this can make an evaluation of the strength of one single muscle as a point of reference questionable.[5]

Sharrock et al. believe, based upon the available evidence, that the Double Leg-Lowering test is an appropriate way to measure core stability as it pertains to athletic function.[12] However, Cowley and Swenson found that both the Front and Side Abdominal Power Tests are reliable tests, and therefore may be used to assess the power component of the core in young women.[13]

To the researchers' knowledge, no other studies have investigated the relationship between core strength and volleyball serve velocity. Therefore, the purpose of this study was to assess the correlation between core strength and power, and serve velocity in collegiate women's volleyball players.

METHODS

The purpose of this study was to assess the relationship between core strength and power, and the velocity of a volleyball serve in Division II collegiate women's volleyball players. This section will include the research design, subjects, instrumentation, procedures, hypotheses, and data analysis.

RESEARCH DESIGN

This research study utilized a correlational design, examining volleyball serve velocity and core strength and power. The independent variables of this study included core strength as measured by the Double Leg-Lowering test and core power as measured by the Front and Side Abdominal Power Test, as well as height, weight, jump height, player position, years of competitive volleyball experience, and age. The dependent variable was volleyball serve velocity. The assets of this study include controlling for external factors such as skill level and age.

LIMITATIONS

Potential limitations of this study include the inability to control the biomechanics of each subject. Another limitation of this study is that the Double Leg-Lowering, and Front and Side Abdominal Power Tests may not be valid measures of core strength. The low number of participants was also a limitation of this study.

SUBJECTS

Ten female collegiate volleyball players volunteered for this study from a participating NCAA Division II University. In order to participate in this study, each player was required to have at least four years of competitive volleyball experience before playing at the collegiate level. In addition, participants must have been free from any injury which removed them from a practice or game within the last month.

HYPOTHESIS

Hypothesis: Core strength will positively correlate with volleyball serve velocity as measured by both the Double Leg-Lowering Test and the Front and Side Abdominal Power Tests.

H^1: There will be no significant correlation between years of experience and volleyball serve velocity.

H^2: There will be no significant correlation between jump height and volleyball serve velocity.

H^3: There will be no significant correlation between height and volleyball serve velocity.

H^4: There will be no significant correlation between weight and volleyball serve velocity.

H^5: There will be no significant correlation between jump height and weight.

H^6: There will be no significant correlation between the Double Leg Lowering test and the Front Abdominal Power Test.

H^7: There will be no significant correlation between the Double Leg Lowering test and the Right Side Abdominal Power Test.

H^8: There will be no significant correlation between the Double Leg Lowering test and the Left Side Abdominal Power Test.

INSTRUMENTS

The instruments used in this study included a universal goniometer, a sphygmomanometer, radar gun, and a demographic questionnaire.

Double Leg-Lowering Test: The Double Leg-Lowering test represented core strength in this study. Due to the lack of a standard valid and reliable measure of core strength, the Double Leg-Lowering test was utilized during this study to measure core strength. Laderia et. al. found that the Double Leg-Lowering test has high reliability, but low validity.[14] The intraclass correlation of the Double Leg Lowering Test was 0.955.[14] However, the researchers stated that the Double Leg-Lowering test may still be a valuable tool for Physical Therapists and Athletic Trainers alike to assess core strength despite the lack of validity they found as it still assess pelvic motor contol.[14]

To administer the Double Leg Lowering Test, the athlete began in a supine position with a sphygmomanometer under their back, centered beneath the umbilicus while also aligned with the spine. The athlete was then instructed to raise her legs into 90 degrees of hip flexion while maintaining full knee extension. The subject placed her arms along the side of her body with her palms facing down.

The subject was instructed to relax her abdominal muscles while keeping her knees fully extended and hips flexed to 90 degrees while the sphygmomanometer was inflated to 20 mmHg. Once the sphygmomanometer was inflated, the subject was then instructed to stabilize her lumbar spine by "pulling her belly-button to her spine" while keeping a posterior pelvic tilt. This position was held until the sphygmomanometer reached 40 mmHg of pressure (Figure 1).

The subject was then instructed to slowly lower her legs, maintain posterior pelvic tilt, and full knee extension until the sphygmomanometer dropped below 20 mmHg. At this point, the researcher took a goniometric measurement of hip flexion (Figure 2).

The goniometer axis was placed over the greater trochanter, with the stationary arm parallel to the mid axillary line of the trunk, and the moveable arm parallel to the longitudinal axis of the femur. This test was repeated two more times with a thirty second rest in between each trial. The three goniometric measurements were recorded in degrees and averaged for data analysis.

Front and Side Abdominal Power Test: The Front and Side Abdominal Power Test is another field test often used to assess core power.[15] Cowley and Swenson found that the Front and Side Abdominal Power Test are reliable in assessing core power, however they are not valid.[13] The Front Abdominal Power Test had an intraclass correlation of 0.95, and the Side Abdominal Power Tests had an intraclass correlation of 0.93.[13]

In order to perform the Front Abdominal Power test, the researcher placed an exercise mat lengthwise on the floor in an open area, and placed a piece of tape at the bottom of the mat. The subject was then instructed to lie on her back with her knees at 90 degrees of flexion, with her feet shoulder width apart and toes lined up with the piece of tape.

The subject was then instructed to place her arms above the head, and was handed a 2kg medicine ball (Figure 3).

The subject was instructed to create a forceful contraction of her abdominal muscles, releasing the medicine ball in a throwing motion when her hands were over the knees, keeping her feet and buttocks on the ground (Figure 4). The subject was also instructed to maintain shoulder flexion with the elbows and wrists extended and thumbs touching (Figure 5).

The distance from the tip of the subject's feet to the point where the ball first landed was measured and recorded. The test was repeated three times and averaged for data analysis.

For the Side Abdominal Power Test, the researcher placed an exercise mat perpendicular to the open area on the floor, and placed a piece of tape at the edge of the mat. The subject then sat on the mat with her knees bent to 90 degrees and her feet shoulder width apart. The researcher then lined up the subject's left foot with the edge of the mat. The subject was instructed to hold her arms directly in front of herself with extended elbows, supinated hands, and the fifth digits touching. The subject was then instructed to lie back until his or her hip flexion reached an angle of 45 degrees. Once 45 degrees of hip flexion was reached, the researcher handed her a 2kg medicine ball (Figure 6).

Finally, the subject was instructed to rotate her torso to the right 90 degrees (Figure 7) and perform an explosive concentric contraction of the core musculature to rotate her core to the left while projecting the medicine ball in a tossing manner, when her hands were over her left knee (Figure 8 and 9).

The subject was also instructed to keep her feet and buttocks in constant contact with the exercise mat at all times. The distance from the lateral edge of the left foot to where the medicine ball landed was measured and recorded. The test was repeated three times and averaged for data analysis. This test was also performed on the right-hand side by reversing the direction the subject was lined up with and rotated.

Radar Gun: The radar gun used was a JUGS (Tualatin, Oregon) brand radar gun, model HTRCR-1K. It accurately records and displays moving ball speeds with an accuracy of ± 0.5 display units. The radar gun was used to measure the velocity of the volleyball during service in miles per hour.

Goniometer: The goniometer was a 12-inch, 360 degree goniometer and was used to obtain all joint angle measurements during the Double Leg-Lowering test to assess core strength.

Sphygmomanometer: The sphygmomanometer was used to measure the amount of pressure beneath the lumbar back during the Double Leg-Lowering test to assess core strength in milligrams of Mercury (mmHg).

Scale: The scale in the California University of Pennsylvania Convocation Center Athletic Training Clinic was used to assess the subjects' weight, and was measured in pounds.

Tape Measure: A tape measure was used to assess the subjects' height and the distance for both the Front and Side Abdominal Power Tests.

Vertec: The Vertec was used to assess the subjects' jump height. The Vertec consists of independent "vanes" which the participant hits with her hand during a standing vertical jump. Each vane relates to a specific height, and is measured in increments of half inches.

Demographic Questionnaire: Demographic questions were used to collect data including age, serve preference, playing position, years of competitive volleyball experience, year in school, and how likely the participant is to serve in a game setting. The questionnaire was used to identify possible information that may affect the serve or core strength of each subject.

Figure 1. Double Leg Lowering Test Starting Position

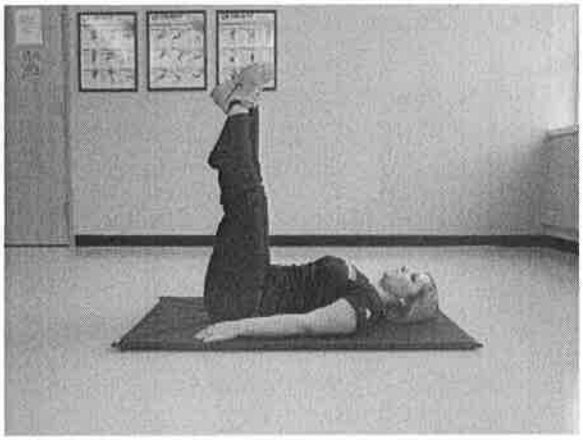


Figure 2. Double Leg Lowering Test Ending Position

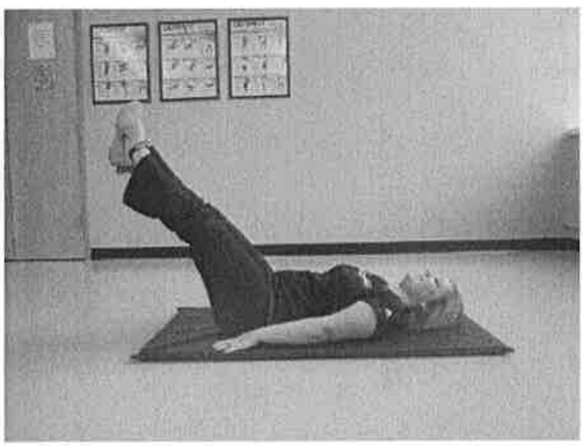


Figure 3. Front Abdominal Power Test Starting Position

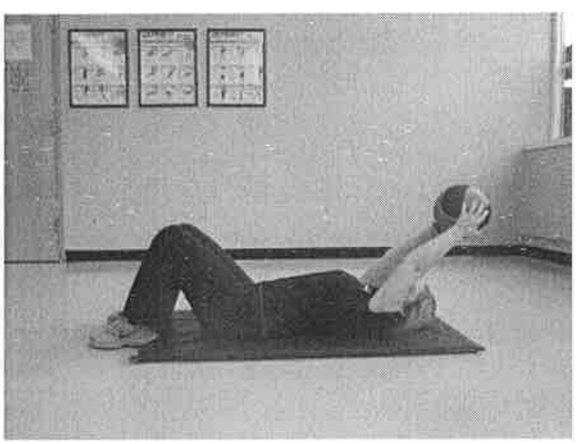


Figure 4. Front Abdominal Power Test Release Position

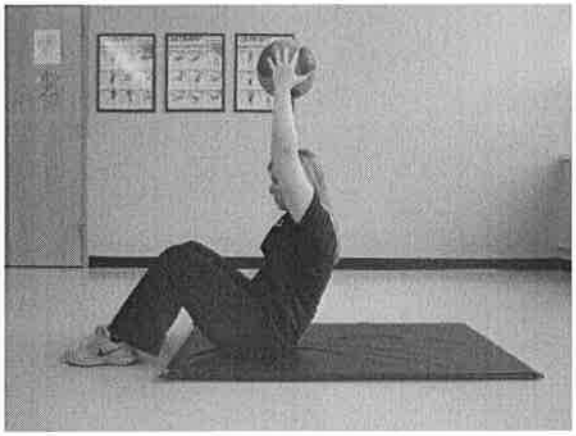


Figure 5. Front Abdominal Power Test Ending Position

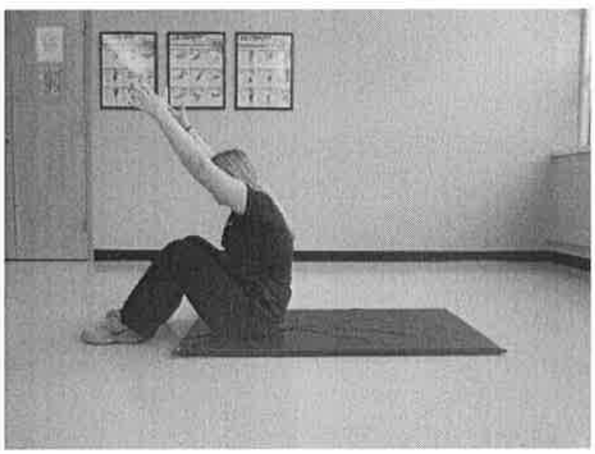
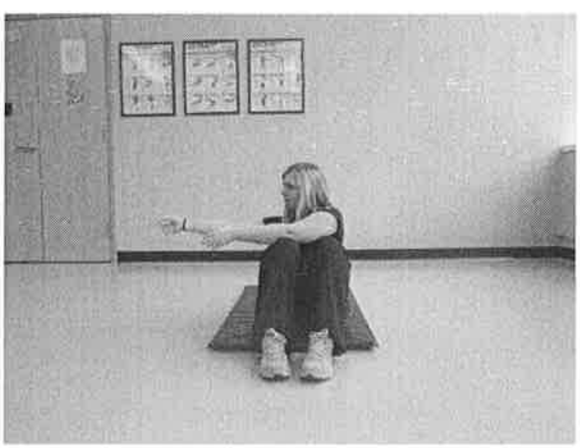


Figure 6. Side Abdominal Power Test Starting Position (Side View)

Figure 7. Side Abdominal Power Test Starting Position (Front View)

Figure 8. Side Abdominal Power Test Release Position

Figure 9. Side Abdominal Power Test Ending Position



METHODOLOGY

This research study was approved by the Institutional Review Board at California University of Pennsylvania. Participants were not asked their name or any identifying information for confidentiality purposes, but were assigned a number for coding purposes.

The subjects were recruited during a team meeting, and were informed that participation in this research was voluntary. The subjects were informed of the research protocol, signed the informed consent, and then completed the demographics.

Following the completion of paperwork, the subject was assessed for height, weight, and jump height. The athlete was then instructed on how to properly complete the Double Leg-Lowering test for core strength and shown an example prior to completing the test.

After completion of the Double Leg-Lowering test, the subject was instructed on how to perform both the Front and Side Abdominal Power Test. Following instruction, the subject completed the Front and Side Abdominal Power Tests.

Finally, the athlete was taken to an indoor volleyball facility, where a game-regulation net was set up. Each participant had a warm-up before serve velocity was measured. The warm-up consisted of two minutes of jogging.

The participants then performed three overhead ball tosses with both arms, three overhead ball tosses with the dominant arm, and three dominant arm hits on the ball, with the researcher. Lastly, the participants performed five warm-up jump-float serves. To perform a Jump Float serve, the volleyball is struck over the head with no spin, but it is struck while the player is in the air during a vertical jump.[116]

The researcher placed the radar gun at the net to measure the velocity of the serve. The subject performed a jump float serve into the court serving from the center of the end-line, aiming at spot number 6, or the middle 10 feet and back 20 feet of the court. In order for the serve to be recorded, the serve could not hit the net. The serve must have also landed into the court on the opposite side of the net within the target area. Finally, the server must not have committed a foot-fault in which the subject's foot touched or crossed the end line from which she was serving, before she had made contact with the volleyball. The velocity of the first three serves that met these criteria were recorded and averaged. This average was used for data analysis as a dependent variable.

PRELIMINARY RESEARCH

A pilot of these methods was performed before the study of this research study. An athletic subject who possessed volleyball experience was used to review the protocol of this study. The subject was tested on the Double Leg-Lowering test to evaluate core strength, and the Front and Side Abdominal Power test to evaluate core power. The subject was then taken through the volleyball warm up and research protocol. The researcher observed the subject's ability to understand the directions, if the warm-up protocol was accurate, and if the time allotted for one testing session was ample. After the preliminary research, no adjustments were made.

DATA ANALYSIS

All data analyses were performed using SPSS version 22.0 for Windows, and an alpha level of 0.05 was used. The main research hypothesis was analyzed using a Pearson Product-Moment Correlation to determine any significant correlation between core strength and power, and serve velocity. Descriptive statistics were used to examine the demographic variables, mean velocity, and mean core strength. Pearson Product-Moment Correlations were used to examine the relationships between volleyball serve velocity and years of volleyball experience, jump height, height, weight, Double Leg Lowering test scores, and Front and Side Abdominal Power Tests scores.

RESULTS

The following section displays the results from the data collected in this study. The purpose of this study was to assess the correlation between core strength and power, and serve velocity in collegiate women's volleyball players. Each subject performed a vertical jump, Double Leg Lowering Test, Front and Side Abdominal Power Tests, a warm-up prior to serving, and three jump float serves. This section is divided into demographic data, hypothesis testing, and additional findings.

Demographic Information

The demographic data allowed the researcher to have a better understanding of the subjects who participated in the study. A total of ten subjects participated in this study. The subjects ranged from freshman to juniors in college. The participants' ages were between 18 and 21 years (M = 19.7 ± 0.949). The participants' height were between 62.5 and 72 inches (M = 67.825 ± 3.042), weights between 132.5 and 179.5 pounds (M = 155.9 ± 14.644), and jump heights between 35.5 and 44 inches (M = 37.725 ± 2.775). All participants had between 4 and 12 years of competitive volleyball experience (M = 7.5 ± 2.273).

Core strength was measured by having the subjects perform the Double Leg Lowering Test as well as the Front and Side Abdominal Power tests. Double Leg Lowering Test scores were obtained using goniometric metric measurements of hip angle in degrees. When analyzing the data from the Double Leg Lowering Test, a greater hip angle indicates a stronger core. The Front and Side Abdominal Power Test scores were measured using distance in inches. A greater distance in inches for the Front and Side Abdominal Power Tests indicated a more powerful core.

Hypothesis Testing

Hypothesis: Core strength and power will positively correlate with volleyball serve velocity.

Pearson correlations were conducted to determine the relationship between the Double Leg Lowering Test scores, Front and Side Abdominal Power Test scores, and volleyball serve velocity. No correlation was found between the Double Leg Lowering test scores and volleyball serve velocity ($r(10) = -0.582$, $p = 0.078$). There was a significant positive correlation between the Front Abdominal Power Test scores and volleyball serve velocity ($r(10) = 0.829$, $p = 0.003$). There was no significant correlation between the Right Abdominal Power Test scores and volleyball serve velocity ($r(10) = 0.42$, $p = 0.227$). Lastly, there was no significant correlation between the

Left Abdominal Power Test scores and volleyball serve velocity (r(10) = 0.505, p = 0.136).

Additional Findings

In addition to the Pearson Correlations run in order to examine the hypothesis in this study, additional Pearson correlations were run to further examine the data recorded during this study.

Abdominal Power Tests and Independent Variables:

Additional Pearson Correlations were conducted to examine the relationships between the Abdominal Power Tests and Independent variables. There was a significant correlation between height and the Left Abdominal Power Test scores ($r(10) = 0.634$, $p = 0.049$). There was no significant correlation between any other independent variables and The Abdominal Power Tests.

Volleyball Serve Velocity and Independent Variable:

Pearson Correlations were performed to determine correlation between volleyball serve velocity and years experience, jump height, height, and weight. No significant correlation between years of competitive volleyball experience and volleyball serve velocity was found ($r(10) = -0.193$, $p = 0.593$). There was a significant positive correlation between jump height and volleyball serve velocity ($r(10) = 0.738$, $p = 0.015$). A significant positive correlation between height and volleyball serve velocity was found ($r(10) = 0.676$, $p = 0.032$). Finally, there was a significant correlation between weight and volleyball serve velocity ($r(10) = 0.755$, $p = 0.012$).

Double Leg Lowering Test scores and Independent Variables:

Pearson Correlations were performed to determine correlation between Double Leg Lowering Test scores, and jump height and height. A significant negative correlation was found between height and the Double Leg Lowering Test scores ($r(10) = -0.738$, $p = 0.015$). No significant correlation between jump height and the Double Leg Lowering Test scores was found ($r(10) = -0.509$, $p = 0.133$).

Double Leg Lowering Test scores and Abdominal Power Test scores:

Pearson Correlations were performed to determine correlation between Double Leg Lowering Test scores and Front Abdominal Power Test scores, Right Abdominal Power Test scores, and Left Abdominal Power Test scores. There was no significant correlation between the Double Leg Lowering Test scores and the Front Abdominal Power Test scores ($r(10) = -0.444$, $p = 0.199$), nor the Left Abdominal Power Test scores ($r(10) = -0.573$, $p = 0.083$). A significant negative correlation between the Double Leg

Lowering Test scores and the Right Abdominal Power Test scores was found ($r(10) = -0.736$, $p = 0.015$).

DISCUSSION

The following discussion section consists of three subsections: discussion of results, conclusions, and recommendations.

Discussion of Results

The purpose of this study was to assess the relationship between core strength and power in Division II Collegiate women's volleyball players, and the velocity of a volleyball serve. The core of the body has a tendency to work as a foundation for any motion of the extremities.[5] Also, during a volleyball serve, potential energy is transferred from the lower extremity, to the core, to the upper extremity, and finally to the ball.[17] These two ideals can lead one to believe that core strength and power can have a profound effect on athletic performance. Nevertheless, the relationship between core strength and power and volleyball serve velocity has not been thoroughly researched. Therefore, this study intended to augment the existing research on this topic.

It is important to note that the researchers only had 10 subjects participate in this study from the 20 the researchers initially hoped to have from the collegiate volleyball team at the institution of which the study was being completed. The 10 subjects were included for several reasons. The first reason being that the researchers could not get in contact with the seniors on the team, as the regular season was over. There were also a number of injured athletes which did not meet the researchers' inclusion criteria. Finally one subject was injured during a normal spring practice before all data could be collected.

Volleyball Serve Velocity and Core Strength Test Scores:

It was hypothesized there would be a positive correlation between core strength and power, and volleyball serve velocity. Through the three core power tests that were performed, only the Front Abdominal Power Test had a significant correlation with volleyball serve velocity. These findings logically made sense to the researchers, as a volleyball serve is performed mainly within the sagittal plane of motion, just as the Front Abdominal Power Test is performed. This finding may indicate that increasing one's core power in the sagittal plane could lead to an increase in volleyball serve velocity. This finding partially supports the hypothesis as only one of the four tests had a significant correlation to volleyball serve velocity.

When examining the relationship between core strength and volleyball serve velocity, there was no significant correlation between the Double Leg Lowering Test and serve velocity. However, although this finding was not statistically significant, the researchers believe that the finding can be considered clinically significant as the Double Leg Lowering test had a strong positive correlation to volleyball serve velocity. This finding may indicate that this relationship can be looked at and utilized by athletes, coaches, and healthcare professionals alike. With this finding it can be suggested that increasing a collegiate volleyball players' core strength will have a positive correlation to an increase in volleyball serve velocity.

Volleyball Serve Velocity and Independent Variable:

The results of the alternative hypotheses were, for the most part, in line with what was expected. There was no significant relationship between years of competitive volleyball experience, and volleyball serve velocity. As each of the participants had over 4 years of competitive volleyball experience, this finding could be attributed to a plateau in serve velocity for a jump float serve once the skill is mastered. Within the sport of volleyball, the serve is a skill which is essential to the game. Silva et. al. found that the skills that discriminate in favor of victory are both the serve point and blocking errors.[3] Therefore the serve is a skill that is mastered early in a volleyball athletes' career, and does not always improve with time and or practice.

There was a significant relationship between jump height and volleyball serve velocity. This may be due to the fact that with a larger jump height the subject is able to strike the ball at less of angle. This means that the volleyball can have a more direct path to the opposite side of the net, with less of an arc. Future research could examine the relationship between jump height and volleyball serve velocity using a tip spin serve, rather than a jump float serve.

There was also a significant correlation between height and volleyball serve. Additionally, there was a significant positive correlation between weight and volleyball serve velocity. This could be attributed to a greater muscle mass in the participants, therefore the greater muscle mass the participant has, potentially the faster the serve will be. This hypothesis must be further researched to examine the actual causation of increase in serve velocity. This research could include an assessment of body mass with an instrument such as a BodPod and volleyball serve velocity.

Double Leg Lowering Test scores and Independent Variables:

There was a significant negative correlation between the participants' height, and the Double Leg Lowering Test scores. This may be attributed to the fact that with longer legs, it may be more difficult to control abdominal stability. There was no significant correlation between the participants jump height, and the Double Leg Lowering Test scores. This seems logical to the researcher as the muscles needed to improve one's jump height are not the same muscles needed to improve one's Double Leg Lowering Test scores.

Double Leg Lowering Test scores and Abdominal Power Test scores:

There was a negative relationship, but no significant correlation between Double Leg Lowering Test scores and Front Abdominal Power Test scores. On the other hand, there was a significant negative correlation between the Double Leg Lowering Test scores and the Right Abdominal Power Test scores. This finding was surprising, and not truly explainable, as the two tests measure two different aspects of core performance. These findings may be attributed to limb dominance, as the subject always serves with her dominant hand. During this study, 8 of the subjects were right hand dominant therefore the trail arm may have produced extra force during this test, as opposed to the force simply coming from the subjects' core. Finally, there was a negative relationship, but no significant correlation between the Double Leg Lowering Test scores and the Left Abdominal Power Test scores. As with the Front Abdominal Power Test, this finding was not surprising as the tests are measuring two separate aspects of the core. These findings are not surprising as the Double Leg Lowering Test measures core strength, while the Abdominal Power Test measures core power.[13,14] However, the negative relationship was surprising due to the fact that both tests are measuring some aspect of the core musculature, and therefore one could be lead to believe that an increase in one area of performance of the core would correlation with an increase in another area of core performance.

There was no correlation between jump height and weight. This was surprising, because as discussed earlier, weight and volleyball serve velocity had a positive correlation which could be attributed to increased muscles mass. Therefore, on could think that jump height and weight would have a significant positive correlation based upon the theory that increased muscle mass may lead to increase in power and strength. However, with an increased jump height, there was no correlation to an increase in weight, meaning that there is no potential for lower extremity muscle mass to increase jump height within these participants.

The sample size in this study was very small, as only 10 subjects participated in this study. Therefore, the results of this study should be used and examined with caution regarding final conclusions. Although Pearson Correlations were run, it is important to note that any significant/not significant findings are very limited due to sample size, and do not hold the power to be generalized to a larger population.

Conclusions

Although there were several significant and strong correlations in this study, the results and therefore the conclusions, are limited due to small sample size. Additionally, causation cannot be identified in any of the results, and therefore all that can be drawn from the results are the relationships between the variables examined, but we do not know what causes these relationships. The following conclusions are based on the findings and limitations of the study:

1. Frontal core power may be related to volleyball serve velocity; however more extensive research must be conducted to validate this finding.
2. Height and jump height had no significant correlation to volleyball serve velocity. However, participants' weight had a significant positive correlation to volleyball serve velocity. This may be due to a possible increase in muscle mass with increased weight, but this finding needs to be further explored in future studies

Muscles of the core help to both generate and transfer energy from the large to small body parts during sporting activities.[18,19] This study partially supports this theory, as frontal core abdominal power was positively related to volleyball serve velocity. Therefore, despite the small correlations found between core strength, power, and demographics, and volleyball serve velocity, further research should be conducted with a larger sample size to assess if there is in fact any relationship between these variables. However, despite the limitations of these results, this study still contributes to the limited research in this area. This study also provides a foundation for further research to be explored within this subject.

Recommendations

It can be recommended that core power training in the frontal plane should be implemented as there is a significant correlation at the 0.01 level between frontal plane abdominal power and volleyball serve velocity.

There can be many future studies based on this study. First, and foremost utilizing a muscle latency test to assess core strength should be used, and compared to volleyball serve velocity. Zazulak et. al. utilized muscle latency tests to prove that there decrease core musculature proprioception leads to an increase in risk of injury.[11] Therefore muscle latency could be considered the "gold-standard" in assessing core strength. Due to limited time and resources the Double Leg Lowering Test and the Front and Side Abdominal Power Tests were used in this study.

Future studies should also include a larger sample size, both sexes, and a wider range of both age and experience. An increase in participant numbers will lead to an increase in statistical power, which this study was lacking. Future research could also asses how muscle mass, upper extremity strength, and lower extremity strength could affect volleyball serve velocity. Additionally the negative relationship found in this study between the

Double Leg Lowering Test and the Right Abdominal Power test could be investigated.

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APPENDICES

APPENDIX A

Review of Literature

REVIEW OF LITERATURE

The purpose of this Review of Literature is to enlighten the reader on previous research regarding the anatomy of the core, core strength, volleyball serves, and what an athlete can gain from increasing core strength or power. This will be accomplished in the following sections: Anatomy of the Core, Core Strength, Volleyball Serves, and What an Athlete Can Gain.

Anatomy of the Core

Core and trunk are occasionally used interchangeably to include the articular cartilage, fibro cartilage, ligaments, tendons, muscles, and fascia within the axial skeleton.[1] The core also includes the main muscles that move both the arms and the legs which attach to the pelvis and the trunk.[2] The core of the body has a tendency to work as a foundation for any motion of the extremities.[2] The muscles of the core include the muscles of the trunk and pelvis that help to maintain the stability of the spine and pelvis.[3,4] There are three muscles that are thought to have the most profound effect on athletic performance are the lumbar multifundus, transverse abdominis, and quadratus lumborum.[5] Through research it has become known that there is moderate evidence that the lumbar multifundus is activated more so during free weight exercises in comparison to a ball or device exercise.[5] There is also moderate evidence to show that the transverse abdominis is activated during a core stability exercise, or during a ball/device exercise. [5] However, there is no evidence to show an activation of the quadratus lumborum during physical fitness exercises. [5]

Kinetic chain: All body movement is said to be part of a kinetic chain, where moving one part of the body causes a chain reaction in another area, allowing the movement to occur. There are two types of kinetic chains; an open kinetic chain, and a closed kinetic chain. An open kinetic chain can be defined as a movement where the distal segment of a limb moves freely, while the proximal segment of the limb is fixed.[6] A volleyball serve would be an example of an open kinetic chain activity, as the hand is free to move and strike the ball, while the shoulder is fixed to the core of the body. A closed kinetic chain is when the distal segment is fixed, and the proximal segment moves, such as a leg squat. During a volleyball serve, potential energy is transferred from the lower extremity, to the core, to the upper extremity, and finally to the ball.[7] The kinetic, or kinematic chain, helps to produce an increase in velocity from the proximal to distal joints.[8-11] It is thought to believe that the muscles of the core help to both generate and transfer energy from the large to small body parts during sporting activities.[3,4] It is included in integrated kinetic chain activities, such as throwing, due to the thoracolumbar fascia that connects the lower and upper limbs via the gluteus maximus and latissimus dorsi respectively.[2,12] The core is also used to create rotational forces around the spine to transfer to the extremeities.[7] Trunk kinematics have also been associated with sagittal plane hip and knee kinematics.[13] There is also research that suggests that limb movement is delayed when a task has a high postural demand.[14,15]

Core Strength

Core strength is a heterogeneous term, due to the fact that the definitions obtained from literature are tailored to diverse ranges of populations from collegiate athletes, to non-active adults, to elderly adults.[16] It is a broad term used to include proprioceptive control, strength, power, and endurance of the core.[17] Hibbs et. al. stated that it is difficult to differentiate between core strength and core stability, but that they are two concepts that are both fundamental, but also extremely different.[18] Zazulak et. al. utilized muscle latency tests to prove that there decrease core musculature proprioception leads to an increase in risk of injury.[19] In future research, if there were to be a field test that were to be tested and deemed both valid and reliable, the ability to study the relationship between core stability and athletic performance would increase drastically.[17]

Core strength is an arbitrary term that can be defined in many different ways. The core has come to be known to play a critical role in transferring power within the body from the axial to the appendicular skeleton.[20] This means that core strengthening has become an essential component of exercise training.[20] Core strength has also been defined as the ability of the core musculature to stabilize the lumbar spine and or generate and maintain a force.[16,21]

Core Stability

Core stability is very difficult to accurately quantify as well, as it is difficult to single out each individual component.[2] It is a subjective term that can be defined as the ability of passive and active stabilizers in the lumbopelvic region to maintain appropriate trunk and hip posture, balance, and control during both static and dynamic movements.[16,19,22] Wilson et al. defined core stability as the ability of the lumbopelvic-hip structures and musculature to withstand compressive forces on the spine and return the body to equilibrium after perturbation.[23]

How to improve the core: The athletes in this day and age, from youth to professional athletes, are striving to improve his or her own performance.[16] The increase in performance is usually sought after by varying activities including some aspect of core strengthening.[16] Martuscello et al. found that free weight exercises including the squat and deadlift produce optimal activity of the lumbar multifundus.[24] On the other hand, there was not a specific type of exercise that was shown to be more effective than others at activating either the transverse abdominis or the quadratus lumborum.[24]

Importance of Core Strength

To maintain successful stability of the core, the body must combine sensory, motor-processing, and biomechanical strategies along with learned responses and the ability to anticipate change.[25] During every day activities, core strength is important as the body must maintain balance during every day activities such as walking, running, or sitting.[26] It also must work together with other systems of the body to accomplish these actions.[26] While standing, the body must maintain a center of gravity over ones feet, his or her base of support, by using visual, somesthesia, and vestibular cues that it receives from ones surroundings.[27] Based upon the cues, the body then produces synchronized muscle contractions to maintain an upright posture.[26]

However, during athletics, core strength has more demands. It is a pivotal component in most every athletic activity.[2] Sports that require overhead movements rely heavily on core musculature as it appears to produce torque during athletic performance.[27] There has also been found to be a relationship between core stability and injury prevention.[17] For instance, Shinkle et al. found a correlation between medicine ball throws and performance variables, which suggests that the core does have some relationship with performance.[25] Another example is from Sharrock et al. who found a weak to moderate correlation between core isometric endurance exercises and performance measures in Division I college football players.[17,28] After the study performed by Shinkle et al. the authors recommended the athlete to train the lateral aspects of the core with specific dynamic exercises.[29]

However, despite the lack of evidence to prove the direct relationship of core strength and athletic performance, core training is still a mainstay in most all athletic development training programs.[16] Even elite athletes partake in core stability and strengthening programs as a part of his or her total strengthening program.[18] Even though research has failed to yield conclusive findings.[27]

Assessing Core Strength

Muscles fire in groups to produce a task-specific pattern providing core strength, making an evaluation of one single muscle as a point of reference questionable.[2] Sharrock et al. believes that based upon the available evidence that the Double Leg Lowering Test is an appropriate way to measure core stability as it pertains to athletic function.[17] It is also supported within the literature as a reliable measure of core strength.[30-32] However, Knudson believes that tests to assess the core should focus more on muscular endurance rather than strength or power, as muscular endurance is functionally more important in supporting the axial skeleton.[35]

Therefore, in recent years, the plank test has been gaining popularity as a test of core muscular endurance as it provides an adequate stimulus for endurance training.[34] There are many different tests that have been used in order to assess both core strength and core stability such as frontal abdominal power test, sagittal abdominal power test, and the double leg lowering test. Cowley and Swenson found that both the Frontal Abdominal Power Test, and the Sagittal Abdominal Power Test are reliable tests and therefore may be used to assess the power component of core stability in young women.[19]

Volleyball Serves

The main goal of a serve during a volleyball game is to score an ace or to force the receiving team to produce an error or make an offensive attack more difficult.[37] There are three main types of volleyball serves, the Float Serve, the Jump Float Serve, and the Jump Serve.

According to Ciuffarella et al. the Float Serve was used so rarely in their study that it seemed to serve only as a game-specific employment.[37] In order to perform a Float Serve, the player strikes the volleyball over his or her hand with no spin, while both feet are planted on the ground.[37]

One study found that the Jump Float serve has a low incident of errors, and therefore concluded that the Jump Float serve could be used against a team with weak attackers.[37] This would help to reduce the server's potential for error during service in hopes that the opposing team would make an attack error.[37] It would also be useful when a team would like to prepare for the next defense.[37] To perform a Jump Float serve, the volleyball is also struck over the head with no spin, but it is struck while the player is in the air during a vertical jump.[37]

The Jump Serve has become increasingly relevant in high-level volleyball.[37] It is also the serve that maintains the highest failure percentage of failure as compared to the other types of serves.[38,39] This serve has the potential, when successfully completed, to increase the defensive errors, leading the opposing team into a crisis mode.[34,38] During a jump serve, the volleyball is struck over the head with much pace and topspin.[37] It is completed in the air through a great vertical jump.[37]

Why a serve is important: The serve in a volleyball match is one of the most important attack actions because it is the first chance a team has for an offensive play within the match, and therefore coaches and players similarly focus on this fundamental action.[36,40] Silva et al. found that the skills that discriminate in favor of victory are both the serve point and blocking errors.[27] It can be inferred that the serve is a critical component in the success of volleyball teams, and emphasis should be placed upon this skill during the training process.[40]

What an Athlete Can Gain

With an increase in serve velocity, a volleyball player can improve his or her own game by making the opposing team's reception of his or her serve more difficult, as there would be less time to react with an increase in serve velocity.

Summary

Within the sport of volleyball, the serve is a skill which is essential to the game. The serve can, for some, be the hardest skill to master as there are multiple types of serves. They are the float serve, jump float serve, and top spin serve. The float serve is a serve where the ball is struck in such a way where no spin is produced, and both feet stay on the ground.[38] The jump float serve occurs when the ball is struck in such a way that no spin is produced, while the player is in the air through a small vertical jump.[37] Finally, a Jump Serve is performed when the ball is struck with much force and at such an angle that the ball spins forward in the air while the player is in the air through a large vertical jump.[37] Each serve requires a different skill set, and therefore different muscles must be utilized to maximize success rate. Knowing how core strength may affect serve velocity could help coaches increase his or her players' performance, and therefore decrease service errors.

APPENDIX B

The Problem

STATEMENT OF THE PROBLEM

Muscular performance is a large part of athletics, and a lack of strength in a particular muscle group could lead to a decrease in performance of a skill or movement. It is unknown if there is a correlation between core strength and serve velocity in serve velocity in collegiate volleyball players. Therefore, the purpose of this study is to assess the correlation between core strength and power, and serve velocity in collegiate women's volleyball players.

Definition of Terms

The following definitions of terms will be defined for this study:

1) Core: the lumbar multifundus, transverse abdominis, and quadratus lumborum
2) Volleyball Serve Velocity: the velocity at which the ball passes over the net after a serve.
3) Competitive Volleyball Experience: years of competitive club volleyball, high school volleyball, and collegiate volleyball combined.

Basic Assumptions

The following are basic assumptions of this study:

1) The subjects will be honest when they complete their demographic sheets.
2) The subjects will perform to the best of their ability during testing sessions.

Limitations of the Study

The following are possible limitations of the study:

1) It has not been shown that the Double Leg-Lowering Test or the Front and Side Abdominal Power Test are valid tests.
2) Athletes can be inconsistent in performance, and thus measurements can be a little subjective.
3) There is no gold standard to assess core strength.

Significance of the Study

Within the sport of volleyball, the serve is a skill which is essential to the game. The serve can, for some, be the hardest skill to master as there are multiple types of serves. Each serve requires a different skill set, and therefore different muscles must be utilized to maximize success rate. Understanding the relationship between core strength and serve velocity could help coaches increase his or her players' performance, and therefore decrease service errors.

APPENDIX C

Additional Methods

APPENDIX C1

Informed Consent Form

Informed Consent Form

1. Samantha Herbert, who is a Graduate Athletic Training Student at California University of Pennsylvania, has requested my participation in a research study at California University of Pennsylvania. The title of the research study is *Correlation Between Core Strength and Serve Velocity in Collegiate Volleyball Players.*

2. This research study will include two assessments of core strength, known as the Double Leg-Lowering Test and the Front and Side Abdominal Power Tests. The Double Leg-Lowering Test involves the participant lying on her back with her legs straight up in the air, and slowly lowering her legs to the ground until a break of form is noticed by the researcher. The Front Abdominal Power Test involves the participant forcefully sitting up while tossing a medicine ball as far as she can. The Side Abdominal Power test involves the participant forcefully rotating her body while tossing a medicine ball as far as she can. The research study will also include assessing the participants' height and weight using the scale in the California University of Pennsylvania scale in the Convocation Athletic Training Room. The subjects will also be asked to perform three vertical jumps using a Vertec Vertical Jump Training Measurement. The research study will also involve performing three jump float volleyball serves on a regulation indoor volleyball court after a warm-up protocol is performed

3. I have been informed that the purpose of this study is to examine the relationship between core strength, serve velocity, height, weight, and jump height. I understand that I must be 18 years of age or older to participate. I understand that I have been asked to participate along with other varsity athletes participating on the Women's Volleyball team at California University of Pennsylvania due to my collegiate volleyball experience. I understand that in order to participate in this study I must confirm I am not currently suffering from and have had no injury which has removed me from practice or competition in the month prior to the time of testing. I confirm that I am not currently pregnant and in the event I do become pregnant I will immediately notify the Primary Researcher. I understand that the Principal Investigator will terminate my participation if circumstances such as unexpected

pregnancy arise due to the potential risk to the unborn child.

4. I have been invited to participate in this research project. My participation is voluntary and I can choose to discontinue my participation at any time without penalty or loss of benefits. My participation will include self reported age, year in school, playing position, serve preference, years of competitive volleyball experience, and how likely she would be to serve in a game situation. My participation will also include a measurement of height, weight and jump height. As well as performing the Double Leg-Lowering test, Front and Side Abdominal Power Tests, a warm up protocol, and three successful attempts at the jump float serve. All testing materials will be completed over the course of one session.

5. I understand there are foreseeable risks or discomforts to me if I agree to participate in the study. I understand that there is risk of soft tissue damage, muscle soreness, muscle cramping, loss of balance, falling and the possibility of experiencing fatigue during testing. With participation in a research program such as this there is always the potential for unforeseeable risks, such as a subject experiencing exaggerated fatigue due to sickness at the time of testing. I understand that the Double Leg-Lowering test and Front and Side Abdominal Power test are part of data participation. I understand the Principal Investigator will inform me of any significant new findings developed during the research that may affect me and influence my willingness to continue participation.

6. I understand that, in case of injury, I can expect to receive treatment or care in Hamer Hall's Athletic Training Facility. This treatment will be provided by the researcher, Samantha Herbert, under the supervision of the California University of Pennsylvania Athletic Training faculty involved in this study, all of whom can administer emergency care.[1] Additional services needed for prolonged care will be referred to the attending staff at the Downey-Garofolo Student Health Center located in Carter Hall on campus. I understand, in case of prolonged stress, there is on campus counseling services available in Carter Hall Room G-53.

7. I understand that the possible benefits of my participation in this research study relates to developing

a better understanding of the relationship between core strength and athletic performance. My participation may aid in the alteration of training techniques in women's volleyball to increase athletic performance.

8. I understand that demographic information will be asked of me for research purposes including height, weight, age, year in school, playing position, serve preference, years of competitive volleyball experience, and how likely she would be to serve in a game situation. However, identifying information such as name will not be used in this study during publication. Only aggregate data will be reported. In order to maintain confidentially of my records, Samantha Herbert will maintain all documents in a secure location on campus and password protect all electronic files so that only the student researcher and research advisor can access the data. Each subject will be given a specific subject number to represent his or her name so as to protect the anonymity of each subject.

9. I have been informed that I will not be compensated for my participation nor will there be any costs incurred on my behalf.

10. I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by:

Samantha Herbert, LAT, ATC
STUDENT/PRIMARY RESEARCHER
HER5285@calu.edu
(410) 598-8008

Lindsey McGuire, PhD, LAT, ATC
RESEARCH ADVISOR
mcguire@calu.edu
(724) 938-4823

11. I have read the above information and am electing to participate in this study. The nature, demands, risks, and benefits of the project have been explained to me. I knowingly assume the risks involved, and understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. I understand the Principal Researcher may terminate my participation at any time without warning. In signing this

consent form, I am not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to me upon request.

12. This study has been approved by the California University of Pennsylvania Institutional Review Board.

13. The IRB approval dates for this project are from: 02/12/15 to 05/08/15.

Subject's signature:____________________________________
Date:_____________________

Witness signature:____________________________________
Date:_____________________

APPENDIX C2

Institutional Review Board –

California University of Pennsylvania

Institutional Review Board
California University of Pennsylvania
Morgan Hall, Room 310
250 University Avenue
California, PA 15419
instreviewboard@calu.edu
Robert Skwarecki, Ph.D., CCC-SLP,Chair

Dear Ms. Herbert,

Please consider this email as official notification that your proposal titled "Correlation Between Core Strength and Serve Velocity in Collegiate Volleyball Players" (Proposal #14-040) has been approved by the California University of Pennsylvania Institutional Review Board as amended.
The effective date of the approval is 3/17/2015 and the expiration date is 3/16/2016 These dates must appear on the consent form .
Please note that Federal Policy requires that you notify the IRB promptly regarding any of the following:

(1) Any additions or changes in procedures you might wish for your study (additions or changes must be approved by the IRB before they are implemented)
(2) Any events that affect the safety or well-being of subjects
(3) Any modifications of your study or other responses that are necessitated by any events reported in (2).
(4) To continue your research beyond the approval expiration date of 3/16/2015 you must file additional information to be considered for continuing review. Please contact instreviewboard@cup.edu

Please notify the Board when data collection is complete.

Regards,
Robert Skwarecki, Ph.D., CCC-SLP
Chair, Institutional Review Board

Appendix C3

Individual Data Collection Sheet

Subject Number: _____________

Height: _____________

Weight: _____________

Jump Height: _____________

Trials	Double Leg-Lowering Test	Medicine Ball Toss	Volleyball Serve Velocity
Trial 1			
Trial 2			
Trial 3			
Average			

Appendix C4

Demographic Information

Demographic Information

Subject Number: ____________

Age: ________________________

Year in school: ________________

Playing Position: _____________________

Serve Preference: _____________________

Years of Competitive Volleyball Experience: ______________

If you were to play in a game situation, how likely would it be that you would serve?

Not Likely				Very Likely
1	2	3	4	5

Appendix C5

Spec Sheet for Radar Gun

8. Specifications

Weight	(with batteries)	2 lbs .91 kg
	(without batteries)	1.33 lbs .60 kg
Height	10 in 24.40 cm	
Width	3.13 in 7.94 cm	
Length	7.13 in 18.10 cm	
Operating Temperatures		-4°F to +140°F -15°C to +60°C

8.1 Antenna Parameters

K-Band

Nominal transmission frequency	24.150 GHz ± 50 MHz
Nominal horizontal beamwidth	12°
Polarization	circular
Nominal microwave power output	10 mW
Maximum aperture power density	1 mW / cm²

Environment

Ambient operating temperatures -22°F to +158°F
-30°C to +70°C

Maximum humidity 90% relative humidity at 98.6°F (37°C) (non-condensing)

Water resistance meets International Robustness Standard IEC 529:1989 and European Community Standard EN 60529 Classification IP55. These set international standards for immunity from damage by solid protrusions and water.

8.2 Voltages

Supply voltage	6.2 VDC – 8.0 VDC
Power supplied from replaceable Ni-Cad batteries	
Low voltage threshold	6.2 VDC

8.3 Speed Range Parameters

Range	25 – 125 mph 40 – 200 kph
Display accuracy	± 1 display unit
Internal accuracy	± 0.4 display unit
Target acquisition time	0.021 seconds

8.4 Power Consumption Parameters

Power output	5 mW nominal
Power density	0.5 mW / cm²

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ABSTRACT

Title:	The Correlation Between Core Strength and Serve Velocity in Collegiate Volleyball Players
Researcher:	Samantha M. Herbert
Advisor:	Dr. Lindsey McGuire
Date:	May 2015
Research Type:	Masters' Thesis
Purpose:	The purpose of this study was to assess the relationship between core strength in Division II Collegiate Women's volleyball players, and the velocity of a volleyball serve.
Problem:	To find if core strength is an imperative aspect in increasing ones' volleyball serve velocity.
Method:	Ten female NCAA Division II collegiate volleyball players participated. Each participant performed height, weight, jump height, Double Leg Lowering Test, and Front and Side Abdominal Power Tests. Each participant also completed a demographic questionnaire.
Findings:	There was a positive correlation between volleyball serve velocity and the Front Abdominal Power Test. No correlation was found between the Double Leg Lowering Test, Left or Right Abdominal Power Test and volleyball serve velocity.
Conclusion:	Frontal plane core strength seems to play a role in volleyball serve velocity. However, further research must be conducted with a larger sample size to validate this assessment.