4-15-2011

Association of Drop Vertical Jump Displacement with Select Performance Variables

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Recommended Citation

Feldmann, Christina Rose, "Association of Drop Vertical Jump Displacement with Select Performance Variables" (2011). *Electronic Theses and Dissertations*. 166.
https://digitalcommons.memphis.edu/etd/166

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The Thesis Committee for Christina Feldmann certifies that this is the final approved version of the following electronic thesis: “Association of Drop Vertical Jump Displacement with Select Performance Variables.”

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ASSOCIATION OF DROP VERTICAL JUMP DISPLACEMENT WITH SELECT PERFORMANCE VARIABLES

By

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A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Health and Sport Sciences

The University of Memphis

May 2011

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor and thesis chair, Dr. Lawrence Weiss, for his guidance throughout this process. His determination for excellence and integrity in his work has influenced my research practices in addition to other aspects of my life. My success on this thesis project is a result of the challenges he encouraged me to face and the support he provided to overcome those challenges. I am very grateful of the many influences he has had on my career at the University of Memphis.

I would also like to thank my thesis committee members, Dr. Brian Schilling and Dr. Zsolt Murlasits. Their support throughout the entire process, in addition to their recommendations on the project, was invaluable to the completion of my thesis. I would also like to thank Dr. William Ebben, my advisor during my undergraduate studies. His enthusiasm and passion for research persuaded me to attend graduate school and pursue an advanced degree.

ABSTRACT

Feldmann, Christina Rose. M.S. The University of Memphis. May 2011. Association of drop vertical jump displacement with select performance variables. Major Professor: Lawrence W. Weiss, Ed.D.

A variety of performance variables have been proposed as methods of measuring jumping performance including ground contact time (GCT) during a drop vertical jump (DVJ), Reactive Strength Index (RSI), Eccentric Utilization Ratio (EUR), and Elasticity Index (EI). This study assessed the stability reliability and precision of these variables and their associations with DVJ displacement in trained men and women. Data for all variables were reliable and precise ($ICC \geq 0.70$, $CV\% \leq 15.0$) except for EUR for both men and women. Correlations with DVJ displacement were fairly low for GCT, moderate for RSI, and negligible for EUR for both men and women. GCT and EUR explained very little of the variability in DVJ performance and are likely to represent unique performance characteristics not related to DVJ displacement. RSI accounts for a portion of variability in DVJ displacement but may have limited utility for explaining performance beyond displacement.

Key words: ground contact time; reactive strength index; eccentric utilization ratio; elasticity index; reliability

PREFACE

This thesis was written in article format for submission to the *Journal of Strength and Conditioning Research* following defense. The content and organization of this thesis represent and fulfill the requirements for submission to this journal.

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INTRODUCTION

Vertical jumping is a fundamental component of many sports and also may be predictive of performance in other sports in which jumping is not the primary component (1). Although vertical displacement is probably the most common measurement of jumping performance, a variety of additional indices and variables have been proposed. For example, strength and conditioning professionals have examined the Reactive Strength Index and ground contact time during drop vertical jumps (DVJ), and the Elasticity Index and Eccentric Utilization Ratio during static and countermovement vertical jumps.

The Reactive Strength Index (RSI) is calculated by dividing DVJ displacement by the elapsed ground contact time (25). RSI has been used to address stretch-shortening cycle capabilities of athletes, to monitor jumping performance throughout a training period, and to establish the optimal drop height for DVJ performance (15). Although RSI appears to be a reliable measure (6,7), little is known about the strength of the association of this variable with DVJ displacement.

Ground contact time (GCT) during a drop vertical jump is also typically analyzed as a performance variable if success depends on how quickly an athlete can perform the jumping task. In addition to RSI, GCT has been shown to be a highly reliable measurement in a combined group of male and female athletes during DVJ; however, separate gender analyses were not performed (7). Previous research suggests that a positive association may exist between GCT and jump displacement or takeoff velocity during a DVJ (21,23), but this association may be fairly weak (21).

The Eccentric Utilization Ratio (EUR) and the Elasticity Index (EI) are two performance variables that have been proposed as being reflective of the stretch-shortening cycle (SSC) capabilities associated with jumping. Both variables are ratios that assess the difference between a static jump (SJ) and a countermovement jump (CMJ). Furthermore, both have been used to assess SSC capabilities throughout different training periods (16), evaluate gender differences in SSC capabilities (19,20), and compare the performances of two different groups of athletes (9). Although the reliabilities of these ratios have yet to be determined, the reliability of jump displacement during SJ and CMJ has been well documented (14,17,18).

The purpose of the current investigation is to determine the association of drop vertical jump displacement and a variety of performance variables including RSI, GCT, EUR, and EI. As a secondary purpose, these same associations were assessed for any gender-specific tendencies. Since the stability reliability and precision of these variables have yet to be firmly established for men and women separately, both were assessed prior to the correlational analyses of this investigation. To our knowledge, a comprehensive study establishing the correlations between jump displacement and the aforementioned variables has not been published. Determining these associations may help identify variables highly related to vertical jumping displacement that may also be independent of each other. Absent this understanding, the acquisition of redundant measures appears more likely.

METHODS SECTION

EXPERIMENTAL APPROACH TO THE PROBLEM

The aim of this investigation was to examine the association of DVJ displacement (from multiple drop heights) with four different variables purportedly related to jumping ability. These variables include RSI, GCT, EI, and EUR. As a secondary purpose, associations were assessed for gender-specific tendencies by determining correlations for men only and for women only. The reliability and precision of each jump performance measure for men and women were also established in this investigation.

SUBJECTS

Forty-eight subjects (26 men, 22 women) between the ages of 18 and 30 participated in this study (Table 1). All subjects had participated in lower-body resistance training and plyometric training for at least six months prior to the study. Athletes (track and field athletes, and softball athletes) volunteering as subjects were not currently in a competitive season of their sport. All subjects provided written informed consent as approved by the University of Memphis Institutional Review Board.

Table 1. Descriptive statistics for men and women

Variable	Men (n = 26)	Women (n = 22)
Age (yrs)	21.3 ± 2.5	21.2 ± 1.9
Height (m)	1.79 ± 0.08	1.68 ± 0.04
Weight (kg)	79.0 ± 8.5	63.8 ± 6.2
Max CMJ (cm)	39.6 ± 0.06	27.8 ± 0.05

*Max CMJ = maximum countermovement vertical jump performed during the habituation session

TESTING PROTOCOL

Subjects reported to the laboratory on three separate occasions wearing the same type of clothing and footwear to each session. The first session was used to obtain informed consent, relevant health and physical activity history, and subject descriptive information, and to habituate the subjects to the testing. The final two sessions, separated by 48 hours, were used for data collection. Subjects were asked to refrain from strenuous resistance training for 24 hours prior to each testing session.

Subject descriptive information included height, body weight, age, and maximum countermovement jump displacement. A standardized warm-up was performed prior to the jumping tests. This warm-up included five minutes of stationary bicycling, 10 slow bodyweight squats, 10 fast bodyweight squats, and two vertical jumps. Following the warm-up, subjects performed a maximum countermovement jump test (with self-selected depth) on a force platform.

For habituation, subjects completed trials of all jump tests in a randomized order. The jump tests included two attempts each of the 1) countermovement jump, 2) static jump, as well as drop vertical jumps from absolute drop heights of 3) 30cm and 4) 60cm, and relative drop heights of 5) 50% and 6) 75% of each subject's maximum countermovement jump displacement. In previous research, drop jumps have been performed from absolute drop heights (4,15,23) and from drop heights relative to a subject’s vertical jump performance (12). During this habituation session, subjects performed two repetitions of each jump interspersed by a one-minute rest period.

Two testing sessions were used to assess stability reliability and precision for all jump performance variables. Subjects completed the same standardized warm-up prior to testing as was used during the preliminary session. Subjects then performed two repetitions of each jump in a randomized order on a force platform. A one-minute recovery period was implemented between every jump trial. The second testing session followed the same protocol and was conducted 48 hours after the first testing session.

Vertical Jump Protocol

Each subject was provided standardized verbal instructions for performing each type of vertical jump test. For the static jump (SJ), subjects were instructed to descend to a position of 90 degrees of knee flexion. They were asked to hold this position until verbally commanded to jump (approximately 2 seconds). Force-time records were also assessed to confirm that no countermovement was taken prior to the jump. For the countermovement jump (CMJ), subjects began upright with knees fully extended. Subjects then performed a self-paced downward movement (countermovement) to 90 degrees of knee flexion before they jumped. To insure each subject reached a depth of 90 degrees of knee flexion for the SJ and CMJ, an elastic cord was positioned so that each subject descended to the appropriate depth (Figure 1). To perform the drop vertical jumps (DVJ), subjects started on top of a box at each of the four specified heights. Subjects stepped off of the box, landed simultaneously with both feet, and jumped as high and quickly as possible. For all jumps (CMJ, SJ, and DVJ) during the habituation and testing sessions, subjects held a plastic pipe across the tops of their shoulders to standardize arm position similar to that used for a barbell back squat. The rationale for using the plastic pipe was to eliminate any contributions of arm swing to the vertical jumps.

Measurements

Jump displacements were determined using a force platform (Roughdeck™ Rice Lake Weighing Systems, Rice Lake, WI) to determine flight time. Force output was channeled through a signal conditioner/amplifier (TMO-2; Transducer Techniques, Temecula, CA) interfaced to a PC via a 12-bit analog digital converter (PCI-DAS1200, Measurement Computing, Middleboro, MA) and sampled at 500Hz. Datapac 5 (v5.0, Mission Viejo, CA) was utilized for data extraction. Data were low-pass filtered (4th order, zero-lag Butterworth) with a cutoff frequency of 30Hz. Force output was used to measure flight time (all jumps) and contact time (DVJ only). The on/off times for contact and flight time were visually selected. The flight time data were then used to estimate jump displacements based on equations for uniformly accelerated motion (8).

Jumping Indices

Indices from the jump data were Reactive Strength Index (25), Elasticity Index (19), and Eccentric Utilization Ratio (16), and were calculated as follows:

- RSI = DVJ Displacement (m) / DVJ Ground Contact Time (s)

- EI = (CMJ-SJ) / SJ x 100%

- EUR = CMJ / SJ

Statistical Analysis

For each jumping task, the best of two attempts, as measured by jump displacement, was used for analysis. Previous research has demonstrated the reliability of assessing the best jump trial from a set of jump trials (17). Stability reliability and precision were assessed for displacement, GCT, and RSI during the DVJ repetitions from all four drop heights. Stability reliability and precision were also assessed for EI and EUR obtained from the CMJ and SJ data. Intraclass correlations (ICC, two-way random model) were used to assess stability reliability, and coefficients of variation (CV%) were used to assess precision. Coefficients of variation were reported instead of the standard error of measurement because it better reflects the precision of a measure when dealing with heteroscedastic data, a common phenomenon in physical performance measures (10,11,24). Previous research has established minimally-acceptable statistical standards for stability reliability, $ICC \geq 0.70$ (3) and precision, CV% $\leq$ 15.0 (22). Associations were assessed by bivariate correlations. Although no universally-acceptable standard exists for correlations (3), the minimum selected herein was the same as used for reliability ($r \geq 0.70$) so that each viable index would account for no less than 49% of the variability in DVJ displacement. Associations with DVJ displacement were assessed for RSI, GCT, EUR, and EI. These associations were analyzed for all subjects, men only, and women only. One female subject only completed the familiarization and first testing sessions. Therefore, her data were included when determining associations for the first testing session but were dropped from the reliability and precision analyses.

RESULTS

Reliability of Jump Displacements

Gender-specific stability reliability and precision data for jump displacements appear in Tables 2 and 3. Data for jump displacements during all jumps were reliable and precise for men (*ICC* = 0.89 to 0.95, *CV* = 3.8 to 6.6%) and for women (*ICC* = 0.88 to 0.97, *CV* = 3.0 to 6.4%).

Reliability of Jump Performance Variables

Gender-specific stability reliability and precision data for all performance variables and indices are shown in Tables 4 and 5. Data for GCT during DVJ's from all four drop heights were reliable and precise for men (*ICC* = 0.82 to 0.88, *CV* = 7.3 to 9.6%) and for women (*ICC* = 0.80 to 0.96, *CV* = 5.8 to 12.8%). Data for RSI were also reliable and precise for men (*ICC* = 0.87 to 0.90, *CV* = 8.6 to 9.0%), and for women (*ICC* = 0.82 to 0.95, *CV* = 8.2 to 14.6%). When analyzing the data for EI and EUR, it was determined that these two indices are mathematically redundant. The EI resulted in a value that was always 1.0 less than the EUR and both indices had the same standard deviations. Therefore, only data from the EUR were reported. EUR data were unreliable for men and for women (*ICC* = 0.31 to 0.52), although they were precise (*CV* = 5.3 to 5.4%).

Association of DVJ Displacement and Performance Variables

Since data were mostly reliable and precise, correlations were reported for the two individual testing sessions for all subjects, for men only, and for women only. Negligible, non-significant correlations were found between DVJ displacement and GCT at all drop heights for all subjects and in both testing sessions, $r = -0.11$ to 0.11 ($p > 0.05$) (Table 6). Correlations between these two variables for men were mostly low and non-significant, $r = 0.18$ to 0.34 ($p > 0.05$) except for the DVJ from 30cm and from 75% maximum jump displacement during the first session only, $r = 0.57$ and 0.41, respectively ($p < 0.05$) (Table 7). Correlations ranged from low negative to low positive between these two variables for women during both sessions, $r = -0.31$ to 0.14 ($p > 0.05$) (Table 8). Associations between DVJ displacement and RSI were moderate for all subjects for the two testing sessions, $r = 0.59$ to 0.67 ($p < 0.05$) (Table 9). When assessed separately for both genders, associations were much lower for the men and only some correlations reached a significant level, $r = 0.34$ to 0.44 (Table 10). Associations were moderate for the women, $r = 0.50$ to 0.60 ($p < 0.05$) except for the DVJ from 75% maximum jump displacement for the second testing session, $r = 0.43$ ($p > 0.05$) (Table 11). All of these correlations were still below the criterion set in this study (3). Correlations were also calculated between DVJ displacement and EUR for both testing sessions. Negligible, non-significant associations were found between these two variables for all subjects, $r = -0.06$ to 0.21, for men only, $r = -0.12$ to 0.09, and for women only, $r = -0.16$ to 0.23, ($p > 0.05$) (Tables 12-14).

DISCUSSION

Stability reliability and precision were determined for the jump displacements of all jumps (CMJ, SJ, and DVJ from all four drop heights). Even with reduced variability in measures when men and women were treated separately, stability reliability and precision for the CMJ and SJ were well within the standards set in this study (3,22). The *ICC* and *CV* values for the CMJ and SJ are very similar to values published in previous research for men and women assessed separately (14,17). DVJ displacements from 30cm, 60cm, as well as 50% and 75% of maximum jump displacement were also reliable and precise. Previous research has demonstrated that jump displacements during DVJ from a single, absolute drop height are reliable and precise measurements (2,5,7). However, our study indicates that DVJ displacement is reliable and precise from multiple drop heights including absolute drop heights and drop heights relative to a subject's jumping ability for both men and women.

Stability reliability and precision were also determined for additional jump performance variables including GCT, RSI, and EUR. GCT and RSI data from all four drop heights were within the reliability and precision standards set in this study (3,22). Although the GCT data during DVJ's from all four drop heights were within the standards set in this study, the data were generally not as reliable or precise as DVJ displacement. This is in accordance with other published research on the reliability and precision of DVJ variables (2,5,7). RSI data from all four drop heights resulted in high *ICC* values for men and women separately. Many of the *ICC* values were similarly high to those found in research by Flanagan, et al (5) and Feldmann, et al (7), and were much higher than those reported by Barnes, et al (2). Precision standards for RSI were also met; however, the coefficients of variation were typically higher than DVJ displacement and GCT.

EUR data were not reliable for men or for women; however, data were always precise. Even though the mean trial-to-trial differences were low, the concurrent low between-subject variability is likely largely responsible for the low reliability (11,24). Since *ICC* values are adversely affected by a homogeneous distribution of scores, precision in this case may be a more useful indicator of the utility of the data. Precision may be assessed using the standard error of measurement which uses the same units of measure as is used for the mean. However, owing to the heteroscedastic nature of most physical performance data, the coefficient of variation (CV) better reflects precision as it is expressed as a percentage (10,13). Low *CV* values for EUR indicated good precision existed for the men and women in this sample. Therefore, EUR data were still used to assess correlations with DVJ displacement.

Since output for all jump displacements and performance variables were mostly reliable and precise, associations of these variables were determined for individual testing sessions. The associations between DVJ displacement and GCT at all drop heights were positive but mostly non-significant for men, except for two drop heights during the first testing session. Previous research with male sprinters resulted in moderately low correlations between DVJ displacement and GCT (21); however, non-significant negative correlations were found in a group of resistance trained men (5). Since GCT during DVJ's from the four different heights accounted for a maximum of 1% of the variability in DVJ displacement for combined men and women, a maximum of 32% for men only, and a maximum of 10% for women only, GCT appears to be largely unrelated to DVJ performance. These results are in accordance with those found in a group of female volleyball players and in resistance trained women (2,5). Therefore, GCT during DVJ's particularly appears to explain very little of the variability in DVJ performance, especially in women.

As previously noted, RSI is calculated as follows: DVJ displacement divided by GCT. Since GCT has very little association with DVJ displacement, only the dividend of the equation is likely to contribute anything to the explanation of RSI. If the dividend of the equation is the only contributing factor, it follows that very little is likely to be gained by measuring RSI. That being said, correlations between DVJ displacement and RSI were moderately high for all subjects, but when assessed separately by gender, correlations were only moderate for the women and even lower for the men. In addition, all of these correlations were below the standard of $r \geq 0.70$ set for this study (3). For men, RSI accounted for only 11.4% to 19.4% of the variability in DVJ displacement, values similar to those found in male sprinters (21) but lower than those found in resistance trained men (5). The moderate correlations found between DVJ displacement and RSI in women were higher than those found for men, but were still lower than the criterion set for this study (3). In this study, RSI accounted for only 25.3% to 35.9% of the variability in DVJ displacement in women. Considering RSI accounts for only a small portion of variability in DVJ performance and because of the reasons previously stated, it appears that RSI may have negligible utility when measuring performance from multiple drop heights.

If EUR is hypothesized to be a measure of an athlete's stretch shortening cycle capability, then it should be highly correlated to jumping performance since jumping requires the execution of an efficient SSC. However, the present findings indicate that almost no association exists between EUR and DVJ displacement from any of our tested drop heights. Based on these results, the utility of EUR is unclear when assessing performance. Due to its obvious redundancy with EI, the utility of EI is also unclear. Future research needs to assess the associations between different performance measures and either EUR or EI to further elucidate any possible relationships with specific facets of athletic performance.

PRACTICAL APPLICATIONS

When measuring performance, strength and conditioning practitioners should look to variables that are reliable. In addition, practitioners typically test groups of athletes and have strict time constraints to complete the testing. Therefore, it is important to avoid redundancy in measurements and only report variables that evaluate performance. Based on the results of this study, measurements including DVJ displacement, GCT, RSI, and EUR are reliable; however, some of these variables may have limited utility when predicting performance or identifying specific training needs. EUR has almost no association with DVJ displacement and should be further studied to determine what, if any, performance qualities this variable reflects. In addition, GCT has very little association with DVJ displacement and may not be a practical measure of jumping performance unless the timing of the jump is critical such as a rebound in basketball or a block jump in volleyball. Although RSI appears to be somewhat associated with DVJ displacement, this variable also has questionable utility since DVJ displacement is the dividend of RSI, and GCT has very little association with displacement. Therefore, the findings of this study emphasize the importance of selecting reliable and unique performance variables while avoiding variables that may not predict performance or trainable characteristics.

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Table 2: Stability reliability and precision of jump displacements for men only (2 testing sessions)

Variable	Session	Mean	SD	n	ICC	CV%
CMJ	1	0.379	0.056	26	0.95	3.8
	2	0.383	0.058			
SJ	1	0.348	0.051	26	0.92	4.7
	2	0.354	0.053			
DVJ30cm	1	0.353	0.062	26	0.89	6.5
	2	0.358	0.060			
DVJ60cm	1	0.361	0.060	26	0.89	6.2
	2	0.351	0.059			
DVJ50%	1	0.350	0.056	26	0.9	5.8
	2	0.352	0.059			
DVJ75%	1	0.361	0.062	26	0.89	6.6
	2	0.360	0.061			

CMJ = countermovement jump (m); SJ = static jump (m); DVJ30cm = drop jump (m) from 30cm; DVJ60cm = drop jump (m) from 60cm; DVJ50% = drop jump (m) from 50% of subject's maximum CMJ; DVJ75% = drop jump (m) from 75% of subject's maximum CMJ; ICC = intraclass correlation; CV% = coefficient of variation

Table 3: Stability reliability and precision of jump displacements for women only (2 testing sessions)

Variable	Session	Mean	SD	n	ICC	CV%
CMJ	1	0.263	0.045	21	0.97	3.0
	2	0.261	0.048			
SJ	1	0.244	0.041	21	0.94	4.6
	2	0.248	0.045			
DVJ30cm	1	0.270	0.038	21	0.92	5.0
	2	0.265	0.048			
DVJ60cm	1	0.263	0.047	21	0.91	6.4
	2	0.256	0.052			
DVJ50%	1	0.259	0.047	21	0.91	6.1
	2	0.261	0.049			
DVJ75%	1	0.271	0.041	21	0.88	6.3
	2	0.266	0.046			

CMJ = countermovement jump (m); SJ = static jump (m); DVJ30cm = drop jump (m) from 30cm; DVJ60cm = drop jump (m) from 60cm; DVJ50% = drop jump (m) from 50% of subject's maximum CMJ; DVJ75% = drop jump (m) from 75% of subject's maximum CMJ; ICC = intraclass correlation; CV% = coefficient of variation

Table 4: Stability reliability and precision of performance variables for men only (2 testing sessions)

Variable	Session	Mean	SD	n	ICC	CV%
DVJ30cm GCT	1	0.309	0.054	26	0.82	9.60
	2	0.307	0.065			
DVJ60cm GCT	1	0.327	0.062	26	0.87	8.10
	2	0.328	0.064			
DVJ50% GCT	1	0.314	0.055	26	0.88	7.30
	2	0.316	0.064			
DVJ75% GCT	1	0.318	0.069	26	0.88	8.40
	2	0.317	0.068			
DVJ30cm RSI	1	1.161	0.223	26	0.87	8.60
	2	1.212	0.299			
DVJ60cm RSI	1	1.140	0.271	26	0.89	8.70
	2	1.108	0.276			
DVJ50% RSI	1	1.141	0.225	26	0.89	8.90
	2	1.155	0.275			
DVJ75% RSI	1	1.174	0.261	26	0.90	9.00
	2	1.186	0.308			
EUR	1	1.089	0.056	26	0.31	5.40
	2	1.083	0.080			

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; GCT = ground contact time (s); RSI = reactive strength index (m/s); EUR = eccentric utilization ratio; ICC = intraclass correlation; CV% = coefficient of variation

Table 5: Stability reliability and precision of performance variables for women only (2 testing sessions)

Variable	Session	Mean	SD	n	ICC	CV%
DVJ30cm GCT	1	0.347	0.090	21	0.94	6.9
	2	0.318	0.074			
DVJ60cm GCT	1	0.375	0.092	21	0.96	5.8
	2	0.356	0.095			
DVJ50% GCT	1	0.341	0.086	21	0.80	12.8
	2	0.332	0.074			
DVJ75% GCT	1	0.341	0.079	21	0.80	12.0
	2	0.326	0.070			
DVJ30cm RSI	1	0.842	0.291	21	0.95	8.2
	2	0.880	0.274			
DVJ60cm RSI	1	0.747	0.233	21	0.94	9.3
	2	0.771	0.268			
DVJ50% RSI	1	0.815	0.272	21	0.85	14.6
	2	0.835	0.277			
DVJ75% RSI	1	0.848	0.249	21	0.82	13.8
	2	0.854	0.261			
EUR	1	1.085	0.083	21	0.52	5.3
	2	1.055	0.076			

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; GCT = ground contact time (s); RSI = reactive strength index (m/s); EUR = eccentric utilization ratio; ICC = intraclass correlation; CV% = coefficient of variation

Table 6. Association of DVJ displacement and ground contact time: All subjects

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm GCT	-0.03	x	x	x
DVJ60cm GCT	x	-0.11	x	x
DVJ50% GCT	x	x	-0.05	x
DVJ75% GCT	x	x	x	
Session 2				0.03
DVJ30cm GCT	0.07	x	x	x
DVJ60cm GCT	x	-0.06	x	x
DVJ50% GCT	x	x	-0.06	x
DVJ75% GCT	x	x	x	0.11

All $p > 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; JH = displacement; GCT = ground contact time

Table 7. Association of DVJ displacement and ground contact time: Men only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm GCT	0.57*	x	x	x
DVJ60cm GCT	x	0.34	x	x
DVJ50% GCT	x	x	0.24	x
DVJ75% GCT	x	x	x	0.41*
Session 2				
DVJ30cm GCT	0.28	x	x	x
DVJ60cm GCT	x	0.24	x	x
DVJ50% GCT	x	x	0.18	x
DVJ75% GCT	x	x	x	0.25

*$p < 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; JH = displacement; GCT = ground contact time

Table 8. Association of DVJ displacement and ground contact time: Women only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm GCT	-0.31	x	x	x
DVJ60cm GCT	x	-0.09	x	x
DVJ50% GCT	x	x	-0.04	x
DVJ75% GCT	x	x	x	-0.22
Session 2				
DVJ30cm GCT	0.02	x	x	x
DVJ60cm GCT	x	-0.06	x	x
DVJ50% GCT	x	x	-0.18	x
DVJ75% GCT	x	x	x	0.14

All $p > 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; JH = displacement; GCT = ground contact time

Table 9. Association of DVJ displacement and reactive strength index: All subjects

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm RSI	0.60*	x	x	x
DVJ60cm RSI	x	0.67*	x	x
DVJ50% RSI	x	x	0.66*	x
DVJ75% RSI	x	x	x	0.59*
Session 2				
DVJ30cm RSI	0.61*	x	x	x
DVJ60cm RSI	x	0.66*	x	x
DVJ50% RSI	x	x	0.65*	x
DVJ75% RSI	x	x	x	0.60*

*$p < 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; RSI = reactive strength index; JH = displacement

Table 10. Association of DVJ displacement and reactive strength index: Men only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm RSI	0.34	x	x	x
DVJ60cm RSI	x	0.38	x	x
DVJ50% RSI	x	x	0.44*	x
DVJ75% RSI	x	x	x	0.36
Session 2				
DVJ30cm RSI	0.37	x	x	x
DVJ60cm RSI	x	0.43*	x	x
DVJ50% RSI	x	x	0.44*	x
DVJ75% RSI	x	x	x	0.39*

*$p < 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; RSI = reactive strength index; JH = displacement

Table 11. Association of DVJ displacement and reactive strength index: Women only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
DVJ30cm RSI	0.60*	x	x	x
DVJ60cm RSI	x	0.55*	x	x
DVJ50% RSI	x	x	0.50*	x
DVJ75% RSI	x	x	x	0.59*
Session 2				
DVJ30cm RSI	0.52*	x	x	x
DVJ60cm RSI	x	0.58*	x	x
DVJ50% RSI	x	x	0.59*	x
DVJ75% RSI	x	x	x	0.43

*$p < 0.05$

DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; RSI = reactive strength index; JH = displacement

Table 12. Association of DVJ displacement and eccentric utilization ratio: All subjects

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
EUR	-0.01	-0.02	-0.01	-0.06
Session 2				
EUR	0.21	0.17	0.19	0.19

All *p* > 0.05
DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; EUR = eccentric utilization ratio; JH = displacement

Table 13. Association of DVJ displacement and eccentric utilization ratio: Men only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
EUR	-0.03	-0.10	-0.06	-0.12
Session 2				
EUR	0.05	-0.03	0.03	0.09

All *p* > 0.05
DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; EUR = eccentric utilization ratio; JH = displacement

Table 14. Association of DVJ displacement and eccentric utilization ratio: Women only

Session 1	DVJ30cm JH	DVJ60cm JH	DVJ50% JH	DVJ75% JH
EUR	-0.12	-0.08	-0.08	-0.16
Session 2				
EUR	0.23	0.22	0.20	0.11

All *p* > 0.05
DVJ30cm = drop jump from 30cm; DVJ60cm = drop jump from 60cm; DVJ50% = drop jump from 50% of subject's maximum CMJ; DVJ75% = drop jump from 75% of subject's maximum CMJ; EUR = eccentric utilization ratio; JH = displacement

Figure 1. Set-up for performing the countermovement jump and static jump

Appendix B – Extended Literature Review

A variety of performance indices have been proposed as being indicative of jumping capability. The purpose of this review is to examine the associations between drop vertical jump (DVJ) displacement and a variety of unique performance measures including Reactive Strength Index (RSI), DVJ ground contact time (GCT), Elasticity Index (EI), and Eccentric Utilization Ration (EUR). In addition, inter-correlations between RSI, GCT, EUR, and EI will be addressed.

Jumping Performance Measures

Jumping is a common athletic skill involved in the execution of many sports. Previous research has demonstrated that jumping performance is one of the integral components to success in sports (1). One investigation examined the correlation between a variety of sport performance measures and success in football as ranked by coaches and starting status. The 59 Division I players performed two jumping tests, in addition to many other tests, and were separated for analysis by starters and non-starters and by a subjective ranking of the players by the coaches (1). The static vertical jump test had the strongest correlation with coaches' rankings of all performance variables tested during the two sessions, r = -0.73 and -0.76, and the countermovement jump also had a fairly high correlation with coaches' rankings, r = -0.59 and -0.72 (1). (Correlations appear negative because the best perceived player received a ranking of 1). In addition, starters had greater jump performance than non-starters (1). Considering the importance that coaches and researchers place on jumping, measuring jump performance has become an essential part of athletic testing. Therefore, coaches and researchers have created additional variables and indices to measure jump performance. The variables that will be addressed here include RSI, GCT, EUR, and EI.

Reactive Strength Index

What is the Reactive Strength Index and how has it been used?

The Reactive Strength Index (RSI) was initially developed at the Australian Institute of Sport as a way to measure an athlete's ability to utilize elastic energy in the muscle and change quickly from an eccentric to concentric contraction (21). The two components of the reactive strength index are jump displacement and ground contact time during a DVJ (21). To perform a drop vertical jump, the subject drops from a specific height (either a box or force-sledge apparatus) and upon landing, the subject quickly performs a vertical jump. The variables of jump displacement and ground contact time can be measured during drop jumps by the use of a force platform or a switch mat. RSI is then calculated by dividing the jump displacement of the drop jump by the ground contact time (21).

$$\text{RSI} = \text{Jump Displacement} / \text{Ground Contact Time}$$

A higher RSI value reflects greater reactive strength qualities and ultimately, greater jumping performance.

Various applications of RSI have been proposed. In one investigation, 23 rugby players performed drop jumps from three different box heights (15cm, 30cm, and 45cm) during three testing sessions. As the drop height of the box increased, RSI values were evaluated to determine the fast stretch shortening cycle (SSC) abilities of the individual (13). If RSI values increased or were maintained as the box height increased, the individual had adequate reactive strength at that box height (13). Similarly, another article assessed the effect of drop jumps from various heights in a force-sledge apparatus, but this study examined the effect of various drop heights on fascicle and tendinous tissue. Ten trained men performed four drop jumps from various heights, and the four heights were based on percentages of the subjects' maximum squat jump height (11). By assessing the lengthening and shortening of the muscle tissues using real-time ultrasonography, it appears that each individual has a specific drop height threshold in which the individual lacks the strength necessary to overcome the eccentric loading required for the drop jump (11).

RSI has also been proposed as a way of monitoring and optimizing plyometric training. Coaches have used RSI to quantify athletes' reactive strength capabilities throughout a certain training period or sport season (13). This provides coaches and trainers another method of assessing the efficacy of their plyometric training programs. In addition, RSI has been proposed as a method for prescribing specific drop heights for an individual's plyometric training program (13). RSI values can be recorded at various drop heights to find the threshold where RSI values begin to decrease. A drop height that is higher than this threshold may be considered as placing too great of a stretch-load on the athlete, and therefore, this threshold height should be the maximum drop height prescribed for the individual's plyometric program (13). In addition, RSI can be implemented as a motivational tool during training (6). Coaches will motivate an athlete by providing feedback about ground contact times, jump displacements, and reactive strength indices during a training session to encourage improvement on subsequent performances. These practical applications of RSI are methods in which coaches have employed RSI values for measuring jumping performance in their athletes. However, to be of much use, these RSI values must be reliable measures and must be indicative of performance.

Reliability of RSI

The reliability of RSI during drop jumps has been assessed in a variety of studies (2,5,7,8). In recently published data, 52 resistance trained men and women performed DVJ from a 40cm box height. RSI was shown to be reliable and precise in this subject population as assessed by intraclass correlations, ICC = 0.94, and coefficients of variation, CV = 11.3% (8). A study by Barnes (2) assessed RSI in a group of 29 female volleyball players from a drop height of 30cm. This study found relatively good reliability and precision for RSI, ICC = 0.75 and CV = 13.5% (2). Two additional studies reported the reliability of RSI using alpha coefficients and intraclass correlations. One study consisted of 22 track and field athletes performing three drop jumps from a 30cm box (7). Drop jump trials were found to be reliable as assessed by Cronbach (alpha) reliability coefficient $\alpha > 0.95$, and intraclass correlations, ICC > 0.95 (7). Flanagan (5) also found high trial-to-trial reliability for RSI using dominant and non-dominant legs. For this study, eight subjects performed three unilateral drop jumps on a force-sledge apparatus. The results of the reliability analysis revealed alpha reliability coefficients, $\alpha > 0.9$ and intraclass correlations, ICC > 0.85 (5). Overall, RSI appears to be a reliable measure during DVJ.

The association between RSI and drop vertical jump displacement

It is apparent that RSI will increase when jump displacement increases, as long as ground contact time is held constant. However, the association of RSI and jump displacement is important to assess because ground contact time may be altered when jump displacement is increased. An article by Smirniotou (20) assessing strength and power variables as predictors of sprinting performance in male sprinters evaluated drop jump variables and RSI as it relates to sprint performance. In addition, associations between DVJ displacement and RSI values were also assessed (20). There was only a weak correlation between RSI and DVJ displacement from 40cm, and this association was not significant, $r = 0.311$ (20). However, two other studies reported much higher correlations between DVJ displacement and RSI (2,8). Twenty-nine female collegiate volleyball players performed a variety of jumping and agility tests including DVJ from 30cm (2). A strong correlation, $r = 0.753$, was found between RSI and DVJ displacement (2). Strong correlations were also seen in a group of 52 resistance trained men and women (8). Two repetitions of DVJ were performed from a height of 40cm, and correlations were determined separately for men and women (8). Fairly strong correlations were found between RSI and DVJ displacement for men, $r = 0.66$ and 0.68, and even stronger correlations were found for the women, $r = 0.86$ and 0.81 (8). Based on the results of these studies, RSI appears to have a strong positive association with DVJ displacement.

Drop Vertical Jump Ground Contact Time

What is DVJ ground contact time and how has it been used?

Ground contact time during a drop jump refers to the length of time an athlete spends on the ground after dropping from the box and prior to flight. Previous research has used ground contact time (GCT) during plyometrics such as the drop jump to classify a variety of jumping tasks. An article by Schmidtbleicher (19) has classified the stretch shortening cycle (SSC) as either fast or slow SSC plyometrics. These classifications are based on the GCT and muscle contraction times of the plyometrics. A fast SSC plyometric is defined as having short contraction times (<0.25secs) and smaller angular joint displacements (19). A slow SSC plyometric is defined as having longer contraction times (>0.25secs) and larger joint angular displacements (19). Depending on the nature of the task and the goal of the task, a shorter or longer GCT may be desired. Therefore, it would be important to know if GCT during drop vertical jumps is a reliable measure and the association between GCT and DVJ displacement.

Reliability of ground contact time during drop vertical jumps

Obtaining reliable ground contact times during drop jumps is often over-looked since measurements such as jump displacement or RSI are more commonly assessed as performance variables. Since RSI has been shown to be a reliable measure during drop jumps, it would be assumed that GCT during drop jumps would also be reliable. In a study by Flanagan, et al (7), 22 Division I track and field athletes performed drop vertical jumps for a reliability analysis. Ground contact times during DVJ were shown to be highly reliable, alpha coefficient = 0.976 and intraclass correlations > 0.934 (7). GCT during DVJ from 40cm was also shown to be reliable and precise in a group of 52 resistance trained men and women as assessed by high intraclass correlations, ICC = 0.83, and relatively small coefficients of variation, CV = 8.2% (8). Similar results were seen for GCT in a group of female volleyball players who performed DVJ from 30cm (2). In this study, reliability and precision were both adequate, ICC = 0.72 and CV = 8.7% (2). Based on these results, it appears that ground contact time during DVJ is a reliable measure.

The association between drop vertical jump displacement and ground contact time

Previous investigations have examined the association between DVJ displacement and ground contact time, all finding low correlations between these two variables. An article describing certain power variables as predictors of sprinting performance in male sprinters evaluated drop jump variables as they relate to sprint performance. In addition, the association between DVJ displacement and GCT from a 40cm box was also assessed (20). There was a moderately low, positive correlation between DVJ displacement and GCT, $r = 0.370$ (20). The correlation between DVJ displacement and GCT has also been assessed in a group of 29 female volleyball players. There was a weak but negative correlation between these two variables, $r = -0.25$ (2). A weak association between DVJ displacement and GCT from a 40cm drop height was also found in a group of 52 resistance trained men and women (8). The data in this study were analyzed for both men and women during two different sessions. Correlations between displacement and GCT were low and negative for the men, $r =-0.21$ and -0.23, and women, $r = -0.33$ and -0.26 (8). Therefore, there appears to be a weak correlation between DVJ displacement and GCT; however, previous research is inconclusive on the direction of this correlation.

Eccentric Utilization Ratio and Elasticity Index

What are these indices and how have they been used?

An athlete’s ability to effectively use the stretch shortening cycle during dynamic movements is critical to success. Therefore, coaches and researchers have attempted to quantify the performance of an athlete’s SSC by using a variety of indices and ratios that assess the difference between a static jump (SJ) and a countermovement jump (CMJ). Two of the primary indices used in the literature are the Eccentric Utilization Ratio

(EUR) and the Elasticity Index (EI). Both of these measures have been used by coaches and researchers as an indicator of stretch shortening cycle performance (9,14,17,18). The elasticity index, sometimes referred to simply as SSC Performance, is typically calculated as the difference between the jump displacements of the CMJ and SJ divided by the jump displacement of the SJ, multiplied by 100%.

Elasticity Index = (CMJ-SJ) / SJ x 100%

The Eccentric Utilization Ratio is commonly calculated as the jump displacement (or peak power) of the CMJ divided by the jump displacement (or peak power) of the SJ.

Eccentric Utilization Ratio = CMJ / SJ

If an athlete obtains an EUR ratio greater than 1.0, that athlete is said to be very "explosive." Athletes who only perform heavy resistance training may not be as explosive and would typically have an EUR ratio less than 1.0 (10).

The difference in performance of the SJ and CMJ is attributed to the athlete's ability to use their SSC. A majority of athletes achieve greater jump displacements during the CMJ compared to the SJ because of the use of the countermovement. Research has proposed multiple theories for why the CMJ enables greater jumping performance (3,4). In 1996, the kinematic and kinetic jumping data of six male volleyball players were assessed (3). The athletes jumped approximately 3.4cm higher in the CMJ compared to the SJ. This study attributed the difference in jump displacement to greater joint movements at the start of the push-off phase of the jump (3). Greater joint movements during the early phase of the push-off would allow more work to be done in the CMJ compared to the SJ, leading to a greater change in kinetic energy (3).

Almost ten years later, the same researcher used a computer simulation to test a number of theories about why the CMJ results in greater jump displacement than the SJ (4). He proposed five different theories for the discrepancy in jump displacements. Four of these theories included: a triggering of neural responses during the CMJ to increase muscle stimulation, an enhanced force-producing capacity of the contractile machinery in the CMJ, a more optimum length-tension relationship of the muscle fibers at the beginning of the concentric phase of the CMJ, and a more coordinated completion of the jump due to training. The fifth theory, which was proposed as being responsible for the difference in jump displacements between the CMJ and SJ, was termed muscle active state (4). Muscle active state refers to the fraction of actin binding sites available for cross-bridge formation. It was proposed that this active state could be developed prior to the propulsion phase of the CMJ whereas the athlete develops this active state mostly during the propulsion phase of the SJ (4).

Despite the inconclusive research of why CMJ displacement is greater than SJ displacement, coaches still use EUR and EI to monitor their athletes' SSC capabilities. EUR has been evaluated in field hockey and rugby players in the off-season and pre-season to evaluate SSC capabilities during different training periods (14). A gender analysis was also performed in this study, and there were no gender differences in EUR (14). Another study supported these findings and found no gender differences in EUR for a group of 14 male and 16 female beach volleyball athletes (18). However, a study by Pradas reported contradictory findings when measuring EI in a group of male and female athletes. Interestingly, the females had significantly greater jump displacements in both the CMJ and SJ (17). However, the females showed no significant differences in EI when compared to males (17). In a different study, a group of sprinters and a group of distance runners performed the CMJ and SJ to evaluate their EUR values. Although the sprinters jumped significantly higher than the distance runners, there were no significant differences in the EUR data for these two groups (9). Research has reported significant differences between a variety of groups of athletes when assessing CMJ and SJ performance. Despite these differences in jumping performance, the data indicated no significant differences in EUR or EI in these groups.

Reliability of the EUR and EI

Currently there are no studies that have assessed the reliability of the Eccentric Utilization Ratio or the Elasticity Index. However, the reliabilities of the component parts of these indices, SJ displacement and CMJ displacement, have been well-researched (12,15,16). In a study by Markovic et al (12), 93 physically active college-age men performed CMJ and SJ for reliability analysis. The data were reliable for both styles of jumps as evidenced by their intraclass correlation coefficients (ICC) and coefficients of variation (CV%). The SJ had an ICC of 0.97 and CV of 3.3%, and the CMJ had an ICC of 0.98 and CV of 2.8% (12). This study used flight times of the jumps to determine jump displacements. However, a recent study assessed the intersession reliability of flight time and total vertical displacement of the center of mass in male and female subjects (16). Both measurements were shown to be reliable in both genders with ICC's ranging from 0.82-0.97 and CV's ranging from 1.7% - 6.6% (16). Previous research has also demonstrated that CMJ displacement is reliable in physically active men and women when the best jump of three trials is reported or when the three jump trials are averaged for data analysis (15). For both analysis methods and for both genders, ICC values ranged from 0.87-0.95 and CV values ranged from 3.6% - 6.6% (15). Based on these data, CMJ and SJ performance measures appear to be reliable for both men and women; however, the actual reliabilities of EUR and the EI have yet to be determined.

The Association of EUR and EI to Jump Performance

Coaches and researchers have used EUR and EI as an indication of stretch shortening cycle capabilities as well as a method for monitoring training adaptations over a specific period (9,14,17,18). Therefore, it would be important to know whether these indices were associated with jumping performance. However, there are very few investigations that have assessed EUR or EI as well as jumping performance. In addition, none of these studies have evaluated the association between these indices and jumping performance. Future research should focus on establishing these associations to help determine what these indices measure during jumping tasks.

Inter-Correlations between these indices

The reactive strength index, DVJ ground contact time, eccentric utilization ratio, and elasticity index were all developed to assess jumping performance and/or measure the SSC capabilities of an athlete. Therefore, it would be expected that all of these variables would be related somehow. However, these associations have not been verified or even studied in depth in current literature. One study does present limited insight into a few of these associations. A group of 25 male sprinters performed drop vertical jumps to measure RSI and GCT. The data resulted in a fairly high negative correlation, $r = -0.758$ (20). This article also reported an index that relates the sprinters’ performance in the SJ and CMJ. The index used in this study was calculated as the jump displacement of the SJ subtracted from the jump displacement of the CMJ (CMJ – SJ) (20). This index resulted in a moderate negative correlation with RSI (r = -0.380) and a moderate positive correlation with GCT (r = 0.332) (20). This study presents limited insight into the inter-correlations between these various jumping indices. However, additional data are still needed to establish the associations of these seemingly-related measurements.

Conclusion

Although coaches have used a variety of indices to measure jumping performance, limited scientific research has been conducted that has assessed these indices or their associations to performance. Coaches and researchers have used the reactive strength index, elasticity index, and the eccentric utilization ratio as indicators of jumping performance and stretch-shortening cycle abilities. However, whether these indices are valid portrayals of jumping performance has yet to be determined. Therefore, a need exists for future research to focus on what these indices measure and how they should be used when representing jumping performance.

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To:	Christina Feldmann Health & Sport Sciences
From:	Chair, Institutional Review Board for the Protection of Human Subjects
Subject:	Association of Drop Vertical Jump Displacement with Select Performance Indices (H11-21)
Approval Date:	9/23/2010

This is to notify you of the board approval of the above referenced protocol. This project was reviewed in accordance with all applicable statutes and regulations as well as ethical principles.

Approval of this project is given with the following obligations:

5. At the end of one year from the approval date an approved renewal must be in effect to continue the project. If approval is not obtained, the human consent form is no longer valid and accrual of new subjects must stop.
6. When the project is finished or terminated, the attached form must be completed and sent to the board.
7. No change may be made in the approved protocol without board approval, except where necessary to eliminate apparent immediate hazards or threats to subjects. Such changes must be reported promptly to the board to obtain approval.
8. The stamped, approved human subjects consent form must be used. Photocopies of the form may be made.

This approval expires one year from the date above, and must be renewed prior to that date if the study is ongoing.

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Approved

Cc: Dr. L. Weiss