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Analyzing Sex Differences in Human Performance Through 3D Isotonic Resistance

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ANALYZING SEX DIFFERENCES IN HUMAN PERFORMANCE THROUGH 3D ISOTONIC RESISTANCE

By

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Dedication

This Thesis is dedicated to my sister, who always keeps me grounded amid adversity. You have helped me as a sibling in more ways than you know. To my mother, who always ensures that I do not lose sight of who I am as an individual. Thank you for always pushing me to become better, while seeing my potential. And to my father, who always lends a helping hand even when I am miles away. I appreciate your patience, and consistent advice you give me. May this work stand as the culmination of all the effort you have placed onto me finally coming to fruition. I love you all.

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Thank you all for making me a better student, and human.

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Abstract

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Appraisal of scientific literature and understanding continues to grow in the domain of human performance. The effects of sex on concentric resistance training and power output are not well understood. Recent advancements in technology permit more precise measurements of force output and the kinematic changes elicited by training stress. A unique device in capturing kinematic performance output is Proteus Motion. The machine produces an external magnetic load through a protruding apparatus connected to a gyrosphere, which in turn captures concentric movement through all three planes of movement (sagittal, coronal, transversal). The aim of this study is to investigate power output discrepancies between the sexes in upper extremity concentric movements. After 5 training sessions females expressed significant increases in concentric bilateral bicep curl power by 22.4 ± 30.1 w ($p=0.001$) and bilateral tricep extensions by 34.1 ± 30.3 w ($p<0.001$). Male subjects improved mean and peak power between sessions 1-5 ($p<0.001$), while there was no significant improvement from sessions 5-8 ($p>0.250$). In horizontal and vertical exercises females and males shared similar power profiles in pull motions, but not push movements. Future studies investigating biological sex, and its influence on power output are needed.

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CHAPTER 1: INTRODUCTION

Resistance training is a form of exercise where an individual repeats specific movements against an external load in multiple sets (Lopez et al., 2022). This form of exercise efficiently combats mortality, sarcopenia, and other aspects that may hinder quality of life (Hunter et al., 2004; Shailendra et al., 2022; Stone et al., 2022). Implementation of resistance programs can help body composition when paired with a suitable diet (Lopez et al., 2022). However, there remains a lack of literature assessing sex differences and the association of implemented resistance training (Hunter et al., 2023; Roberts et al., 2020). Combining various forms of resistance training can improve athletic performance in athletes (Oliver et al., 2023).

Improvement of strength, rate of force development, power, and exercise endurance can be attributed to implementation of resistance training (Stone et al., 2022). The definition of mechanical power is concisely defined as the rate of performing work (Haff et al., 2012; Knudson, 2009). Calculating power properly requires the rate of force output produced by skeletal muscle to be multiplied by the velocity of movement (Haff et al., 2012). Integration of multiple resistance exercises implemented in studies aiming to optimally assess concentric power output can be challenging due to different intervening variables, and physical restrictions of equipment. Novel performance technology has expanded the capability to properly analyze and assess multiple variables of human performance. Proteus Motion (Brooklyn, New York, USA) is a novel device which permits subjects to perform concentric movements in three-dimensional space. The following chapters will assess power performance in females, males, and between the sexes, respectfully.

CHAPTER 2: POWER IMPROVEMENT OF THE UPPER LIMB DURING NOVEL TRAINING IN FEMALES

Background

The pursuit of discovering distinctions between resistance training-induced outcomes in males and females has remained ongoing over 35 years (Lewis et al., 1986). Although physiological differences exist between sexes, it has been widely accepted that responses to progressive resistance training produce similar myofibril hypertrophic responses (Lewis et al., 1986). Research investigating sex and strength differences has indicated females retain a greater capacity to increase relative strength compared to male counterparts (Huba et al., 2005; Hunter et al., 2004; Roberts et al., 2020). This finding could be partly explained by the lower level of fitness among women, consequently exhibiting a “ceiling effect” within subjects (Roberts et al., 2020). Another explanation for greater relative strength increases may be neural adaptations (Roberts et al., 2020).

At the onset of physical training, neural adaptations account for much of the improvement in skeletal muscle performance. These adaptations include changes in golgi tendon organ activity, muscle spindles, rate coding, and neurotransmitter activity (Suchomel et al., 2018), however, the primary source of neural adaptation across individuals remains uncertain (Škarabot et al., 2021). Both strength and power have been assessed in relation to the neural adaptations in specific or athletic populations (Tøien et al., 2023). The most appropriate and basic understanding of the previous claim can be expanded on in regards to Henneman’s “Size Principle”. The “Principle” expands on the concept of Denny-Brown’s “Orderly Recruitment” where the recruitment of larger motor units are the result of a larger external load (Denny-Brown et al., 1938).

"Size Principle" appraises the notion that a larger nerve would require more fibers in a motor unit, and the larger motor units would require a larger excitatory stimulus to activate said motor units (Henneman, 1957). Some research in assessing upper limb power output has been evaluated among untrained females.

Purpose

The purpose of this chapter is to measure changes in upper limb performance among females initiating a novel training program.

Methods

We tracked 28 women during consecutive exercise sessions using a Proteus device. The user holds a handle at the end of the arm, which can be moved through three-dimensional space. It produces isotonic, concentric-only resistance, negating gravitational moment arms, thereby establishing a means for more accurate assessments of concentric movements. Subject data was received from multiple Proteus locations throughout the United States. Inclusionary criteria were: 1) Subjects performed a minimum of five sessions on separate days. During each training session, the subject performed bilateral biceps curls (BC), bilateral triceps extensions (TE), and unilateral BC and TE with both dominant and nondominant arms. A retrospective analysis was completed after all subject data were assimilated, which spanned over two years. Data included subject characteristics, exercise power in watts, sport, and position.

All statistical analyses were performed using SPSS Version 28 (IBM Corporation, Chicago, IL, USA). Peak power (w) was captured in each individual set throughout the study period. Descriptive statistics characterizing all subjects (means and standard deviations) were calculated. We used paired-samples t-tests to compare power output between the initial training session and the fifth session. We used multiple linear regression models to isolate the effect of training session number (one through five) on peak power output, while holding subject age constant.

Table 1

Descriptives From Original Pool of Data

	N	Minimum	Maximum	Mean	Std. Deviation
Age	**1616**	**13.00**	**63.54**	**34.57**	**14.52**
Height (in)	**1836**	**58.00**	**69.00**	**65.03**	**2.93**
Weight (lb)	**1716**	**98**	**250**	**160.46**	**29.40**
BMI	**1716**	**19.22**	**40.35**	**26.54**	**4.90**

Note. The descriptives encompass all female subjects from the original analyzed database.

Results

Subjects were 34.6 ± 14.5 years old. Mean height was 65.0 ± 2.9 in, and mean body weight was 160.5 ± 29.4 lb. During the initial session, subjects achieved peak powers of 163.0 ± 107.3 w in bilateral BC, 151.3 ± 64.4 w in dominant arm BC, 144.2 ± 67.0 w in nondominant arm BC, 163.1 ± 108.5 w in bilateral TE, 151.6 ± 75.8 w in dominant arm TE, and 133.1 ± 79.9 w in nondominant arm TE. At session 5, subjects increased bilateral BC by 22.4 ± 30.1 w ($p=0.001$), dominant arm BC by 10.4 ± 29.3 w ($p=0.103$), nondominant arm BC by 8.4 ± 31.5 w ($p=0.186$), bilateral TE by 34.1 ± 30.3 w ($p<0.001$), dominant arm TE by 15.0 ± 44.0 ($p=0.131$), and nondominant arm TE by 14.2 ± 46.2 w ($p=0.155$).

Table 2

Descriptives for T-Tests

	N	Minimum	Maximum	Mean	Std. Deviation
Session 1 - Bicep Dominant	14	15.66	151.34	64.36	40.11
Session 1 - Bicep Non-Dominant	12	15.70	144.22	67.00	40.64
Session 1 - Bicep Bilateral	23	47.78	163.03	107.26	37.49
Session 5 - Bicep Dominant	14	5.94	138.88	74.76	32.52
Session 5 - Bicep Non-Dominant	14	5.86	142.08	74.09	35.10
Session 5 - Bicep Bilateral	22	51.78	216.64	129.37	42.29
Session 1 - Triceps 1 Hand Non-Dominant	12	27.45	133.10	79.90	40.81
Session 5 - Triceps 1 Hand Non-Dominant	12	35.39	161.25	94.08	36.56
Session 1 - Triceps 1 Hand Dominant	13	27.90	151.64	75.77	42.43
Session 5 - Triceps 1 Hand Dominant	12	33.27	162.30	93.63	38.11
Session 1 - Tricep Bilateral	23	42.17	163.09	108.51	39.99
Session 5 - Tricep Bilateral	22	49.55	252.83	142.21	49.79

Table 3

Paired Samples Statistics

		Mean	N	Std. Deviation
Pair 1	Session 1 - Bicep Non-Dominant	67.00	12	40.64
	Session 5 - Bicep Non-Dominant	75.45	12	37.75
Pair 2	Session 1 - Bicep Dominant	64.36	14	40.11
	Session 5 - Bicep Dominant	74.76	14	32.52
Pair 3	Session 1 - Biceps Bilateral	106.95	22	38.34
	Session 5 - Biceps Bilateral	129.37	22	42.29
Pair 4	Session 1 - Triceps 1 Hand Non-Dominant	79.90	12	40.81
	Session 5 - Triceps 1 Hand Non-Dominant	94.08	12	36.56
Pair 5	Session 1 - Triceps 1 Hand Dominant	78.59	12	43.03
	Session 5 - Triceps 1 Hand Dominant	93.63	12	38.11
Pair 6	Session 1 - Triceps Bilateral	108.13	22	40.89
	Session 5 - Triceps Bilateral	142.21	22	49.79

Table 4

Unilateral Bicep Curl Linear Regression

	Unstandardized Coefficients				95% CI	
	B	Std. Error	t	Significance	Lower Bound	Upper Bound
Exercise Session	3.156	1.324	2.383	0.018	0.552	5.760
Age	-1.366	0.130	-10.470	<0.001	-1.623	-1.110
Dominance	0.871	3.633	0.240	0.811	-6.274	8.016
Dependent variable: Power					R square: 0.240	

Note. For every additional session performed, unilateral bicep curl power is predicted to increase by 3.2 watts (p=0.018; 95% CI of β: 0.6, 5.8).

Linear regression found each additional bout of training to increase unilateral BC power by 3.2 w (p=0.018; 95% CI of β: 0.6, 5.8) while holding age constant (p<0.001; 95% CI of β: -1.6, -1.1); dominance was insignificant (p=0.811) and not controlled.

Table 5

Unilateral Tricep Extension Linear Regression

	Unstandardized Coefficients				95% CI	
	B	Std. Error	t	Significance	Lower Bound	Upper Bound
Exercise Session	7.150	1.595	4.483	<0.001	4.010	10.290
Age	-1.412	0.136	-10.345	<0.001	-1.680	-1.143
Dominance	-2.812	4.372	-0.643	0.521	-11.422	5.797
Dependent variable: Power					R square: 0.330	

Note. For every additional session performed, unilateral tricep extension power is predicted to increase by 4.9 watts (p=0.014; 95% CI of β: 1.0, 8.8).

Utilizing the linear regression, each additional exercise session predicted an increase in unilateral TE power by 4.9 w ($p=0.014$; 95% CI of β: 1.0, 8.8) holding age constant ($p<0.001$; 95% CI of β: -1.9, -1.2); dominance was insignificant ($p=0.521$; B= -2.812; 95% CI of B: X, Y) and not controlled.

Conclusion

Among females initiating a novel, concentric-only exercise program, improvements in upper limb power occurred within the first five sessions. Subjects expressed more robust strength increases in bilateral motions compared to unilateral. The ability to perform the double-handed curl with a heavier load as compared to the unilateral movement showcases the concept of "Orderly Recruitment" where muscle fiber types will meet the heavier demands of an external load (Denny-Brown et al., 1938). A larger nerve would lead to more fibers in a motor unit, and the larger motor units would yield a larger requirement of an excitatory stimulus to activate said motor units (Henneman, 1957). The bilateral exercises require the recruitment of the more explosive larger motor units, similar to "Henneman's Size Principle".

Although the unilateral exercises were not as robust in power output values as compared to the bilateral movements, the unilateral exercises were more easily predictable in determining anticipated performance values. The lower loads would create a lower "ceiling effect" for performance, and therefore a more feasible means of accurately predicting smaller, and consistent increases of power. The robust power outputs from the bilateral exercises are more challenging to accurately predict incremental increases of weight. Regardless of experience or age, power output can be performed in females performing concentric exercises in the upper extremities.

CHAPTER 3: POWER PROFILE IMPROVEMENT IN MALES PERFORMING THREE-DIMENSIONAL CURLS

Background

Human skeletal muscle is a versatile tissue, with multifaceted mechanical signaling cascades, and purposes. The degradation of skeletal muscle during aging is a significant health concern for older individuals (Hunter et al., 2004; Lavin et al., 2019; McGregor et al., 2014). Sarcopenia (i.e., loss of muscle mass and strength) is a well-researched subject (Lavin et al., 2019; McGregor et al., 2014) with no concrete aetiology (Hunter et al., 2004). The physiological issues induced by sarcopenia are commonly associated with hindrances to metabolic function, movements, disease prevention (Hunter, 2014) and quality of life (Lavin et al., 2019; Lu et al., 2021; McGregor et al., 2014). Implementation of resistance training can reduce the risk of all-cause mortality and cardiovascular mortality in adult populations (Shailendra et al., 2022).

Nonetheless, there is a need to investigate an optimal method of assessing the relationship between resistance training and mortality outcomes (Shailendra et al., 2022). Resistance training robustly combats power decline in older adult populations (Hunter et al., 2004; Lavin et al., 2019). Reintroduction into resistance training after previous experience can accelerate neural adaptations to near maximal strength in older populations in a matter of weeks (Sakugawa et al., 2019; Taaffe et al., 1997). Younger populations at the age of 30 may even begin to experience a decline of muscle mass by 3-8% every year (Volpi et al., 2004). The neuromuscular fibers most associated with strength (IIa, and IIx) atrophy with aging (evans, 2000; Lavin et al., 2019).

Assessing differences of male power output through multiple recurring sessions may showcase deterioration of neural adaptation and concentric function. Assessing robust responses of power output in a broadened male population with resistance training beyond the various planes of motion has not been well-documented in the literature. Proteus Motion allows for such assessment to be attained in a safe manner, while also letting subjects produce the most forceful contractions possible. Thus, the machinery acts as a means of recruiting the type IIx fibers in a non-invasive manner, which may be at risk of atrophy.

Purpose

To assess increases in power and acceleration of the biceps brachii among males performing novel three-dimensional isotonic exercise.

Methods

We measured 40 males across the lifespan initiating exercise on a Proteus device, which produces three-dimensional concentric loads via electromagnetic resistance. All subject data was derived from different Proteus locations throughout the United States. Each subject completed a minimum of five exercise sessions involving bilateral bicep curls on separate days. 23 subjects were retained through 8 sessions. We captured peak power achieved in each repetition, and we exported average peak power of all repetitions (mean power) and the highest power achieved in any repetition (peak power). We also exported mean and peak acceleration. Repeated measures ANOVA tested differences in performance metrics across days 1, 5, and 8 (n=23). Paired-samples t-tests measured differences between sessions 1 and 5 (n=40).

Results

Subject age was 35.1 ± 21.3 years, height was 69.6 ± 3.8 in, and weight was 176.8 ± 35 lb. During the initial session, mean power was 107.8 ± 63.0 W, peak power was 121.8 ± 68.4 W, mean acceleration was 6.7 ± 5.0 m/s^2 , and peak acceleration was 8.6 ± 5.8 m/s^2. Outputs began to change with each session.

Table 6

Mean Descriptives

	N Statistic	Mean	Minimum	Maximum	Std. Deviation	Variance	Skewness	Kurtosis
Age	276	35.091	12.00	79.28	35.091	21.32165	454.613	-.802
Height	282	69.564	60.00	76.00	69.564	3.77449	14.247	.321
Weight	266	176.786	105.00	240.00	176.786	35.01993	1226.395	-1.074
BMI	266	25.347	17.15	35.44	25.347	4.31589	18.627	-.737
Resistance 2 Hand Biceps	282	11.201	5.00	35.00	11.201	3.527	12.436	8.233
Reps	282	10.266	4.00	30.00	10.266	4.038	16.305	6.038
Mean Power 2 Hand Biceps	282	143.289	17.78	707.62	143.289	91.105	8300.153	5.029
Mean Acceleration 2 Hand Biceps	282	8.998	.55	60.16	8.998	7.306	53.383	11.897
Peak Power 2 Hand Biceps	282	159.509	23.36	858.00	159.509	101.109	10223.119	7.782
Peak Acceleration 2 Hand Biceps	282	16.123	.77	588.29	16.123	49.545	2454.743	111.040

Table 7

Paired-Samples T-Test (Days 1 and 5 N=40)

		Mean	Std.. Deviation	Std. Error Mean
Pair 1	Mean Power 5	107.799	62.970	9.956
	Mean Power 5	162.563	122.870	19.427
Pair 2	Peak Power 1	121.781	68.358	10.808
	Peak Power 5	184.192	145.611	23.023
Pair 3	Mean Accel 1	6.741	5.005	.791
	Mean Accel 5	10.285	8.712	1.378
Pair 4	Peak Accel 1	8.605	5.830	.922
	Peak Accel 2	28.4816	92.798	14.673

Note. Table 8 showcases the correlating p value with this table.

Table 8

Session 1-5 Paired Samples Test

					95% Confidence Interval				Significance	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	**Mean Power 1-5**	**-54.764**	**83.003**	**13.124**	**-81.310**	**-28.218**	**-4.173**	**39**	**<.001**	**<.001**
Pair 2	**Peak Power 1-5**	**-62.412**	**98.072**	**15.507**	**-93.777**	**-31.047**	**-4.025**	**39**	**<.001**	**<.001**
Pair 3	**Mean Accel 1-5**	**-3.544**	**7.413**	**1.172**	**-5.915**	**-1.173**	**-3.024**	**39**	**.002**	**.004**

(Table 8 Continued)

Pair 4	**Peak Accel 1-5**	**-19.877**	**91.811**	**14.517**	**-49.240**	**9.485**	**-1.369**	**39**	**.089**	**.179**

Table 9

Means at All Time Points

Day of Exercise		Mean Power	Peak Power	Mean Accel	Peak Accel
Day 1	Mean	107.799	121.781	6.741	8.605
	Std. Deviation	62.970	68.358	5.001	5.830
Day 2	Mean	126.473	140.516	7.456	9.120
	Std. Deviation	78.454	54.714	4.574	5.378
Day 3	Mean	138.789	153.550	9.843	24.794
	Std. Deviation	75.992	82.688	9.616	85.607
Day 4	Mean	145.112	161.854	8.512	10.504
	Std. Deviation	89.699	97.812	5.470	6.491
Day 5	Mean	162.563	184.19	10.285	28.482
	Std. Deviation	122.870	145.611	8.712	92.798
Day 6	Mean	156.699	171.707	9.447	12.689
	Std. Deviation	85.656	90.491	7.100	13.573
Day 7	Mean	158.408	174.730	11.039	17.290
	Std. Deviation	91.904	99.090	9.537	26.525
Day 8	Mean	169.064	186.807	9.795	18.05
	Std. Deviation	108.557	118.890	6.923	34.024

Comparing sessions 1 to 5, mean power increased to 162.6 ± 122.9 W ($p<0.001$), peak power increased to 184.2 ± 145.6 W ($p<0.001$), mean acceleration increased to 10.3 ± 8.7 m/s^2 ($p=0.002$), and peak acceleration increased to 28.5 ± 92.8 m/s^2 ($p=0.089$). Improvements in mean and peak power were both significant between sessions 1 and 5 ($p<0.001$), but not between sessions 5 and 8 ($p>0.250$). Improvements in mean acceleration were significant between session 1 and 5 ($p=0.002$), but not between 5 and 8 ($p=1.000$). Holding subject age constant, linear regression on days 1 through 5 found each additional exercise session to predict an improvement of 11.0 W mean power ($p=0.001$), 12.4 W peak power ($p<0.001$), and 0.9 m/s^2 mean acceleration ($p=0.011$). Tables will showcase different outcomes and variables from sessions 1-5, and session 8.

Table 10

Session 1-8 Mean Power Descriptive Statistics

	Mean	Std. Deviation	N
Mean Power 1	97.634	59.315	23
Mean Power 5	146.980	88.331	23
Mean Power 8	169.064	108.557	23

Table 11

Session 1-8 Mean Power Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound

(Table 11 Continued)

Session	.746	6.150	2	.046	.798	.850	.500

Table 12

Session 1-8 Mean Power Tests of Within-Subject Effects

		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial ETA Squared
Session	Sphericity Assumed	61526.036	2	30763.031	14.604	<.001	.399
	Greenhouse-Geisser	61526.036	1.595	38572.726	14.604	<.001	.399
Error (session)	Sphericity Assumed	92688.200	44	2106.550			
	Greenhouse-Geisser	92688.200	35.091	2641.332			

Table 13

Session 1-8 Mean Power Pairwise Connections

(I) Session	(J) Session	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	-49.347	11.155	<.001	-78.250	-20.443
	3	-71.431	16.559	<.001	-114.338	-28.523

(Table 13 Continued)

2	1	49.347	11.155	<.001	20.443	78.250
	3	-22.084	12.285	.258	-53.916	9.748
3	1	71.431	16.559	<.001	28.523	114.338
	2	22.084	12.285	.258	-9.748	53.916

Table 14

Session 1-8 Peak Power Descriptive Statistics

	Mean	Std. Deviation	N
Mean Power 1	109.866	63.064	23
Mean Power 5	167.015	104.112	23
Mean Power 8	186.807	118.889	23

Table 15

Session 1-8 Peak Power Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Session	.800	4.697	2	.095	.833	.893	.500

Note: Significance was not met. We therefore fail to reject the Null Hypothesis and must therefore assume all variance between variables is equal.

Table 16

Session 1-8 Peak Power Tests of Within-Subject Effects

		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial ETA Squared
Session	Sphericity Assumed	73427.584	2	36713.792	12.703	<.001	.366
	Greenhouse-Geisser	73427.584	1.666	44072.533	12.703	<.001	.366
Error (session)	Sphericity Assumed	127168.071	44	2890.183			
	Greenhouse-Geisser	127168.071	36.653	3469.478			

Table 17

Session 1-8 Peak Power Pairwise Connections

Session	Session	Mean Difference	Std. Error	Sig.	95% CI Lower Bound	95% CI Upper Bound
1	2	-57.149	12.541	<.001	-89.646	-24.651
	3	-76.940	18.758	.001	-125.545	-28.336
2	1	57.149	12.541	<.001	24.651	89.646
	3	-19.791	15.647	.657	-60.336	20.753
3	1	76.940	18.758	.001	28.336	125.545
	2	19.791	15.647	.657	-20.753	60.336

Table 18

Session 1-8 Mean Acceleration Descriptive Statistics

	Mean	Std. Deviation	N
Mean Power 1	6.059	3.875	23
Mean Power 5	9.781	7.330	23
Mean Power 8	9.795	6.923	23

Table 19

Session 1-8 Mean Acceleration Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Session	.938	1.333	2	.513	.942	1.000	.500

Note: Significance was not met. We therefore fail to reject the Null Hypothesis and must therefore assume all variance between variables is equal.

Table 20

Session 1-8 Mean Acceleration Tests of Within-Subject Effects

		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial ETA Squared
Session	Sphericity Assumed	213.205	2	106.603	6.521	.003	.229
	Greenhouse-Geisser	213.205	1.884	113.159	6.521	.004	.229

(Table 20 Continued)

Error (session)	Sphericity Assumed	719.286	44	16.347			
	Greenhouse-Geisser	719.286	41.451	17.353			

Table 21

Session 1-8 Mean Acceleration Pairwise Connections

(I) Session	(J) Session	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	-3.722	1.041	.005	-6.418	-1.025
	3	-3.736	1.227	.018	-6.915	-.557
2	1	3.722	1.041	.005	1.025	6.418
	3	-.014	1.295	1.000	-3.369	3.341
3	1	3.736	1.227	.018	.557	6.915
	2	.014	1.295	1.000	-3.341	3.369

Table 22

Session 1-8 Peak Acceleration Descriptive Statistics

	Mean	Std. Deviation	N

(Table 22 Continued)

Mean Power 1	**7.926**	**4.590**	**23**
Mean Power 5	**16.417**	**24.959**	**23**
Mean Power 8	**18.051**	**34.024**	**23**

Table 23

Session 1-8 Peak Acceleration Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Session	.633	9.610	2	.008	.731	.770	.500

Table 24

Session 1-8 Peak Acceleration Tests of Within-Subject Effects

		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial ETA Squared
Session	Sphericity Assumed	1359.309	2	679.655	1.151	.326	.050
	Greenhouse-Geisser	1359.309	1.463	929.237	1.151	.314	.050
Error(session)	Sphericity Assumed	25980.364	44	590.463			
	Greenhouse-Geisser	25980.364	32.182	807.293			

Table 25

Session 1-8 Peak Acceleration Pairwise Connections

(I) Session	(J) Session	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	-8.491	4.986	.308	-22.412	4.430
	3	-10.126	7.102	.504	-28.528	8.277
2	1	8.491	4.986	.308	-4.430	21.412
	3	-1.634	8.873	1.000	-24.626	21.358
3	1	10.126	7.102	.504	-8.277	28.528
	2	1.634	8.873	1.000	-21.358	24.626

Conclusion

Men across the timespan experienced rapid increases in force and acceleration upon initiating novel three-dimensional concentric exercise. Observed increases in power output, peak power, and acceleration could be attributed to a variety of performance factors. The unfamiliarity with the machine combined with the adaptation of performing specific kinematic patterns against the device's external load could have created an optimal environment to develop acute neural adaptations. Secondly, previous training experience may have also impacted power output improvement throughout the first five sessions. The aforementioned notions may have also explained why performance was not significant between sessions 5-8, as the neural adaptations were acutely utilized during the first five sessions.

CHAPTER 4: BOTH SEXES EXPRESS SIMILAR POWER PROFILES IN PULL MOTIONS BUT NOT PUSH

Background

Athletic performance is largely determined by individual sex, thereby meaning that human performance is influenced by the inherent differences between sex physiology, and sex anatomy (Hunter, 2014; ACSM, 2023). Most studies assessing physiological responses due to resistance training have focused on male populations; therefore, there is a lack of female discrepancies and appreciation of physiological sex differences (ACSM, 2023; Hunter, 2014; Hunter et al., 2023). Comparatively, women have expressed robust improvements in all realms of athletic performance mainly due to inclusionary access of facilities, opportunities, training, and equipment within the last 100 years (ACSM, 2023). Tremendous strides in appraising the discrepancies between the sexes is due to the culmination of recent studies assessing male and female characteristic's role in athletic performance.

Hormonal variance plays a crucial role in explaining synthesis and degradation rates of muscle and tendon composition (Hansen et al., 2014). The necessity of proper protein balance and synthesis to promote muscle composition begets athletic performance, and is therefore one of the many reasons hormonal differences are crucial for human performance. Within the blood brain barrier, the hypothalamus acts as the primary initiator of the sex hormone releasing cascade within the hypothalamic-pituitary-gonadal axis (HPG Axis) (Durán-Pastén, 2013). From the Hypothalamus, gonadotropin-releasing hormone is released, thereby recruiting the activation of the pituitary gland outside of the blood brain barrier (Durán-Pastén, 2013). Subsequently, the pituatary's release of luteinizing hormone and follicle-stimulating hormone elicits the release of androgens (Durán-Pastén, 2013). The primary role of androgens is through androgenic receptor binding inside of the cell. Through the process of binding at the receptor site, the complex binds to a sequence of DNA thereby regulating transcription. (Denayer et al., 2010).

The role of steroid hormones are not solely isolated to genomic function, but also assist in signaling cascades in mitogen-activated protein kinase (MAPK), calcium, and other cascades (Dent et al., 2012). Consequently, sex steroid hormones influence skeletal muscle, organ systems, reproductive organs, bone, the nervous, and vascular system (Velders. 2013). Both testosterone and estrogen are sex hormones which influence calcium influx, thereby increasing the force of contractions within skeletal muscle (Dent et al., 2012). Although both hormones may work in congruence with one another, the inherent differences between the steroid hormones vary. Estrogen is a product of cholesterol which is formed within the ovaries (Chidi-Ogbolu et al., 2019).

The most common form of estrogen is identified as 17β-estradiol formed through the conversion of testosterone to estradiol from enzyme aromatase (Chidi-Ogbolu et al., 2019). While most steroid hormones undergo prolonged periods of activating varying cascades, estrogen has a rapid effect on calcium influx (Dent et al., 2012). 17β-estradiol inhibits tuberin (TSC), in turn turning off the inhibition of the anabolic protein synthesis cascade of mammalian target of rapamycin complex 1 (mTORC1) (Yu et al., 2006). mTORC1 activation consequently initiates protein synthesis in skeletal muscle (Goodman, 2019). Coincidentally, estrogen stimulates liver kinase B1 (LKB1) thereby promoting autophagy through adenosine monophosphate activated protein kinase (AMPK) (McInnes et al., 2012).

Women appear on average to have four times the amount of estrogen compared to men before menopause (Hansen et al., 2014). Evidence from animal studies suggests estrogen may play a crucial role in skeletal muscle repair, while also enhancing inflammation and muscle damage post-exercise (Velders. 2013). Other animal research utilizing rats has suggested estrogen is vital in preventing muscle injury through suppressing remodeling within the extracellular matrix (McClung et al., 2006). Compared to rats, and human males, research on effects of estrogen in human females in relation to muscle or physiological performance is not as well understood (ASM, 2014; Chidi-Ogbolu et al., 2019; Hansen et al., 2014; Velders. 2013).

The predominant androgenic hormone: testosterone, is commonly interconnected with power, hypertrophy and strength (Storey et al., 2012; Vingren et al., 2010). Testosterone activates protein kinase B (PKB) and mTOR consequently inducing protein regulation and muscular hypertrophy signaling cascades (Basualto-Alarcón et al., 2013). In contrast to estrogen, testosterone inhibits LKB1 thereby inhibiting the AMPK pathway (Shan et al., 2017). The induction on nandrolone (a lab-created version of testosterone) on hamsters significantly increased contractile strength, isometric strength, while also robustly increasing the hypertrophy of the type IIx fibers (Lewis et al., 2002). Men more or less retain 15 times the amount of testosterone the average female has at age 18 (ACSM, 2023). One of the more useful applications of testosterone maintenance and research is its role as being a common indicator of lying illness or disease (U.S. National Library of Medicine). Variance in testosterone levels may indicate underlying illness such as but not limited to; chronic illness, tumors, thyroid function, infection, and problems associated with the hypothalamus (U.S. National Library of Medicine).

A crucial component of athletic performance is muscle fiber type, which determines the contractile speed of skeletal muscle (Hunter et al., 2023). Although some researchers argue that the proportion of fibers can be altered due to physical activity, the proportion of fiber types tends to be derived from innate genetics (Miller et al., 1993). The fiber types routinely investigated in research are muscle fiber type I, IIa, and IIx. When investigating the less catabolic uncoupling binding protein 3, Type IIx retained the highest presence of the protein followed by IIa, and I (Russell et al., 2003). Training while performing aerobic activity may affect type I, and IIa muscle (Russell et al., 2003). Summarily, the type IIx fibers are the most anabolic fibers of the skeletomuscular system within the human body. Accordingly, type IIx fibers produce the most strength, hypertrophy, and power in the musculoskeletal system.

A meta-analysis evaluating 110 different studies including 2,400 men and women concluded men exhibited greater distribution of explosive type II fiber types as compared to women (Nuzzo, 2024). Women comparatively maintained greater type I fiber type distribution compared to the male subjects (Nuzzo, 2024). Females may express 52% of strength in the upper body and 66% of lower body strength compared to male counterparts (Miller et al., 1993). Fiber type differences may also explain how males perform better in strength movements compared to their female counterparts (Alway et al., 1985). Males on a strength training program experienced twice the hypertrophic gain of muscle opposed to females (Ivey et al., 2000). Females inversely are able to withstand fatigability inducing exercises due to a higher proportion of type I fibers (Hunter, 2014). Regardless of sex, any individual pushing to or near failure can establish optimal improvements in strength in a resistance program (Davies et al., 2016; Vieira et al., 2021)

Resistance training outcomes between the sexes is not solely mediated by sex hormones. Differences in skeletal muscle between the sexes must also be considered (Roberts et al., 2020). Some studies fail to find a significant difference in muscle hypertrophy after completing an exercise program (Roth et al, 2001; Cureton et al., 1988; O’Hagan, 1995; Staron et al., 1994; Hubal et al., 2005). A multitude of studies assessing sex differences in regards to hypertrophy utilize untrained subjects, in turn altering potential results and findings (Roberts et al., 2020).

The relatively small sample size in similar studies aiming to assess sexual discrepancies in training tend to lack external validity, and consequently a lack of definitive conclusions (Hubal et al., 2005). Regarding athletic performance, assessing the variance of muscle fiber type between sexes may better explain differences of neuromuscular physiology between the sexes (Nuzzo, 2024). The restriction of movement from most resistance-based training equipment negate the proper means of assessing true power output in recreationally active subjects. Whereas most machinery used in experiments is confined by a restrictive movement pattern, Proteus Motion allows for natural kinematic movement from subjects. The device is one of the only forms of equipment capable of assessing concentric power efficiently and in real time.

Purpose

To determine power output differences between men and women using collinear resistance in the upper extremities.

Methods

We enrolled 32 recreationally active men (n=14) and women (n=18), ages 18-25, to evaluate power profiles in horizontal and vertical push and pull exercises using Proteus Motion which applies continuous, three-dimensional, concentric resistance. An orientation was hosted with all subjects to familiarize them with Proteus Motion. Each subject signed a waiver, assuming risk of exercise as well as completed PAR-Qs to meet medical clearance of exercise. A warmup was completed with all subjects performing each movement that would be tested. The movements were: unilateral horizontal row, Unilateral Horizontal Push, Unilateral Vertical Press, Unilateral Vertical Pull. The warmup utilized a set resistance of 3lb to familiarize each subject with the use of freedom of movement across multiple planes. Lab staff observed and corrected subject form during the warmup as a means of reiterating the importance of proper technique for the procedure.

During the day of examination, subjects performed all movements in an enclosed room with the Proteus Motion device. All subjects performed each movement as consistently as possible. The apparatus contains a motion capture sensor at the distal end of the machine, allowing real time discrepancies in technique to be made apparent. This technology in turn would mark the initial starting phase and ending location of each concentric exercise performed. If subject technique altered in any way compared to the initial movement performed the test would stop. Any pause from the machinery would warrant the subjects a 15 second break to recuperate. As the magnetic load would drop during the paused test, subjects would be granted the ability to practice the oncoming movement pattern once more. Every subject completed every repetition.

Subsequent data collection involved two repetitions with the dominant arm in each exercise at each of the following loads: 7lb, 14lb, 21lb, and 28lb in each exercise (32 total repetitions). Independent samples t-test determined the power compared within one movement. Significance was set at $p<0.05$; owing to the moderate sample and Proteus equipment. Proteus software computed power output in watts for each set performed. Analysis of variance (ANOVA) with repeated measures tested differences between sexes and loads. Data were analyzed using SPSS version 24.0 (IBM SPSS Statistics, IBM Corporation, Chicago, IL, USA). Independent samples t-tests were used to compare dominant arm power performance results between men and women. Paired samples t-tests were used to compare dominant and non-dominant arm performance results among men and women.

Results

In both horizontal and vertical pull motions, there was a significant difference by load ($p<0.001$) and an interaction effect by sex ($p<0.001$). The expression of power was most similar between men and women at the lowest resistance horizontally ($p=0.020$) and vertically ($p=0.038$); both deviated more as weight increased. No plateaus were demonstrated in either motion; higher loads were required for both sexes to achieve peak power. In horizontal and vertical push motions, there was a significant difference by load ($p<0.001$) and an interaction effect with sex ($p<0.001$). Men and women were closest in power at 7lb horizontally ($p=0.017$) and vertically ($p=0.004$). Women experienced a plateau at 21lb; further change was insignificant both horizontally ($p=0.147$) and vertically ($p=0.519$). Men did not exhibit a plateau; power continued to increase from 21lb to 28lb ($p<0.001$).

Table 26

Sex Comparison Descriptives

	N	Mean	Minimum	Maximum	Std. Deviation
Age	32	21.047	18.500	30.700	2.279
Weight	32	168.28	118	280	36.202
Height	32	66.91	58	75	4.298
BMI	32	26.291	19.889	40.171	4.263

Note: The mean age was 21 years of age. Unlike the first two chapters this study contains the youngest population.

Table 27

Independent Samples T-Tests Sex Comparisons for Horizontal Movements

									95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-Tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Push 7lbs	Equal Variances Assumed	.710	.406	2.258	30	.017	18.730	7.410	3.596	33.864
	Equal Not Variances Assumed			2.569	29.467	.016	18.730	7.292	3.827	33.633
Push 14lbs	Equal Variances Assumed	.437	.514	4.194	30	.000	57.024	13.595	29.259	84.789
	Equal Not Variances Assumed			4.191	28.010	.000	57.024	16.606	29.154	84.893
Push 21lbs	Equal Variances Assumed	.001	.972	5.284	30	.000	97.960	18.539	60.098	135.823
	Equal Not Variances Assumed			5.119	24.052	.000	97.960	19.138	58.467	137.454
Push 28lbs	Equal Variances Assumed	.354	.557	5.807	30	.000	160.770	27.684	104.232	217.307
	Equal Not Variances Assumed			5.506	21.105	.000	160.770	29.198	100.067	221.473
Row 7lbs	Equal Variances Assumed	1.264	.270	2.467	30	.020	18.738	7.596	3.226	34.250
	Equal Not Variances Assumed			2.535	29.935	.017	18.738	7.393	3.639	33.837
Row 14lbs	Equal Variances Assumed	.168	.685	3.593	30	.001	53.373	14.853	23.039	83.707
	Equal Not Variances Assumed			3.571	27.389	.001	53.373	14.947	22.726	84.021
Row 21lbs	Equal Variances Assumed	1.361	.253	4.385	30	.000	90.183	20.568	48.178	132.188
	Equal Not Variances Assumed			4.212	22.871	.000	90.183	21.413	45.872	134.493
Row 28lbs	Equal Variances Assumed	1.174	.287	5.055	30	.000	138.754	27.451	82.691	194.817
	Equal Not Variances Assumed			4.840	22.432	.000	138.754	28.671	79.361	198.147

Table 28

Independent Samples T-Tests Sex Comparisons for Vertical Movements

									95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-Tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Push 7lbs	Equal Variances Assumed	4.768	.037	3.417	30	.002	24.825	7.264	9.990	39.661
	Equal Not Variances Assumed			3.216	20.128	.004	24.825	7.719	8.730	40.920
Push 14lbs	Equal Variances Assumed	1.408	.245	4.302	30	.000	46.968	10.917	24.672	69.264
	Equal Not Variances Assumed			4.094	21.600	.000	46.968	11.472	23.151	70.786
Push 21lbs	Equal Variances Assumed	.218	.644	5.664	30	.000	95.722	16.901	61.205	130.240
	Equal Not Variances Assumed			5.488	24.087	.000	95.722	17.442	59.730	131.715
Push 28lbs	Equal Variances Assumed	2.180	.150	7.468	30	.000	157.310	21.064	114.292	200.327
	Equal Not Variances Assumed			7.118	21.809	.000	157.310	22.100	111.453	203.166
Row 7lbs	Equal Variances Assumed	2.979	.095	2.168	30	.038	17.794	8.209	1.029	34.559
	Equal Not Variances Assumed			2.054	21.034	.053	17.794	8.663	-.220	35.807
Row 14lbs	Equal Variances Assumed	2.205	.148	3.040	30	.005	41.079	13.515	13.478	68.681
	Equal Not Variances Assumed			2.896	21.766	.008	41.079	14.185	11.644	70.515
Row 21lbs	Equal Variances Assumed	.102	.752	4.007	30	.000	77.810	19.420	38.148	117.471
	Equal Not Variances Assumed			3.912	25.121	.001	77.810	19.892	36.852	118.767
Row 28lbs	Equal Variances Assumed	1.009	.323	4.811	30	.000	128.984	26.811	74.229	183.739
	Equal Not Variances Assumed			4.709	25.476	.000	128.984	27.389	72.628	185.340

Table 29

Paired Samples Statistics Horizontal Movements 21lbs-28lbs

					95% Confidence Interval				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig.(2-tailed)
Pair 1	Row 21lbs-28lbs	-34.500	32.935	7.763	-50.878	-18.122	-4.444	17	.000
Pair 2	Push 21lbs-28lbs	-12.833	35.822	8.443	-30.647	4.980	-1.520	17	.147

Table 30

Paired Samples Statistics Vertical Movements 21lbs-28lbs

					95% Confidence Interval				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig.(2-tailed)
Pair 1	Row 21lbs-28lbs	-33.111	31.354	7.390	-48.703	-17.519	-4.480	17	.000
Pair 2	Push 21lbs-28lbs	-4.056	26.132	6.159	-17.051	8.940	-.658	17	.519

Note: When looking at both 2-tailed significant values, both paired samples statistical analyses showcased significance to have been met in all pulling motions($p<0.001$). There was no change of significance or plateaus observed at the 21lb-28lb load. In the horizontal pushing movement, (Continued) pushing at a load of 21lbs-28lbs was insignificant at (p=.147), while the vertical pushing was even more insignificant at (p=.519).

Conclusion

In a three-dimensional analysis of power output, resistance in press power varied between the sexes. Horizontal expression of power was most similar between the sexes at the lowest load (p=0.020) as compared to vertically (p=0.038) in pulling motions at the lowest resistance. More notably, both sexes did not plateau in vertical and horizontal pulling motions, as compared to the pushing motions. Contrarily, all concentric movements were performed in a superset method based on the horizontal or vertical pathway; a horizontal row was immediately followed by a horizontal press. Thus, female resistance to fatigability is only a consideration, and not the primary mediator variable of explaining the absence of plateauing.

A lack of plateau may also be explained by the higher rate of upper body strength improvement women have relative to body weight (Hubal et al., 2005; Hunter et al., 2004; Roberts et al., 2020). Men and women also express no difference in the number of motor units, nor difference in motor unit activation according to one investigation (Miller et al., 1993). Additionally, the previously mentioned study investigated the bicep brachii, a muscle that is involved with both horizontal and vertical pulling motions given its function of elbow flexion. Alterations past 21lbs were less significant in the vertical pressing movement (p=0.519) compared to the horizontal movement (p=0.147) among female subjects. The mechanically disadvantageous position of both presses resembles the likes of a class three lever. In addition to the lever, the vertical movement pattern inhibits the contraction of the pectoralis major as compared to a horizontal press (Rodríguez-Ridao et al., 2020). Thus, less cumulative skeletal muscle recruitment in the vertical press may have explained the vast difference of insignificance between presses. Likewise, the greater composition of the IIx fiber type in the male subjects may explain some of the disparity in power output.

CHAPTER 5: CONCLUSION

Power output increased in concentric bicep curls between both sexes after five different training sessions. Bilateral exercises produced more pronounced power output compared to unilateral movements. After five training sessions, changes in power output became insignificant in a large male sample. Comparatively between the sexes, men and women were similar in power performance of upper extremity concentric pull motions in the horizontal, and vertical pathways. Conversely, females began to plateau in power after 21lbs of loaded magnetic resistance in concentric pushing movements, while men expressed no plateau in performance. Although men appeared to effectively lift more load efficiently, these findings suggest females and males have similar physical characteristics of power output. Subjects varied in age, and sport experience. The varying subject characteristics may present sufficient external validity of how power profiles operate within the general populace. Studies using specific populations on Proteus would offer coaches applicable evaluations of athlete performance within the season.

More research investigating specific physiological influence of testosterone, estrogen, and endogenic factors on resistance training would help explain significant disparities between biological sex influence. Further investigations into differences of myofiber types within the musculoskeletal system of the sexes would better explain divergences observed with strength, power output, and fatigability. Likewise, advancement in the understanding of neural adaptations within human performance could explain disparities in force production and rate of adaptation. In summary, both sexes display similar power profiles, excepting the differences in overcoming heavier external resistance. Future research assessing sex-mediated differences on power output is still warranted.

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