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INTER-LIMBS EFFECT, DIFFUSION AND STRENGTH PREDICTORS IN ARM FLEXORS

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ABSTRACT

Background: Strength training is a methodical exercise regimen that enhances muscle action, and is the act of repeated voluntary muscle contractions against a resistance greater than usually accomplished during activities of daily living. However, there are controversial reports on the effects of cross education and strength diffusion in untrained muscles.

Aims: The aim of this study was to establish the inter-limb phenomenon between trained and untrained contralateral homologous muscle and other adjacent muscle groups of the trained extremity.

Materials and Methods: Forty undergraduate students participated in this study. They were randomly assigned to 2 groups. For progression, One-Repetition Maximum (1-RM) was determined four times within six weeks isometric training of the arm flexors for participants in the experimental group (group 1) while participants in group 2 served as control. Using standard procedures, spring balance was used to measure the strength of the arm flexors and other selected muscles in both limbs, at onset and at the 6th week. The Body Mass Index (BMI) was computed while height, weight, and girth were measured. Descriptive statistics, Paired and Independent t-tests; and ANOVA were used to analyze the data. Level of significance was set at 0.05.

Results: There were significant differences between the right and left right arm flexor strength following 6 weeks isometric strength training in both the experimental and control groups ($t = 6.57$, $p = 0.001$; $t = 5.10$, $p = 0.001$). There were significant differences between the initial and final for both right and left right arm flexor muscle strength following 6 weeks isometric strength training ($t = -7.95$, $p = 0.001$; $t = -8.97$, $p = 0.001$ respectively) but none in the control group. There was only significant increase in the selected adjacent muscles in the experimental group despite that they were not trained ($p = 0.001$). Height was the most significant predictor of arm flexors strength, contributing 29% ($p = 0.005$).

Conclusion: There was cross education effect at the untrained contralateral homologous muscle (arm flexors) following 6 weeks training of the other opposite extremity. Similarly, there were strength gains in the untrained shoulder flexor, extensor, abductor, adductor; and extensor, muscle groups, implying strength diffusion. Also, height of the participants was the most significant predictor of arm flexors strength.

Keywords: Muscle Strength, Inter-limb effects, Diffusion, Isometric training, Arm flexors

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INTRODUCTION

Strength is the amount of force produced in a muscle during a single maximal effort and it can only be achieved through effective training that largely depends on time tested principles, experimentation, exercise and sequence variations, and appropriate selection of procedures[1, 2]. Resistance training is any form of exercise that causes muscles to contract against an external resistance to build strength and hypertrophy[3]. Strength training is a methodical exercise regimen used to improve the capacity to apply or resist force[4]. Strength training is an engagement that enhances muscle strength and it is the act of repeated voluntary muscle contractions against a resistance greater than those usually accomplished during daily living activities[5, 6].

Most old literature are still very relevant in the principles of using 1-RM and progressive overloading with external resistance. The external resistance has to be progressed and the training stimulus must gradually and constantly be increased in order to achieve the goal. However, it is noteworthy that if overload increases too rapidly, injury may occur and if overload progresses too slowly, improvements will be minimal or non-existent[1, 7].

The term "cross-education" had been postulated for several decades and it was a phenomenon of strength gains in an untrained contralateral limb after unilateral resistance training[8,9,10,11]. There are so many reports on the inter-limb effects but it is generally accepted that the transfer effect is muscle-specific, primarily affecting the homologous contralateral muscles alone. However, some reports speculated that there may be a minimal effect to some synergist group of muscles[12]. The clinical significance of the radiating effects is considered to be small by some researchers[13,14]. The analysis conducted in the reviews of were restricted to studies that used training intensities higher than 50% of maximum strength for at least 2 weeks[15,9,11].

The prime movers for flexion activities at the elbow joint are the biceps brachii, the brachialis, and the brachioradialis, however, the biceps is a major flexor whose strength cannot be neglected for full hand functions after impairment[16,17]. Onigbinde *et al* established the existence of cross training effect in patients with unilateral orthopaedic and neurological disorders[18,19,20]. However, the findings could not be generalized because of the small sample size and weak self-control design adopted in the studies. There is need to have a true experimental design with control in order to be able to generalize the findings. Asides this, most previous studies were not explicit in the values of 1-RM and progression adopted in the isometric training. Furthermore, while there are some studies on cross education effect, there are limited empirical data on the establishment of strength gains (diffusion) to untrained synergist and adjacent muscles in the same trained ipsilateral extremity. This study therefore aimed at determining the effects of cross education to contralateral homologous muscle and strength diffusion from trained arm flexors to other untrained heterologus muscles of the same upper extremity.

MATERIALS AND METHODS

Participants

Participants in this study were 40 undergraduate students at the University of Medical Sciences, Ondo State, Nigeria.

Inclusion and Exclusion criteria

Included in this study were apparently healthy and right hand dominant undergraduate students within the ages of 18 to 30 years. Excluded were students with musculoskeletal abnormalities, who engaged in active sports or were taking stimulants or steroid drugs.

Site of Study

The investigation took place at the gymnasium of the Physiotherapy Department, Faculty of Medical Rehabilitation, University of Medical Sciences, Ondo State.

Study Design

The design was a randomized control trial (RCT). There were two groups; the experimental and the control group. The participants were randomly assigned to the group using fish-bowl technique.

Sampling technique

A convenience sampling technique was utilized to recruit the participants. The sample size was determined using the sample size equation of Araoye *et al*[21]. The size was computed to be 35 for both groups, however, 40 participants were recruited for the study in order to give room for attrition.

Instruments

Bathroom weighing scale was used to measure the weight while Stadiometer was used to measure the height of the participants. The spring balance was used to quantify the strength of the selected muscle groups. The spring balance is graded from 0 to 100kgf but the values were converted to Standard Unit, Newton(N) to have a grade of 0 to 980.67N, (1kgf=9.8067N)[22]. The Multigym Exercises was used to strengthen the bicep brachii muscles while the BMI (Body Mass Index) was computed by dividing the body weight in kilograms by the square of the height (kg/m^2).

Procedures

Ethical approval was obtained from the Ethics and Research Committee of University of Medical Sciences, Ondo. Individual undergraduate students were approached to participate and those who met the inclusion criteria were recruited. The procedures were explained to each participant. A quick interview was used to determine the participants' dominant hand, using the procedure of Balogun and Onigbinde[22]. One-Repetition Maximum (RM) was determined for the dominant right hand by measuring the heaviest weight the subject could only carry once to execute the final elbow flexion[23]. This was determined for all the subjects prior to commencement, at 3rd, 5th and 6th week. The value of RM determined the amount of weight used to strengthen the biceps brachii muscles for each patient at each week. The dosage of training was 3sets and 10 repetitions with a passive recovery time of 3 minutes[24].

Procedures for training and quantification of the arm flexors muscles

The biceps curl exercises were done to train the muscles of the upper limb with one end of the pulley connected to the multigym. Each exercise was performed in a standing position. The arm was maintained parallel to the trunk. Each

participant was instructed to flex the elbow joint and pulled the loaded weight at the other side of the multigym and sustained the contraction, isometrically, sustaining it for 10 seconds, 10 repetitions and 3 sets[25]. Each exercise phase was separated by at least 3 minutes of passive recovery[24]. Prior to the main exercise phase, 25% of the determined1-RM was used as warm-up, consisting of 3 sets x 10 repetitions of biceps curl exercise. The strength of the arm flexors, arm extensors, shoulder flexors, extensors, adductors and abductors muscles were quantified and recorded at onset, (2) after 2 weeks, after 4 weeks and after 6weeks (Fig 1 - 6).

Procedures for measurements of arm flexors muscle strength

Each participant was in a seated position with elbow in 90° flexion. The wrist attachment of the spring balance was fixed proximal to the wrist joint while the other side of the spring balance was anchored to the bottom of the plinth. The forearm was abducted against the thorax ensuring that the anchor points are in line with the movement trajectory. Each participant was instructed to maintain the neutral spine position, avoiding lateral trunk flexion to the opposite side, as well as the elevation of the scapula of the same side. The participant was instructed to pull the spring balance upward, maximally, the applied force was then quantified on the balance and the measurement was recorded[26].

Procedures for measurements of arm extensors muscle strength

The participants were in supine position, with 90 degrees flexion in both shoulder and elbow. The attachment of the spring balance was placed on the wrist with patient thumb facing downward. The distal end of the spring balance was anchored to the plinth in line with the wrist ensuring that the anchor points are in line with the movement. Each participant was instructed to pull the spring balance backward, maximally, the measurement on the spring balance was recorded[26].

Procedures for measurements of shoulder flexors strength

The participants were positioned in a sitting position, with their shoulder at 90° flexion and arm pronation. The wrist attachment of the spring balance was firmly placed proximal to the elbow joint, while the distal end was anchored to the bottom of the plinth on the opposite side ensuring that the spring balance anchor points are in line with the movement trajectory. The participant was instructed to maintain the neutral spine position and to avoid the lateral flexion. To additionally eliminate compensations, a manual pressure was applied to the opposite shoulder while the movement is performed. The participant was instructed to pull the spring balance upward, when complete, the participant released the applied force and the measurement was recorded[26].

Procedures for measurements of shoulder extensors

The participants lied in a prone position with arm in pronation. The wrist attachment of the spring balance was firmly placed proximal to the elbow joint while the distal end of the spring balance was anchored to the bottom of the plinth on the opposite side ensuring that the spring balance anchor points are in line of the movement trajectory. The participant

was instructed to pull the spring balance upward, when complete, the participant released the applied force and the measurement was recorded[26].

Procedures for measurements of shoulder abductors

The participants in sitting position, kept the shoulder joint in 90° abduction with the arm pronation. The wrist attachment of the spring balance was firmly placed proximal to the elbow joint while the distal end of the spring balance was anchored to the bottom of the plinth at the opposite end ensuring that the spring balance anchor points are in line with the movement trajectory. The participant was instructed to maintain the neutral spinal position throughout the measurement, avoiding lateral flexion. To additionally eliminate compensation, a manual pressure was applied to the opposite shoulder while the movement is performed. The participant was instructed to pull the spring balance upward, when completed, the participant released the applied force and the measurement was recorded[26].

Procedures for measurements of shoulder adductor and abductor muscles

Standard procedures were used to quantify the shoulder adductor and abductor muscles using the spring balance (Figures 5 & 6). The protocols adopted for this study with regards to training and testing positions, and verbal motivation are standard procedures where maximum peak isometric forces could be generated[27].

The assessments were done at onset, after 2 weeks, after 4 weeks, and after 6 weeks.

Fig 1: Procedure for measurements of arm flexors

Fig 2: Procedure for measurements of arm extensors

Fig 3: Procedure for measurements of shoulder flexors

Fig 4: Procedure for measurements of shoulder extensors

Fig 5: Procedure for measurements of arm abductors

Fig 6: Procedures for measurements of shoulder adductors

Procedures for warm up for each training

The participant stood in an erect position with elbow extension and held the sandbag in front of the body with forearm in supine position. The weight of the sandbag is the 25% of the 1-RM that was determined for the participant, the participant was instructed to execute full elbow flexion and extension, and perform the exercise for 10 reps.

Data Analysis

The data were summarized using descriptive statistics of (range) mean and standard deviation. Paired t-test was used to compare the right and left upper limb, the initial and final strength within the groups. Student t-test was to compare variables of the groups, ANOVA was used to compare the 1-RM at initial, 3rd, 5th and 6th week. Post hoc (LSD) was used to reveal the trend of the differences. Level of significance was set at <0.05.

RESULTS

Gender, Age and Anthropometric Parameters of Participants in the Experimental and Control Groups

There were 7 female (35.0%) and 13 male (65.0%) in the experimental group while there are 11 female (55.0%) and 9 male (45.0%) in the control group. The average age of the participants in the experimental and control groups were 22.05 ± 2.24 and 21.05± 2.52 years respectively. The height, weight and BMI are presented in the table 1. The results showed that there were no significant differences in the age, height, weight and BMI of the participants of the experimental and control groups (Table 1).

Comparison of Selected Muscle Strength and Arm Flexor Girth of the Experimental group

The mean values of one-RM, muscle strength and girths are presented in table 2. The result of the paired t-test (dependent t-test) showed that there was significant difference between the right and left right arm flexor muscle strength following 4 weeks isometric strength training (t = 6.57, p = 0.001). There were significant differences between the initial and final for both right and left right arm flexor muscle strength following 4 weeks isometric strength training (t = -7.95, p = 0.001; t = -8.97, p = 0.001 respectively). The results of comparison of other group of muscles in the upper extremity are presented in Table 2.

At baseline the result showed that the average arm girth of the right and left arm girth was 27.38 ± 2.08cm and 26.85 ± 2.24cm for the participants in the experimental group. There was significant difference between the right and left right arm girth following 6weeks isometric strength training (t = 4.10, p = 0.001). There were significant differences between the initial and final for both right and left right arm girth following 6 weeks of isometric strength training (t = -1.55, p = 0.137; t = -2.93, p = 0.009 respectively).

Table 1: Comparison of Age, and Anthropometric Parameters of both experimental and control group

	Experimental	SD	Control	SD	t	p
Age	22.05	2.24	21.05	2.52	1.33	0.19
Height	1.74	0.09	1.70	0.07	1.79	0.08
Weight	65.88	9.70	71.34	19.44	-1.13	0.27
BMI	21.82	3.39	25.00	7.63	-1.71	0.10

Table 2: Within-group Comparison of Muscle strengths and Girth for the Experimental group

	Mean (N)	S.D (N)	T	p
Arm flexors:				
Right	219.52	65.04		
Left	195.02	57.75	6.57	0.001
Right arm flexors:				
Initial	219.52	65.04		
Final	280.28	71.41	-7.95	0.001
Left arm flexors:				
Initial	195.02	57.75		
Final	248.92	56.91	-8.97	0.001
Right shoulder abductors:				
Initial	237.16	59.96		
Final	303.80	70.67	-6.96	0.001
Right shoulder adductors:				
Initial	196.98	56.69		
Final	270.48	68.07	-7.80	0.001
Right shoulder extensors:				
Initial	195.02	51.46		
Final	283.22	66.84	-8.04	0.001
Right shoulder flexors:				
Initial	252.84	66.97		
Final	340.06	83.71	-7.21	0.001
Right arm extensors:				
Initial	291.05	90.90		
Final	380.73	101.21	-4.83	0.001
Arm girth:				
Right	27.38	2.08		
Left	26.85	2.24	4.10	0.001
Right arm girth:				
Initial	27.38	2.08		
Final	27.82	1.74	-1.55	0.137
Left arm girth:				
Initial	26.85	2.24		
Final	27.75	1.89	-2.93	0.009

Comparison of Selected Muscle Strength and Arm Flexor Girth of the Control group

The mean values of muscle strength and girths for the participants in the control group are presented in table 3. The result of the paired t-test (dependent t-test) was significant difference between the right and left right arm flexor muscle strength after 6 weeks of not training ($t = 5.10$, $p = 0.001$). There were no significant differences between the initial and final for both right and left right arm flexor muscle strength after 6 weeks of not training ($t = -1.14$, $p = 0.27$; $t = -0.37$, $p = 0.72$ respectively). The results of comparison of other group of muscles in the upper extremity are presented in Table 3.

Comparison of Selected Muscle Strength and Arm Flexor Girth of the Experimental and Control groups

At baseline, the result showed that the average muscle strength of the right arm flexors of the experimental and control group 219.52 ± 65.04 and 204.82 ± 62.78N respectively. The result of the student t-test showed that there was no significant difference in the initial right arm flexors of the experimental and control groups. However, there was significant difference in the final right arm flexors of the experimental and control groups ($t = 3.58$, $p = 0.001$). The left arm flexors of the experimental and control group were 195.02 ± 57.75N and 188.16 ± 58.77N. Similarly, there was no significant difference in the initial left arm flexors of the experimental and control groups but there was significant difference in the final left arm flexors of the experimental and control groups ($t = 3.44$, $p = 0.001$). The results of other comparisons are presented in Table 4.

Correlation between age, selected Anthropometric variable, Girths, Repetition Maximum and Right arm elbow flexors

The results of the Pearson's Correlation Co-efficiency showed that there were significant correlations between age and right ($r = 0.43$, $p = 0.005$) and left arm elbow flexors ($r = 0.46$, $p = 0.003$). There was also significant correlation between age and the baseline Rep Max ($r = 0.47$, $p = 0.04$). Similarly, height had significant correlations with right elbow flexors ($r = 0.54$, $p = 0.001$), left elbow flexor ($r = 0.50$, $p = 0.001$), baseline RM ($r = 0.61$, $p = 0.004$) and Final RM ($r = 0.66$, $p = 0.002$). However, there was no significant correlation between right elbow extensors and height ($r=0.01$, $p=0.97$). There was also no significant correlation between right shoulder adduction and weight. ($r=0.54$, $p=0.74$). The results of other correlations are presented in Table 5.

Results of the Multiple Regression Analyses

The results of multiple regression analyses showed that age, height, weight, BMI, right and left arms girth were significant predictors of right arm flexors strength ($F=3.85$, $P=0.005$) in Table 6. The results showed that age contributed 18.8% to the prediction of right arm flexors strength while height had 29.0%. The results of other contributions are presented in table 7. The coefficient of determination was found to be 0.41. The predictive equation obtained for the right arm flexor strength:

Right arm flexor strength= *-607.614+ Age (8.55) + height (328.41) + weight (0.686) + BMI (-1.137) + Right girth (0.75) + Lt girth (1.066) .*

Table 3: Within-group Comparison of Muscle strengths and Girth for the Control roup

	Mean	S.D	t	P
Arm flexors:				
Right	204.82	62.78		
Left	188.16	58.77	5.10	0.001
Right arm flexors:				
Initial	204.82	67.78		
Final	207.76	55.95	-1.14	0.27
Left arm flexors:				
Initial	188.16	58.77		
Final	187.18	56.69	0.37	0.72
Right shoulder abductors:				
Initial	239.12	43.87		
Final	243.04	43.32	-1.71	0.10
Right shoulder adductors:				
Initial	203.83	47.34		
Final	204.81	36.80	-0.17	0.87
Right shoulder extensors:				
Initial	185.22	63.10		
Final	182.28	62.01	1.00	0.33
Right shoulder flexors:				
Initial	253.82	49.45		
Final	253.82	49.86	0.001	1.00
Right arm extensors:				
Initial	282.24	85.65		
Final	281.26	82.25	0.15	0.88
Arm girth:				
Right	28.95	6.01		
Left	29.02	6.18	-0.72	0.48
Right arm girth:				
Initial	28.95	6.01		
Final	29.32	6.18	-0.72	0.48
Left arm girth:				
Initial	29.02	6.18		
Final	29.17	6.01	2.03	0.06

Table 4: Comparison of the Arm Flexor Muscle strength and Girth of the Experimental and Control groups

	Experimental		Control group			
	Mean	**S.D**	**Mean**	**S.D**	**t**	**p**
Right arm flexors:						
Initial	219.52	65.04	204.82	62.78	0.73	0.47
Final	280.28	71.41	207.76	55.95	3.58	0.001
Left arm flexors:						
Initial	195.02	57.75	188.16	58.77	0.37	0.71
Final	248.92	56.9s1	187.18	56.69	3.44	0.001
Rt shld abd Initial	237.16	59.96	239.12	43.87	-0.12	0.91
Final	303.80	70.67	243.04	43.32	3.28	0.002
Right shoulder add						
Initial	196.98	56.69	203.83	47.34	-0.42	0.68
Final	270.48	68.07	204.81	36.80	3.80	0.001
Right shoulder ext						
Initial	195.02	51.46	185.22	63.10	0.54	0.39
Final	283.22	66.84	182.28	62.01	4.95	0.001
Right shoulder flex						
Initial	252.84	66.97	253.82	49.45	-0.05	0.96
Final	340.06	83.71	253.82	49.86	3.96	0.001
Right arm ext						
Initial	291.05	90.90	282.24	85.65	0.32	0.75
Final	380.73	101.21	281.26	82.25	3.41	0.002
Right girth: Initial	27.38	2.08	28.95	6.01	-1.10	0.28
Final	27.83	1.74	29.17	6.01	-0.96	0.35
Left girth: Initial	26.85	2.24	29.02	6.18	-1.48	0.15
Final	27.75	1.89	29.33	6.18	-1.10	0.28

Key: *Shld: shoulder, Abd: abductors, Add: adductors, Ext: extensors, Flex; flexors*

Table 5: **Correlation between age, selected Anthropometric variable, Girths, Repetition Maximum and Right arm elbow flexors**

Variable		Age	Height	Weight	BMI	RTELFL	LTELFL	InitialRM	FinalRM	RTSHAB	RTSHAD	RTSHFL	RTSHEX	RTELEX
Age	R	1												
	P													
Height	R	0.29	1											
	P	0.07												
Weight	R	-0.20	-0.04	1										
	P	-0.21	0.80											
BMI	R	-0.20	-0.40*	-0.93**	1									
	P	0.08	0.011	0.001										
RTELFL	R	0.43**	0.54**	0.10	-0.10	1								
	P	0.005	0.001	0.55	0.53									
LTELFL	R	0.46**	0.50**	0.110	-0.08	0.97**	1							
	P	0.003	0.001	0.51	0.62	0.001								
InitialRM	R	0.47*	0.61**	-0.03	-0.41	0.89**	0.91**	1						
	P	0.04	0.004	0.91	0.073	0.001	0.001							
FinalRM	R	0.32	0.66**	-0.07	0.48*	0.86**	0.86**	0.94**	1					
	P	0.17	0.002	0.77	0.033	0.001	0.001	0.001						
RTSHAB	R	0.37*	0.57**	0.15	-0.06	0.85**	0.85**	0.89**	0.86**	1				
	P	0.002	0.001	0.36	0.71	0.001	0.001	0.001	0.001					
RTSHAD	R	0.45**	0.38*	0.05	-0.08	0.76**	0.77**	0.81**	0.77**	0.76**	1			
	P	0.004	0.02	0.74	0.62	0.001	0.001	0.001	0.001	0.001				
RTSHEX	R	0.41**	0.51**	-0.06	-0.23	0.80**	0.77**	0.76**	0.77**	0.72**	0.66**	1		
	P	0.009	0.001	0.70	0.16	0.001	0.001	0.001	0.001	0.001	0.001			
RTSHFL	R	0.40*	0.36*	0.03	-0.09	0.80**	0.82**	0.84**	0.86**	0.86**	0.80**	0.69**	1	
	P	0.01	0.02	0.86	0.59	0.001	0.001	0.001	0.001	0.001	0.001	0.001		
RTELEX	R	0.40*	0.28	0.01	-0.1	0.76**	0.73**	0.69**	0.70**	0.76**	0.74**	0.73**	0.78**	1
	P	0.01	0.08	0.97	0.54	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	

* Correlation is significant at the 0.05 level (2- tailed) ** Correlation is significant at the 0.01 level (2- tailed)

Key: *BMI: Body Mass Index, RT: Right, LT: Left, RM: Repetitive Maximum, AD: Adductors, AB: Abductors, FL: Flexors, EL: Extensors, SH: Shoulder*.

Table 6: Results of multiple Regression Analysis for the right arm elbow flexors

	Sum of Squares	df	Mean Square	F	p
Regression	64790.411	6	10798.402	3.847	0.005
Residual	92628.753	33	2806.932		
Total	157419.164	39			

Table 7: Percentage Contribution of the independent Variables

Variable	Percentage Contribution
Age	18.8
Height	29.0
Weight	0.9
BMI	1.1
Left girth	1.9
Right girth	2.5

DISCUSSION

The age, height, weight and BMI of both groups are comparable as there were no significant differences in the values, hence, any difference observed in strength cannot be attributed to difference in these variables. The main purpose of this study was to investigate if there was cross education effects on the untrained left elbow flexors after isometric training to the right arm elbow flexors for 6 weeks and if there was (diffusion of strength) at the adjacent muscles after training the right elbow flexors for 6 weeks, with a view to establishing cross training and diffusion effects.

This study found that the arm elbow flexors muscle strength of the untrained left arm elbow flexors increased significantly after 6 weeks isometric training of the right arm elbow flexor muscles, this implies cross education effects. There were significant increases in the final muscle strength of adjacent muscles namely; shoulder

extensors, shoulder flexors, shoulder abductors, shoulder adductors and elbow extensors. This implies that there was diffusion of strength in selected muscles of the right arm following 6 weeks isometric training of only the right arm elbow flexor muscle. There was significant increase in the right and left arm girth following 6 weeks isometric strength training, this, established a significant cross training effect. For the control group, the participants didn't train for 6 weeks, unlike the participants in the experimental group, there was no significant difference between the strength when the initial and final strength were compared for the right and left arm flexors, and adjacent muscles. This implies that there was no diffusion and cross education effects without isometric training.

There are previous reports which had established cross training effects after volitional exercise training[28]. This current finding corroborated the finding of Zhou *et al.,* but contradicted that of Sariyildiz *et al.,* who found no increment in the contralateral strength, although, it was the wrist flexor groups of muscles that were strengthened in their studies[8,29]. This current finding also corroborated the reports of Onigbinde *et al*., who established cross training effect in the quadriceps muscles of apparently healthy individual[19]. They had earlier speculated that the inter-limb phenomenon might be useful for patients with unilateral pathologies such as osteoarthritis and cast immobilization[18]. We observed that our findings were comparable to the effect of high resistance exercise training utilized to improve muscle strength as reported by Abe *et al*., and Onigbinde *et al*., who concluded that it would be clinically useful to train one limb to generate a strength increase in the untrained limb of patients as the un-trained contralateral muscle strength also increased significantly after 6 weeks[19,30]. Physiological changes such as increased hypertrophy and hyperplasia of muscle fibers; neural activation (firing and synchronization of more motor units); increased tensile strength of tendon, ligaments and connective tissues had been reported for exercise strengthening programmes[31]. The implication of this was that it would be non-beneficial if the workload was not progressively increased to keep pace with newly won strength at the third week of training. Since discovery in 1894, subsequent studies have confirmed the existence of cross education in contexts involving voluntary, imagined and electrically stimulated contractions[18]. There are two hypothetical explanations described by Lee and Carroll for cross training effects[5]. The first hypothesis suggested that unilateral resistance training may activate neural circuits that chronically modify the efficacy of motor pathways that project to the contra-lateral untrained limb. The second hypothesized that the opposite untrained limb may access the modified neural circuits by induction from motor areas that are primarily involved in the control of movements of the trained limb. These were not different from the theories of bilateral co-activation of cortico-spinal tract explained by Carr *et al*.; bilateral co-activation suggested activation of afferent modulation at contra-lateral limb by Horgtobagyi *et al.,* and diffusion of impulses between cerebral hemisphere opined by Yue and Cole[32,33,34]. Our finding had lent

credence to previous theories and explanations on cross training.

We found out that age and anthropometric parameters were significant predictors of the right arm elbow flexors strength. For the prediction of arm flexors, we found that age contributed 18.8%, height 29.0%, weight 0.9, BMI 1.1%, right and left elbow girth 2.5% and 1.9% respectively. The findings of this study were similar to that of Onigbinde *et al* [18]. However, Onigbinde *et al* observed that the strongest predictor of strength was weight but this present contribution found height as the highest[18]. The coefficient of determination was found out to be 0.41 and this can be considered to be moderately good. The moderate 0.41 could be attributed to the narrow age range (18-28years) of the participants. Therapists using our present equation should realize that despite the statistically significant predictive potential of age and anthropometric indices, considerable variability remains when they are used to predict the right arm elbow flexors.

Our current findings have clinical implications because it established that the strengthening of right arm elbow flexors produced meaningful and significant increase in strength of the untrained left arm elbow flexors contralateral homologous group of muscles. The increment in both arm flexors may translate to an improvement in functional activities and decreased loading rate at the elbow joint[35]. The inter-limb phenomenon may potentially contribute to more effective use of resistance training protocols that exploit these cross-limb effects to improve the recovery of patients with movement disorders where one side of the body are predominantly affected[5]. The measured effects vary from adaptations of muscle performance to alterations in gene expression, inflammation and tissue remodeling[36].

There are morphological and architectural changes in muscle structure using exercises[37]. It is noteworthy that the clinical significance of this study is high because it has ascertained that training the good limb can generate strength increase in the contralateral extremity with pathology or immobilized in a cast, especially, in patients requiring orthopaedic and neurological rehabilitation. One of the main goals of stroke rehabilitation is training ambulation and this depends to a large extent on the muscle strength of the affected lower limb, asides impairment in balance, and presence of moderate extensor pattern[38].

CONCLUSION

It was concluded that there was cross education effect on the untrained left arm flexor muscles after 6 weeks of isometric training of the right arm flexors. Also, this study established strength gain or diffusion into adjacent muscles (shoulder flexors, extensors, abductors, adductors and triceps) of the right upper extremity following 6 weeks isometric training of only the right arm flexors. It was also concluded that age, weight, height, Body Mass Index, left and right girth are significant predictors of right arm flexor muscles strength.

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