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Biomechanical Pressures and Upper Extremity Asymmetry: A Study on Young Laborers

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A B S T R A C T

The purpose of this study is to reveal the impacts of biomechanical pressures of heavy working conditions on the upper extremities of young laborers. The study covers the examination of the upper extremities of 104 young laborers in the industrial workshops of Ankara, Turkey regarding bilateral asymmetry. The average age of the laborers was 18.48±0.61 years. The control group consisted of 102 non-laborers with an average age of 18.39±0.58 years. The laborers were measured with regard to width of elbows, wrists, and hands, and the length of hands. No significant difference between the groups was observed with the exception of average wrist width. However, while the labor group showed directional asymmetry in all measurements, the non-laborers exhibited directional asymmetry only in hand width and length. Consequently, the study revealed that biomechanical pressures tend to increase directional asymmetry in the upper extremities.

***Key words**: directional asymmetry, biomechanical pressure, upper extremity, young laborers*

Introduction

Biomechanical pressures are known to have an incremental effect on bone and muscular tissues. The increase in the diaphyseal dimensions of the long bones and the change in the cross-sectional morphology are typical responses to biomechanical pressure[1–4]. This responsive transformation was also encountered on joint surfaces and bone length on smaller scales compared to cross-sectional diaphyseal morphology. The cause of lesser impact on these parts is attributed to the fact that the development of these parts is somewhat influenced by genetic factors. In other words, these bone parts have lesser phenotypic plasticity[5,6]. According to some researchers, the biomechanical pressures result in arthritis or similar joint diseases rather than leading to an increase in the tissue content[7,8].

One method of testing the effects of mechanical loading on bone is through the analysis of directional bilateral asymmetries[9–12]. Directional asymmetry results from the excessive development on one side of the bilateral traits and it is usually encountered in studies of persons engaged in continuous sportive activities. Sports, especially those in which one side of the body is used more excessively such as tennis and rodeo, lead to directional asymmetry due to an increase in the tissue content and dimensions of the hand and elbow used in the activity. The findings in a variety of studies of a similar nature indicate that biomechanical pressures are the causes of directional asymmetry[11–14].

The obvious effects of biomechanical pressures can also be observed on the upper extremities of people particularly in those who have been working in more physically demanding occupations since childhood. These people are subject to monotonous and heavy physical tasks that often require them to exceed the limits of their physical capacities through exerting extreme force[15]. Though such activities are known to influence physical development[16–20], few studies have been conducted to determine the extent of the result in asymmetry in the bilateral traits of the upper extremities. Previous studies on laborers mostly concentrated on the muscular volumes of the right and left upper arms as well as grip and pinch strength[21,22]. Such studies tend to point to the differences in grip and pinch strength and changes of one kind or another in the muscular volumes of the upper arms. This study discussed in this paper was conducted to test whether heavy working conditions increase the directional asymmetry level of the upper limbs.

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Material and Method

In order to analyze the effects of the biomechanical pressures of heavy working conditions on the upper extremities where functional asymmetry is frequently encountered, 104 young laborers age 18 and above were examined. All the subjects had a history of doing heavy work during their adolescent growth period. The measurements were done at the Ahi Evran Vocational School (Ahi Evran Mesleki Eğitim Merkezi) and other vocational training centers in Siteler, Ankara, Turkey. (The apprentices have formal education one day per week). Job descriptions and work histories of the individuals along with daily working hours are provided in Table 1 and 2, respectively.

A control group which is made up 102 non-laborer males of the same socioeconomic level and age category was also examined to determine the effects of work on the upper extremities. The control group was chosen from the shanty settlements, or slums, of Ankara. The individuals in this group do not work and attend neighborhood public schools.

TABLE 1
WORK FIELDS OF YOUNG LABORERS

Job	N	%
Automotive repair	43	41.4
Furniture manufacture	37	35.7
Auto reupholstering	10	9.6
Auto-body repair	8	7.7
Metal production	6	3.8
Total	104	100.0

TABLE 2
WORKING BACKGROUND AND HOURS WORKED DAILY

	Min.	Max.	X	SD
Years worked	3	11	5.00	1.45
Hours worked daily	8	17	10.30	1.58

X – mean, SD – standard deviation

The ages of the individuals are recorded as day/month/year and later calculated by the decimal system. The average age of the laboring group was 18.48 (SD=0.61 years), while that of the control group was 18.39 (SD=0.58 years), (p=0.31). Edinburgh Handedness Inventory was also applied to determine the handedness of the individuals[23]. The elbow, wrist, and hand widths, and the hand lengths of the subjects were measured with a digital caliper of 0.01 mm sensitivity in accordance with the techniques proposed by the IBP (International Biological Programme)[24]. Bilateral data was obtained using blind measurement technique[25] and all measurements were taken by the author. A mixed model ANOVA was used for estimating repeatability of the asymmetry as many authors have suggested that this method is more appropriate[26,27]. In this method the factors are Individuals (I), Sidedness (S; right or left) and Replication (R; the repeated measurement). The ratio of the I-by-S mean square to the combined I-by-S-by-R and I-by-R mean squares provides an F-test of whether between-individual variation in estimated asymmetry is significantly greater than what can be accounted for by measurement error[27]. For this analysis, 32 individuals were measured twice in order to determine the measurement error.

Signed, absolute (unsigned), and relative asymmetries were determined by the formulas; R-L, $\sqrt{(R-L)^2}$ and $(\sqrt{(R-L)^2}) / ((R+L)/2)$, respectively. These formulas were defined by Palmer and Strobeck[25,26] to be used in developmental stability and asymmetry studies and are commonly used in studies performed both with humans as well as with different species[28–34]. The mean trait size of the groups was compared by using one-way ANOVA whereas relative asymmetry means were compared through the use of the Mann Whitney U Test. In order to detect the existence of directional asymmetry within the groups, one-sample t-test was used as recommended by Palmer and Strobeck[26] and Swaddle et al.[27]. The Statistical Package for Social Sciences (SPSS of version 11.0) was used for all statistical calculations and processes.

Results

Edinburgh Handedness Inventory showed that each group is comprised 95% of right-handers. This result is significant in reaching dependable findings in the com-

TABLE 3
TWO WAY MIXED MODEL ANOVA (INDIVIDUALS [RANDOM] x SIDES [FIXED]) RESULTS IN LABOR GROUP

Trait	df	Measurement Error			Sides	Individuals
		ms (σ^2_m)	Ms (σ^2_ι)	(σ^2_m/(σ^2_ι)	F	p
Elbow width	15	0.506	4.997	0.101	9.87	0.001
Wrist width	15	0.391	4.109	0.095	10.51	0.001
Hand length	15	1.122	9.361	0.120	8.35	0.001
Hand width	15	0.456	5.271	0.086	11.57	0.001

df – degrees of freedom, ms – mean square, σ^2_m – measurement error variance, σ^2_ι – non-directional symmetry variance, $\sigma^2_m/\sigma^2_\iota$ – magnitude of measurement error relative to the between-sides variation.

TABLE 4
TWO WAY MIXED MODEL ANOVA (INDIVIDUALS [RANDOM] x SIDES [FIXED]) RESULTS IN NON-LABOR GROUP

Trait	df	Measurement error			Sides	Individuals
		ms (σ^2_m)	Ms (σ^2_ι)	($\sigma^2_m/(\sigma^2_\iota$)	F	P
Elbow width	15	0.525	4.097	0.128	7.80	0.001
Wrist width	15	0.276	3.144	0.088	11.39	0.001
Hand length	15	0.875	5.402	0.162	6.12	0.001
Hand width	15	0.655	5.055	0.130	7.72	0.001

df – degrees of freedom, ms – mean square, σ^2_m – measurement error variance, σ^2_ι – non-directional asymmetry variance, $\sigma^2_m/\sigma^2_\iota$ – magnitude of measurement error relative to the between-sides variation.

TABLE 5
COMPARISON OF THE AVERAGE VALUES BETWEEN LABOR AND NON-LABOR GROUPS (ONE WAY ANOVA)

Trait	Labor			Non-labor			p
	N	X (mm)	SD	N	X (mm)	SD	
Elbow width	104	69.35	3.49	102	69.66	3.30	0.52
Wrist width	104	58.05	3.84	102	57.02	4.43	0.05
Hand length	104	189.47	9.08	102	188.12	8.90	0.28
Hand width	104	84.69	3.94	102	85.15	4.03	0.41

X – (R+L)/2, SD – standard deviation

TABLE 6
DIRECTIONAL ASYMMETRY (DA) AND ABSOLUTE ASYMMETRY (AA) VALUES OF LABOR GROUP

Trait	N	Right	Left	DA	T	AA
Elbow width	104	69.68	69.02	0.66	2.62**	2.16
Wrist width	104	58.55	58.12	0.43	2.15*	1.72
Hand length	104	190.73	188.22	2.51	7.06***	3.74
Hand width	104	85.31	84.08	1.22	7.10***	1.80

*p<0.05, **p<0.01, ***p<0.001, DA – (R–L), AA – $\sqrt{(R-L)^2}$

TABLE 7
DIRECTIONAL ASYMMETRY (DA) AND ABSOLUTE ASYMMETRY (AA) VALUES OF THE NON-LABOR GROUP

Trait	N	Right	Left	DA	T	AA
Elbow width	102	69.84	69.47	0.37	1.89	1.59
Wrist width	102	56.88	56.60	0.28	1.67	1.33
Hand length	102	188.74	187.50	1.24	4.25***	2.60
Hand width	102	85.47	84.84	0.64	3.75***	1.49

***p<0.001, DA – (R–L), AA – $\sqrt{(R-L)^2}$

parative analysis of the groups. Tables 3 and 4 display measurement error ranges that are considered essential factors influencing the results of the study. The side-by-individual interaction term was significant (p<0.001) by demonstrating this asymmetry variance was significantly greater than measurement error variance. The rate of the measurement error variance to between-side variation is less than 20% in all measurements (Table 3 and 4).

Measured average values of the traits in each group can be seen in Table 5. According to the table, only the average wrist width of the working group is relatively higher and statistically significant. Other measurements do not display a significant difference.

According to Table 6 which displays the findings related with asymmetry of the labor group, all of the four measurements show statistically significant directional asymmetry. All the figures of the right side extremities in

TABLE 8
RELATIVE ASYMMETRY (RA) VALUES OF LABOR AND NON-LABOR GROUPS

Trait	Labor		Non-labor		P
	RA	SD	RA	SD	
Elbow width	0.031	0.021	0.023	0.018	0.006
Wrist width	0.027	0.018	0.021	0.016	0.026
Hand length	0.020	0.012	0.014	0.010	0.000
Hand width	0.021	0.014	0.018	0.013	0.037
CRA	0.025	0.008	0.019	0.009	0.000

RA – $\sqrt{(R-L)^2 / ((R \quad L)/2)}$, CRA – $\Sigma(\sqrt{(R-L)^2 / ((R \quad L)/2)})/n$, SD – standard deviation

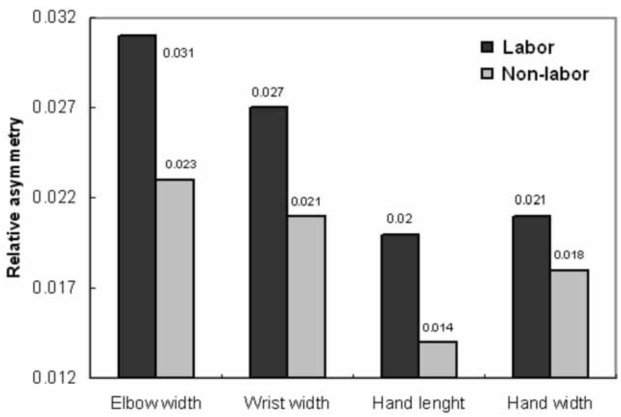

Fig. 1. Relative asymmetry values of labor and non-labor young males.

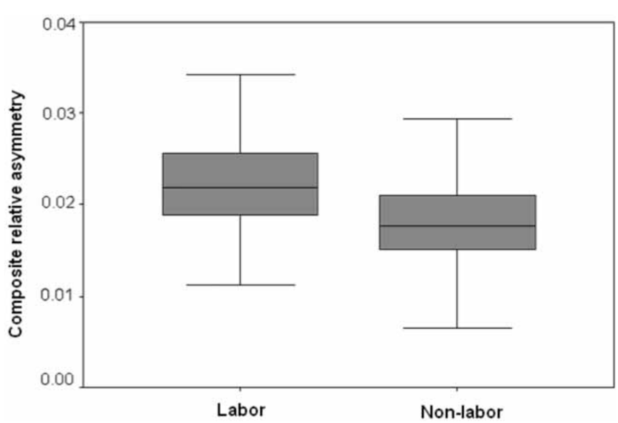

Fig. 2. Composite relative asymmetry values of labor and non-labor young males.

this group are greater than those of the left side. On the other hand, the only statistically significant differences in the extremities of the non-labor group are seen in the hand lengths and widths. The other values do not indicate statistically significant differences (Table 7).

In order to discover and conduct further analysis of the effects of biomechanical pressures on the upper extremities, the deviation levels need to be calculated in proportional values. Such an approach not only enables us to express the average deviation in percentage but also to facilitate an easier statistical comparison of the groups. Table 8 displays the ratio of unsigned asymmetry to the average trait dimension through the formula known as relative asymmetry (RA). The rate of deviation for each one of the traits is greater (Figure 1) for the individuals of the labor group according to the Mann Whitney U Test. The values of the working individuals were also found to be greater according to the composite relative asymmetry (CRA, Figure 2)*.

Discussion

The majority of people throughout the world are dominantly right-handed (dextral). Some researches point to the fact that the ratio of left-handed (sinistral) people is approximately 8%[35]. Preference for the use of the right hand is considered to be a habitual behavior related with genetic basis which is thought to have emerged in early periods of human evolution[35,36].

In the preferential use of the hands, the dominant side is more advantageous in terms of the quality and swiftness of the task accomplished by 5–7% and 3–5% in men and women, respectively and by 10% in either sex in terms of hand strength[37]. Yet, the subject matter differences are applicable only to the individuals who are ei-

* It is certain that the difference between the groups in view of relative asymmetry results, to some extent, from the difference in developmental stability. However, the bilateral deviations in the upper extremities of human beings result from the functional asymmetry rather than a decrease in developmental stability. Higher level of the functional asymmetry over the arms causes one to be overcautious about the use of the measurements of the upper extremities in the studies of developmental stability. Thus, the formulas such as absolute asymmetry and relative asymmetry which are very often used in studies of fluctuating asymmetry can be used mainly to obtain data about the level of biomechanical pressures on the upper extremities.

ther strongly or moderately right-handed or strongly left-handed. In other words, there is not a significant difference between the left and the right hands of weakly left-handed and weakly right-handed people. The same is also true in the muscle volumes of the upper arms[38,39]. This likely results from the necessity for left-handed people to adapt themselves to the conditions of a dominantly »right-handed world.« Research carried out by Josty and his colleagues[21] on workers who perform light, moderate, and heavy work revealed that workers doing heavy work have higher hand grip strengths as measured by hand dynamometers, and both the dextral and sinistral workers' right and left hands did not display any other significant difference. The handgrip strengths of the workers doing lighter work were observed to be low, while it was noted that there was a significant difference in the strengths of the dominant hand and non-dominant hand. The same study reveals that workers doing moderately heavy jobs take an intermediary position between the former groups[21].

Preferential use of hands results not only in differences in ability of performance and strength but also in anatomical differences. Many studies indicate that measurements belonging to the right upper extremities of the individuals are likely to be greater than those of the left side regardless of the type of occupation[40–42]. The findings of the study herein conform to those of the similar studies. Thus, the values of the right extremities tended to be higher in each one of the groups which are both composed of 95% right-handed individuals. In addition, the higher directional asymmetry encountered in the labor group is indicative of the fact that they are exposed to more biomechanical pressures. Furthermore, the young workers have been observed to repeatedly perform tasks requiring arm power when using repair and maintenance equipment while working.

Many of the studies which have been conducted thus far reveal that directional asymmetry is much more obvious in individuals such as tennis, rodeo and baseball players who perform continuous and heavy physical activities. The dominant side of the racket game players becomes bigger due to biomechanical pressures. In a study carried out by Jones et al.[13] on the tennis players, the cortical thickness of the humerus in the dominant hand was observed to be 34.9% and 28.4% greater for men and women tennis players, respectively. A similar set of findings was also observed for rodeo cowboys[14]. In a more recent study, Haapsalo et al.[43] used the peripheral quantitative computed tomography (pQCT) technique to examine the humerus and radius of 12 Finnish tennis players who had been playing tennis for 19.6±5.3 years and started exercising at the age of 10±3. Nine bilateral measurements of this group taken from their humerus and radius were found to be extremely high in view of asymmetry as compared to that of the control group formed for the purpose of comparison[43]. The asymmetry of the cortical thickness at the distal humerus of the players was found to be twice as big as that of the control group. A similar study carried out by Kontulainen et al.[44] examines female tennis and squash players via the pQCT method. Additionally, the asymmetry on the cross-sectional area of the humerus of the players was found to be greater than that of the control group with regard to the cross-sectional thickness. In the same study, it was noted that individuals who had started to exercise prior to puberty had greater asymmetry values[44].

The existing difference between the groups only in terms of the average wrist width (Table 5) raises the idea that biomechanical pressures tend to increase the amount of bilateral asymmetry in the group made up of individuals who had been working an average of 10.5 hours daily for about 5 years rather than leading to an increase in the average trait size (Table 6). However, intensive biomechanical pressures are influential in increasing the amount of not only the directional asymmetry, but also that of the mean trait sizes. Anthropologists are known to acquire data on the environmental pressures on the ancient communities and their livelihood by examining the physical structures of the long bones[45–50]. Related studies point to the fact that the cross-sectional areas of the long bones were subject to hypertrophy especially in communities where livelihoods requiring heavier physical activities were more common[45–47]. If it were true that heavier physical activities lead to excessive hypertrophy in the long bones, one would normally expect the labor group to have higher values in view of the mean trait sizes examined. However, the findings in most of the studies of a similar nature reveal that hypertrophy is encountered in the cross-sectional thickness of the long bone diaphysis, and that, in most cases, only a slight change was observed in the joints and bone lengths[45–47]. Epiphyseal and diaphyseal osteogenic responses to mechanical loading are triggered by two separate molecular pathways. These pathways respond differently to loading and may account for differences in bone length and joint measurement[4,5,48]. A study carried out by Ruff and Hayes[51] on the diaphysis and joint surfaces of the long bones of the skeletons obtained in Pecos Pueblo reveals that the hypertrophy encountered in the femur diaphysis is not observed in the epiphyseal size. Similar findings were also observed in a study carried out by Trinkaus et al.[45] on European Neanderthals with a history of harsher life conditions. The cross-sectional diaphyseal morphology of Neanderthal humeruses in this study was observed to have magnanimous bilateral asymmetry with very low bilateral deviations in epiphyseal size. The mean trait size difference between the labor and non-labor groups was very low is not surprising because the elbow, wrist, and hand widths are believed to be reflective of the measurement of the joints while the hand lengths are indicative of the lengthwise development of the hand bones.

Another point of contention in the study herein is related with the elbow width, which displays the greatest deviation in view of relative asymmetry (Figure 1). Some findings in other studies show that the humerus displays a higher asymmetry when compared to other bones of the upper extremity[12,50–53]. In a study carried out by Auerbach and Ruff[50] on the long bones of 780 adult males of

Holocene epoch, the humerus was observed to have the highest asymmetry among the upper extremity bones. The findings of this study raise the possibility that the greatest effect of functional asymmetry on the biomechanics of the upper extremities is observed to be focused on the humerus. The conspicuous presence of functional asymmetry on the humerus is very often used in determining hand preference of individuals of ancient communities[46,47,50].

In full consideration of the findings of other literature, it can be said that heavy working conditions do not lead to a significant enlargement in the average joint and hand sizes. Yet, the high difference between the bilateral deviation rates of the two groups reveals that biomechanical pressures lead to bilateral asymmetry rather than an increase in the mean trait sizes. Another outcome of this study is the need for the measurement of diaphyseal morphology of the bones apart from that of the joints for a better analysis of the effects of working conditions.

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UTJECAJ BIOMEHANIČKOG PRITISKA NA ASIMETRIJU GORNJIH EKSTREMITETA MLADIH RADNIKA

S A Ž E T A K

Cilj ovog rada bio je procijeniti utjecaj biomehaničkog pritiska na gornje ekstremitete mladih radnika u teškim radnim uvjetima. Istraživanja su za cilj imala procijeniti bilateralnu asimetriju gornjih ekstremiteta na skupini od 104 radnika industrije u Ankari, Turska. Prosječna dob ispitanika bila je 18,48±0,61 godina. Kontrolna grupa sastojala se od 102 ispitanika prosječne dobi od 18,39±0,58 godina. Radnicima su uzimane mjere širine lakta, zgloba te dužine ruke. Nije bilo nikakve značajne razlike između grupa ispitanika, izuzevši mjere širine zgloba. Kod grupe radnika ustanovljena je asimetrija u svim uzetim mjerama dok je kod kontrolne grupe asimetrija bila ustanovljene samo u širini i dužini ruke. Zaključak ove studije je da biomehanički pritisak povećava asimetriju u gornjim ekstremitetima.