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The biomechanical characteristics of elite deaf and hearing female soccer players: comparative analysis

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Purpose: The aim of this study was to examine the differences in body composition, strength and power of lower limbs, height of jump measured for the akimbo counter movement jumps, counter movement jump and spike jumps between deaf and hearing elite female soccer players. *Methods:* Twenty deaf (age: 23.7 ± 5.0 years, hearing loss: 96 ± 13.9 dB) and 25 hearing (age: 20.3 ± 3.8 years) participated in the study. Their WHR and BMI were calculated. Body fat was measured using the BIA method. The maximal power and height of jump were measured by force plate. Biodex dynamometer was used to evaluate isokinetic isometric strength of the hamstrings and quadriceps. *Results:* Significant differences between hearing and deaf soccer players in anthropometric values were for the waist and calf circumferences and the WHR index ($p < 0.01$, effect size 0.24–0.79). Statistically significant differences were observed for flexion of the lower limb in the knee joint for the relative joint torque and relative power obtained for the angular velocity of 300 $deg \cdot s^{-1}$ for both lower limbs ($p < 0.01$, effect size 0.19–0.48) and for 180 $deg \cdot s^{-1}$ during flexion of the left limb ($p = 0.02$, effect size 0.13). The hearing female football players developed significantly greater MVC in all the cases. Statistically significant differences between deaf and hearing athletes were found for spike jump for maximal power (1828.6 ± 509.4 W and 2215.2 ± 464.5 W, respectively; $p = 0.02$, effect size 0.14). *Conclusions:* Hearing impairment does not limit the opportunities for development of physical fitness in the population of deaf women.

Key words: *deaf athletes, anthropometry, body composition, strength, height of jump, power of lower limb*

1. Introduction

Nearly 500 million people all over the world have been estimated to suffer from hearing problems. In Europe, hearing impairment affects over 80 million patients, with around 900,000 reported in Poland. In the world there are around 2,070 sports and social clubs that associate deaf people and have their own websites [24]. Deaf people in Poland are associated in the Polish Deaf Sport Association (PDSA). In PDSA around 30 polish sports clubs are registered. Around 50 deaf girls and women aged over 15 years are the members of national soccer teams.

In the case of deaf people, a plethora of publications have focused on the morphofunctional development of children and youth with deafness. Many studies have been based on the Eurofit test battery while other tests provide information about motor skills, aerobic and anaerobic capacity and physical activity of children and adolescents. However, adult populations have not been examined to date [6]–[8], [10], [16], [23]. A study by Walowska and Bolach [21] showed that hearing children (7–14 years old) have better sense of balance, speed of movement of upper limbs, flexibility, higher explosive strength and better cardiorespiratory endurance compared to deaf people. Hearing girls are characterized by greater running speed and movement agility compared to deaf girls. It is observed that deaf girls have low level of strength and endurance in upper limbs. By the age of 14 to 15 years, the differences between hearing and

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deaf girls disappear, although greater body fat percentage is observed in deaf girls [22].

In soccer the development of strength, power, speed and jumping performance is essential. Therefore, a soccer player has to not only manage technical and tactical tasks, but also to show the required sport skills used in a large number of dynamic actions [16]. Unlike the extensive literature on hearing female soccer players [1], [3], [15], no findings have been published concerning running speed, lower limb power, muscle force and cardiopulmonary fitness of deaf soccer players.

The aim of this study was to examine the differences in body composition, strength and power of lower limbs, height of jump measured for the akimbo counter movement jumps, counter movement jump and spike jumps between deaf and hearing elite female soccer players.

2. Materials and methods

The group of participants comprised 20 deaf female soccer players (age 23.7 ± 5.0 years; body mass 61.2 ± 7.6 kg; body height 164.8 ± 5.1 cm; BMI 22.5 ± 2.2 $kg \cdot m^{-2}$; training experience 7.6 ± 3.5 years; hearing loss 96.0 ± 13.9 dB) , who were the national Polish team members within the Polish Deaf Sport Association, and 25 elite Polish hearing female soccer players (age 20.3 ± 3.8 years; body mass 60.3 ± 6.2 kg; body height 166.4 ± 4.9 cm; BMI 21.8 ± 2.2 $kg \cdot m^{-2}$; training experience 7.9 ± 3.2 years). The Polish Deaf Sport Association is represented by the people who have hearing loss of at least at a moderate level of above 55 dB.

This study was provided by the Bioethics Committee of Collegium Medicum of the Nicolaus Copernicus University in Toruń, Poland (No. KB 330/2014). Each participant (or their legal guardian in the case of underage participants) gave their written informed consent and was informed of the procedure used in the study. The study was performed according to the Declaration of Helsinki. Inclusion criteria required the participants to have been free of all limb and spinal injuries for 3 months prior to the study.

All examinations were performed by the same investigator to ensure measurement reliability. In the anthropometric study, the participants were asked to participate in the tests on empty stomach, after a full night of sleep. All of the variables were measured according to standardized and reliable procedures. All of the anthropometric measures used in this study were evaluated according to the guidelines outlined by the International Society for the Advancement of Kinanthropometry. All tests were performed between 7 and 11 am. Body height was measured using the Siber Hegner anthropometer (Switzerland). Chest circumference (at inhalation and exhalation), thigh circumference, calf circumference, waist and hips circumference were measured by Gullick tape measure. Body mass index (BMI) and Waist-Hip Ratio (WHR) was calculated from standard formulas.

Total lean body mass (LBM), total body fat percentage (FAT), total body water (TBW), lower leg fat and trunk fat were measured by the Tanita BC-418 MA analyzer (Japan).

A Biodex dynamometer (Biodex S4 Pro, Biodex Medical Systems, Inc., Shirley, New York, USA) was used to evaluate the isokinetic strength of the hamstrings (H) and quadriceps (Q) of the participants. Gravity correction was ensured for each limb before testing. Players were seated on the dynamometer chair at 85 deg with stabilization straps. The knee was set at 90 deg of flexion (0 deg = fully extended knee), according to the instruction manual by Biodex Medical Systems. The participants were instructed to perform extension and flexion of the tested leg as fast and as hard as they could over the entire range of motion (from 90 deg to 0 deg). Five maximal repetitions of extension and flexion the knee were performed at each angular velocity: 60 $deg \cdot s^{-1}$, 180 $deg \cdot s^{-1}$ and 300 $deg \cdot s^{-1}$. At each angular velocity, the trial with the highest peak torque was used for the statistical analysis. The hamstring-to-quadriceps ratio (H/Q ratio) – ratio of muscle torques generated by the hamstrings to muscle torques generated by the quadriceps femoris muscle – was also calculated. Maximum voluntary contraction (MVC) was measured at the knee joint angle of 60 degree.

The power of lower extremities and the height of rise of the body mass centre during vertical jumps were measured using a force plate ("JBA" Zb. Staniak, Poland). The MVJ v. 3.4 software package ("JBA" Zb. Staniak, Poland) was used for measurements. The maximum power (Pmax), relative maximum power ($Pmax \cdot body\ mass^{-1}$) and maximum height of rise of the body mass centre during vertical jumps (h) were calculated from the value of ground reaction force recorded by the force plate [2], [14]. Each participant performed nine vertical jumps on the force plate: three jumps of each kind. The characteristics of each jumping test were the following:

- akimbo counter-movement jump (ACMJ): a vertical jump from an upright standing position with hands on the hips and with lowering of the body's centre of mass before the take-off;

- counter-movement jump (CMJ): a vertical jump from a standing erect position, preceded by a counter movement of upper limbs and with lowering of the body COM before the take-off;
- spike jump (SPJ): a vertical jump which is performed with a 3–4 step run-up before the take-off. The participant's task was to take off and land on the platform.

The participants were told to jump as high as possible in each trial. There were 6-second breaks between each ACMJ and CMJ jump and 1-minute breaks between the SPJs. There was also 3-minute break between each series of jumps as well. The jump with the highest elevation of the body's COM was chosen for statistical analysis.

The group of hearing and deaf players were compared using one-way analysis of variance (ANOVA) after verification of its assumptions (normal distribution was verified by means of the Shapiro-Wilk test, whereas the homogeneity of variance was verified using the Brown–Forsyth test). Level of significance in all tests was set at $\alpha = 0.05$. Sums of squares obtained in ANOVA were used to calculate the value of η^2, defining the proportion of variance explained by the experimental effect. To interpret the effect size for statistical differences in the ANOVA we used eta square classified as small ($0.01 < \eta^2 \le 0.06$), medium ($0.06 < \eta^2 \le 0.14$) and large ($\eta^2 > 0.14$) [4]. The calculations were made using Statistica v. 12 (StatSoft) software.

3. Results

The results obtained for body composition for Polish Deaf National Team: FAT% 21.7 ± 3.3%; FATkg 13.4 ± 3.4 kg; LBM 47.8 ± 5.0 kg; TBW 35.0 ± 3.7 kg; right leg FAT 3.1 ± 0.7 kg; left leg FAT 3.1 ± 0.8 kg; trunk FAT 6.1 ± 1.7 kg and for female hearing soccer players: FAT% 21.2 ± 4.8%; FATkg 12.8 ± 3.7 kg; LBM 47.7 ± 4.2 kg; TBW 34.9 ± 3.1 kg; right leg FAT 2.9 ± 0.7 kg; left leg FAT 2.9 ± 0.7 kg; trunk FAT 5.8 ± 1.7 kg. There were no significant differences between hearing and deaf soccer players in body composition and chest, hips and thigh circumferences. A significant difference was observed between waist, calf max circumference and WHR index (Table 1) with large value of η^2 [4].

In Table 2 relative values of torques and power developed during flexion and extension of the knee at various angular velocities (0 $deg \cdot s^{-1}$, 60 $deg \cdot s^{-1}$, 180 $deg \cdot s^{-1}$, 300 $deg \cdot s^{-1}$) are presented. A statistically significant difference was found between the hearing and deaf female soccer players for torques and power generated at velocities of 300 $deg \cdot s^{-1}$ and force generated during isometric contraction (MVC). All groups mentioned, except torques developed during flexion of the knee at 180 $deg \cdot s^{-1}$, had the values of η^2 at large level. For comparison of peak torque to body mass ratio ($PT \cdot BM^{-1}$) at 180 $deg \cdot s^{-1}$ reported the median level of the effect. Statistically significant differences between groups were observed for the hamstring-to-quadriceps ratio (H/Q ratio) in the knee joint (Table 3).

Statistically significant differences in the SPJ were observed for maximal power and the depth of the movement between hearing and deaf soccer players (Table 4). For other types of jumps (ACMJ, CMJ), the differences in all the parameters studied were statistically insignificant.

4. Discussion

To our knowledge, this is the first study to report the biomechanical characteristics of deaf female soccer players compared to hearing female soccer

Table 1. Mean values (±SD) of anthropometric measures in deaf and hearing female soccer players

Variables	DEAF, $n = 20$	HEARING, $n = 25$	F	p	η^2
Chest circumference (diff.) [cm]	5.9 ± 1.9	6.5 ± 2.1	0.99	0.33	0.02
Waist circumference [cm]	77.3 ± 6.0	71.2 ± 5.0*	13.63	<0.01	0.24
Hip circumference [cm]	96.9 ± 5.8	95.5 ± 4.7	0.77	0.39	0.02
Thigh max. circumference [cm]	58.8 ± 3.7	59.0 ± 6.0	0.02	0.90	<0.01
Circumference at 1/2 thigh [cm]	52.3 ± 3.5	51.5 ± 3.6	0.49	0.49	0.01
Calf max. circumference [cm]	26.3 ± 2.1	35.9 ± 2.8*	158.4	<0.01	0.79
WHR [–]	0.80 ± 0.04	0.75 ± 0.03*	23.1	<0.01	0.35

Deaf athletes were significantly different from hearing soccer players (* – $p < 0.05$).

Table 2. Peak torque to body mass ratio (PT·BM^{-1}) at 300 deg·s^{-1}, 180 deg·s^{-1}, 60 deg·s^{-1} and 0 deg·s^{-1} (MVC for angle 60 deg) and average power to body mass ratio (PA·BM^{-1}) at 300 deg·s^{-1}, 180 deg·s^{-1}, 60 deg·s^{-1} (means ± SD)

Variables				DEAF	HEARING	*F*	*p*	η^2
PT·BM^{-1} [N·m·kg^{-1}]	FL	300_{IK}	R	0.98 ± 0.18	0.73 ± 0.30*	9.63	<0.01	0.19
			L	1.08 ± 0.17	0.72 ± 0.31*	20.37	<0.01	0.33
		180_{IK}	R	0.96 ± 0.12	0.86 ± 0.28	2.45	0.13	0.06
			L	1.02 ± 0.14	0.82 ± 0.32*	6.20	0.02	0.13
		60_{IK}	R	1.24 ± 0.21	1.31 ± 0.35	0.48	0.49	0.01
			L	1.19 ± 0.20	1.18 ± 0.22	0.02	0.88	0.00
		MVC	R	1.38 ± 0.23	1.54 ± 0.20*	5.61	0.02	0.14
			L	1.29 ± 0.34	1.56 ± 0.24*	7.99	0.01	0.18
	EX	300_{IK}	R	1.40 ± 0.23	1.25 ± 0.38	2.58	0.12	0.06
			L	1.31 ± 0.20	1.23 ± 0.39	0.74	0.39	0.02
		180_{IK}	R	1.65 ± 0.20	1.56 ± 0.33	0.99	0.33	0.02
			L	1.64 ± 0.24	1.52 ± 0.44	1.19	0.28	0.03
		60_{IK}	R	2.27 ± 0.34	2.33 ± 0.33	0.26	0.61	0.01
			L	2.21 ± 0.41	2.36 ± 0.35	1.51	0.226	0.04
		MVC	R	2.71 ± 0.45	3.11 ± 0.37*	9.28	<0.01	0.20
			L	2.69 ± 0.58	3.01 ± 0.42	3.83	0.06	0.10
PA·BM^{-1} [Watt·kg^{-1}]	FL	300_{IK}	R	1.88 ± 0.39	1.23 ± 0.54*	19.60	<0.01	0.32
			L	1.98 ± 0.32	1.20 ± 0.47*	39.30	<0.01	0.48
		180_{IK}	R	1.54 ± 0.40	1.31 ± 0.47	2.98	0.09	0.07
			L	1.74 ± 0.34	1.27 ± 0.55*	10.87	0.00	0.21
		60_{IK}	R	0.86 ± 0.18	0.84 ± 0.23	0.11	0.74	0.00
			L	0.86 ± 0.17	0.78 ± 0.24	1.78	0.19	0.04
	EX	300_{IK}	R	3.33 ± 0.59	2.34 ± 0.92*	16.82	<0.01	0.29
			L	2.27 ± 0.62	2.34 ± 0.99*	12.93	<0.01	0.24
		180_{IK}	R	2.72 ± 0.53	2.39 ± 0.71	2.85	0.10	0.06
			L	2.79 ± 0.61	2.39 ± 0.85	3.05	0.09	0.07
		60_{IK}	R	1.48 ± 0.28	1.48 ± 0.28	0.00	1.00	0.00
			L	1.46 ± 0.38	1.46 ± 0.29	0.00	1.00	0.00

Legend: R – right leg, L – left leg, IK – isokinetic [deg·s^{-1}], FL – flexion, EX – extension; MVC – maximum voluntary contraction; * – statistically significant differences between means for DEAF and HEARING groups, $p < 0.05$.

Table 3. *H*/*Q* ratio at velocity of 300 deg·s^{-1}, 180 deg·s^{-1}, 60 deg·s^{-1} and MVC (means ± SD)

Variables			DEAF	HEARING	*F*	*p*	η^2
H/*Q* [%]	300_{IK}	R	69.8 ± 10.2	58.1 ± 14.7*	8.86	0.01	0.17
		L	83.2 ± 12.8	55.3 ± 19.3*	29.83	<0.01	0.42
	180_{IK}	R	58.8 ± 6.3	55.7 ± 13.0	0.91	0.35	0.02
		L	62.8 ± 8.6	52.6 ± 11.1*	10.98	<0.01	0.21
	60_{IK}	R	54.8 ± 7.5	55.5 ± 10.6	0.06	0.81	0.00
		L	54.5 ± 7.4	49.6 ± 7.1*	4.88	0.03	0.10
	0_{MVC}	R	49.8 ± 17.4	52.3 ± 8.8	0.68	0.42	0.02
		L	51.5 ± 7.5	49.8 ± 5.3	0.31	0.58	0.01

Legend: R – right leg, L – left leg, IK – isokinetic mode [deg·s^{-1}], MVC – maximum voluntary contraction; * – statistically significant differences between means for DEAF and HEARING groups, $p < 0.05$.

players. The main finding of the study was that no statistically significant differences were observed between deaf and hearing female soccer players in body build and composition and that there were statistically significant differences of biomechanical parameters (strength, power and jump height), but generally with small effect size. The results of the anthropometric measurements revealed no differences in body build and body composition between hearing and deaf soccer players except for waist and calf cir-

Table 4. Height of rise of the body mass centre during vertical jumps (h), depth of jump (L), maximal power (P_{max}), relative maximal power ($P_{max}·BM^{-1}$) during the ACMJ, CMJ and SPJ jumps on the force plate (means ±SD)

Variables	DEAF	HEARING	F	p	η^2
h_{ACMJ} [m]	0.302 ± 0.042	0.285 ± 0.028	1.64	0.21	0.04
h_{CMJ} [m]	0.346 ± 0.051	0.337 ± 0.034	0.30	0.59	0.01
h_{SPJ} [m]	0.380 ± 0.046	0.380 ± 0.028	0.02	0.90	0.00
L_{ACMJ} [m]	–0.350 ± 0.098	–0.317 ± 0.063	3.79	0.06	0.09
L_{CMJ} [m]	–0.353 ± 0.069	–0.347 ± 0.058	0.52	0.47	0.01
L_{SPJ} [m]	–0.32 ± 0.055	–0.27 ± 0.042*	12.93	<0.01	0.25
$P_{maxACMJ}$ [W]	1227.7 ± 271.3	1194.4 ± 208.4	0.00	1.00	0.00
P_{maxCMJ} [W]	1471.5 ± 328.9	1536.7 ± 230.7	1.14	0.29	0.03
P_{maxSPJ} [W]	1828.6 ± 509.4	2215.2 ± 464.5*	6.44	0.02	0.14
$P_{maxACMJ}·BM^{-1}$ [W·kg^{-1}]	20.1 ± 4.5	19.4 ± 3.9	0.00	0.95	0.00
$P_{maxCMJ}·BM^{-1}$ [W·kg^{-1}]	23.9 ± 4.8	25.3 ± 3.3	1.25	0.27	0.03
$P_{maxSPJ}·BM^{-1}$ [W·kg^{-1}]	30.0 ± 8.8	35.8 ± 7.0*	5.57	0.02	0.13

* – statistically significant differences between means for DEAF and HEARING groups, $p < 0.05$.

cumference and WHR ratio. Lower values of WHR ratio at similar BMI suggest a more favourable distribution of body fat in hearing female football players. The results of anthropometric measurements are consistent with the findings documented by Brughelli and Harris [1], Castagna and Castellini [3], Datson et al. [5], Nikolaidis [13], Rosene et al. [17] and Struzik et al. [19] for hearing female soccer players.

The results of measurements of strength and lower limb power in hearing soccer players have been discussed in numerous studies [1], [13], [17], [19]. Brughelli et al. [1] found that absolute muscle torque in hearing female soccer players for the velocity of 60 deg·s^{-1} was 135±36.3 N·m for extension and 101 ± 18.7 N·m for flexion. PT·BM^{-1} values for female soccer players were 2.10 ± 0.54 N·m·kg^{-1} and 1.55 ± 0.26 N·m·kg^{-1}, for extension and flexion, respectively. For the velocity of 60 deg·s^{-1}, the female soccer players developed lower muscle torques in flexion and greater in extension compared to the study by Brughelli et al. [1]. The deaf female soccer players generated statistically significantly greater muscle torques and power for the flexion movement at a velocity of 300 deg·s^{-1} compared to the hearing players, whereas the hearing participants had greater power during extension. The hearing female soccer players also generated significantly higher MVC. For other velocities, no differences were found between the studied groups.

A very important problem in the case of soccer players of both genders is the analysis of the H/Q ratio (ratio of muscle torques generated by the hamstrings to muscle torques generated by the quadriceps femoris muscle). Due to the anatomic build of the pelvic girdle and lower limbs in women, soccer players are much more prone to knee joint injuries than men. For this reason, one should pay much attention to adequate ratio between the strength of flexors to extensors in this joint. Rosene et al. [17] examined female soccer players and found that they had H/Q ratios of 52.53 ± 8.41% (RL – right leg) and 47.16 ± 6.18% (LL – left leg) for 60 deg·s^{-1}, whereas for 180 deg·s^{-1} these values were 58.31 ± 13.12% (RL) and 57.96 ± 10.11% (LL). Furthermore, Struzik et al. [19] documented mean H/Q ratios of 54.1 ± 7.4% for 60 deg·s^{-1}. The values of the H/Q ratio recorded in our study are consistent with the data presented in the literature for hearing female soccer players. Statistically significant differences in the H/Q ratio between the group of deaf and hearing female soccer players were found for the right and left lower limb at 300 deg·s^{-1} and for the left limb at angular velocities of 180 deg·s^{-1} and 60 deg·s^{-1}. This is likely to be caused by developing lower muscle torques in the flexion motion by deaf soccer players.

The test of ACMJ and CMJ jumps has been routinely used in sports testing. Pietraszewski et al. [15] examined female soccer players and found that their CMJ jump height was 0.28 ± 0.04 m in the preparation period and 0.26 ± 0.03 m in the competitive period. In a study by Struzik et al. [19], the CMJ jump height was 0.29 ± 0.04 m. Furthermore, Martinez-Lagunas et al. [12] showed that female soccer players performed CMJ jumps at the height ranging from 28.1 ± 4.1 cm [9] to 49.2 ± 6.9 cm [20]. In his overview study, Datson et al. [5] collected information about the ACMJ jump height which ranged from 26.1 ± 4.8 cm (top Spanish division) to 35.0 ± 1.0 cm (top Danish division) and were substantially different than 51.0 ± 5.0 cm recorded for the Australian national team. In our study, deaf and hearing soccer players, depending on the jump type, jumped at the height of

30.2 ± 4.2, 28.5 ± 2.8 cm during the ACMJ jumps and 34.6 ± 5.1, 33.7 ± 3.4 cm during the CMJ jumps. No statistically significant differences were observed between hearing and deaf soccer players in the ACMJ and CMJ jumps, whereas the results obtained are consistent with the data presented in the literature for hearing soccer players [5], [15], [19]. In the case of the SPJ jump, where a substantial role was played by neuromuscular coordination, both groups jumped at the same height, with the hearing soccer players generating greater power. This is likely to have been caused by performing a deeper downward movement in the amortization phase after the approach run before the take-off phase.

5. Conclusions

The available literature about deaf people lack reliable, systematic and topical statistical data connected with the problems of their physical activity. Many tests concerning physical fitness have been performed in groups aged 7 to 18. These tests have not evaluated the athletes groups, since groups of physically active deaf people are small and scattered.

The results of the study revealed lack of statistically significant differences between the deaf and hearing female soccer players in body build and body composition. In the numerous of the biomechanical parameters analysed in the study (strength, power, H/Q and jumping height) there were statistically significant differences between the deaf and hearing female soccer players although effect size was generally small. The test results clearly show that physical activity like regular football workouts blur the differences between hearing and deaf women in the field of almost all the analysed biomechanical characteristics. If other health problems are not present, hearing impairment does not limit the opportunities for development of physical fitness in the population of deaf women. Further research will give the answer, whether the reference values for hearing female soccer players could be used as a standard for deaf female players.

It would be important to check whether this trend is also relevant in the other population of deaf people. Another study should concentrate on: other motor skills, e.g., locomotion speed, RAST test, BEEP test and $VO_{2\,max}$ with use of QUARK CPET and treadmill; examination of the athletes and non-athletes male and female; determining the differences between hearing and deaf soccer players of both genders and their deaf untrained peers.

The results of the next examinations will shed new light on physical fitness of deaf people and shall be compared (due to the use of professional equipment) to the results found in the scientific literature (that concerns exclusively hearing people). Regular testing can have positive impact on the development of sport of deaf people, giving both the coaches and athletes information on how to prepare for sports events. Polish national female soccer team regularly participate in sporting events at the international level (the bronze medal on the European Championships in Germany, 2015; fourth place on the World Deaf Football Championships in Italy, 2016).

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