EFFECTS OF PROLONGED BENCH STEPPING ON IMPACT FORCES

Kerry W. Hecko and Alfred E. Finch

Indiana State University, Terre Haute, Indiana, USA

INTRODUCTION

This study examined the effects of bench stepping at an 100 bpm cadence on an 20.3 cm bench over a 40 min workout on the vertical ground reaction forces (GRF).

METHODOLOGY

Ten college-aged females experienced in bench step aerobics wearing new aerobics shoes performed a 40 min bench step aerobic routine on a 20.3 cm bench using an arm and leg crossover, alternate lead leg routine at a 200 bpm cadence. Twenty seconds of force platform data was collected at 0 min, 10 min, 20 min, 30 min, and 40 min of the aerobics activity. The vertical GRFs were collected by an Ariel APAS system using a Kistler force plate at an 1000 Hz sampling rate. Three right and 3 left stride impacts were selected from the middle of the 20 second interval for analysis. Each stride was delineated in 3 phases: 1) landing contact (LAND) 2) full weight-double support, (DS) and 3) toe pushoff (TO). The vertical GRFs (Fz) at the 3 phases for the 3 right and left strides, and the stride time durations were calculated. An 2x5x3x3 ANOVA (FT x TIME x STEPS x PHASE) with repeated measures on all factors was used to analyze the vertical forces and an 2x5x3 ANOVA (FT x TIME x STEPS) was used to analyze the stride contact time.

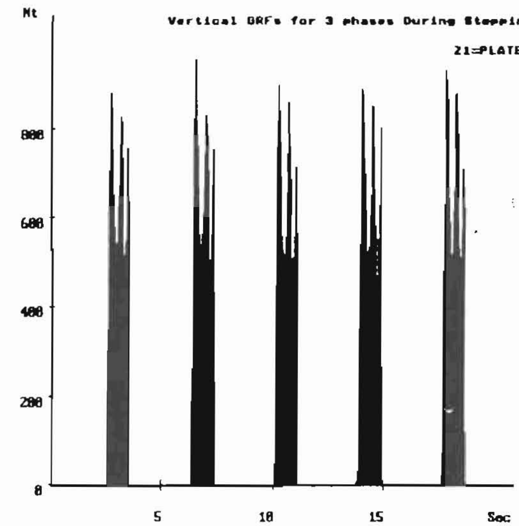


Figure 1 Vertical GRFs for 3 Phases During Stepping

RESULTS

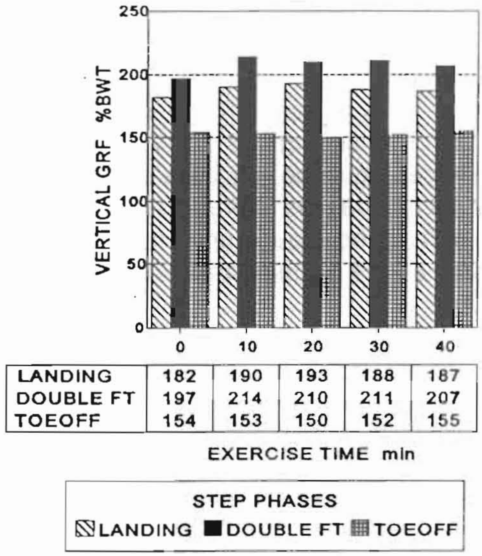
The subjects' mean height was 165.3 ± 5.0 cm, the mean body weight as 526.9 ±39.5 N, and the mean age was 22.7 ± 3.4 years. Table 1 provides a summary of the vertical GRF (Fz) at LAND, DS, and TO. No significant differences in the GRFs were found to exist for the stride factor (right-left) and for the step trial factor. A significant phase factor was found to exist (p=.000) when examining the vertical GRFs. The average left stride contact forces were 978.2N (186% BWT), the average left stride GRF during double support was 1093.7N (208% BWT) and the left foot during the toe-off phase exerted a 795.1N (151% BWT) GRF. The average right stride contact forces were 999.8N (190% BWT), the average right foot double support GRF was 1097.6N (208% BWT), and the right toe-off GRF was 812.6N (154% BWT).

TABLE 1 GROUND REACTION FORCES FOR 3 PHASES ON FOOT IMPACT DURING PROLONGED STEP BENCH EXERCISE

Exercise Time	Left Stride Phase 1 Land M±SD	Left Stride Phase 2 DS M±SD	Left Stride Phase 3 To M±SD	Right Stride Phase 1 Land M±SD	Right Stride Phase 2 DS M±SD	Right Stride Phase 3 To M±SD
0 Min % Body Wt	946.7±164.0 180%	1044.1±141.1 198%	816.1±155.0 155.%	968.3±179.7 184%	1036.5±167.9 197%	805.0±168.3 158%
10 Min	994.3±245.6 189%	1145.2±239.2 217%	792.7±156.8 150%	1003.6±130.6 190.%	1105.0±130.6 210%	821.6±167.9 156%
20 Min	983.1±194.8 187%	1074.6±191.9 204%	775.8±156.7 147%	1051.1±210.9 200%	1135.0±208.7 215%	798.1±170.7 151.%
30 Min	983.6±212.0 187%	1106.7±150.6 210%	776.7±161.8 147%	993.1±229.5 189%	1130.1±183.5 214%	821.0±174.5 156%
40 Min	983.1±222.8 187%	1097.±180.4 208%	814.3±142.1 155%	982.7±180.4 187%	1081.6±170.9 205%	817.1±148.8 155%

NOTE: Each mean force value is a 3 step average, Mean Body Wt = 526.9

Differences in the GRFs over the 40 min workout were marginally significant (p=.10). The subjects' GRFs during the double support phase tended to increase after the initial 10 minutes of stepping and decrease after 30 minutes of stepping. An 8% increase in the double support phase GRFs after 10 to 30 min of step aerobics was the result of greater loading due to fatigue as shown in Figure 2. The combination of these increased GRFs during fatigue and thousands of foot impacts have the potential for the development of musculoskeletal injuries if sufficient recovery time is not provided between workouts.

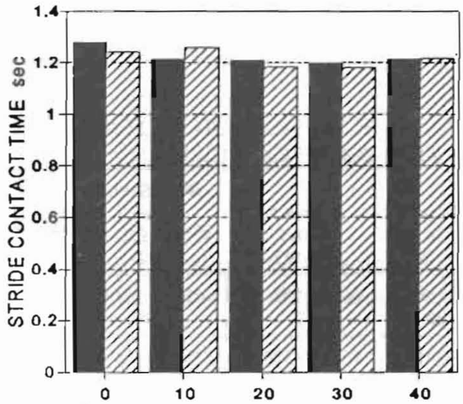


	0	10	20	30	40
LANDING	182	190	193	188	187
DOUBLE FT	197	214	210	211	207
TOEOFF	154	153	150	152	155

Figure 2 Vertical GRFs for 3 Stepping Phases During Prolonged Bench Aerobics Expressed as % BWT

These vertical GRFs were of similar magnitudes reported by Francis & Francis (1992), Humphries & Newton (1991), John, Berry , Rupp & Rupp, (1991), Michaud, Rodriguez-Zayas, Armstrong, Hartnig, (1993), and Ricard & Veatch, (1990).

The analysis found significant differences in the time of contact over the exer-



LEFT FT	1.281	1.215	1.209	1.198	1.214
RIGHT FT	1.242	1.26	1.183	1.182	1.218

EXERCISE TIME min

STRIDE
LEFT FT RIGHT FT

Figure 3 Stride Contact Times During Prolonged Step Bench Exercise

cise duration. No differences in the contact times were found between the right and left strides or over the 3 trials. The mean contact time was 1.262 sec at the beginning of the workout and decreased to 1.19 sec over 30 minutes of step bench aerobics as shown in Figure 3. The reduction in contact time with the platform was the result of the subjects standing on the bench longer and using a more ballistic stepping technique on the platform as the exercise prolonged. Also, this change of technique was reflected in increases in the double support GRFs during the same time durations.

CONCLUSIONS

Prolonged step aerobics on a 20.3 cm bench resulted in marginally significant increases in the vertical GRFs during the double support phase after 10 to 30 min of exercise. The vertical GRFs exhibited after 40 min of bench step aerobics were 188% BWT at landing 208% BWT at double support and 153% BWT at toe-off and these forces would be indicative of a mild impact activity. Also, the timing of the step bench technique was altered as the exercise was prolonged. The subjects used a more ballistic technique during the 10 to 30 min of exercise which was indicated by less time on the platform and more time on the bench.

REFERENCES

Humphries, B. & Newton, R. (1991). Peak ground reaction forces during step aerobics, walking and jogging. Biomechanics in Sports IX, 67-71.

Johnson, B.F., Berry , S.A., Rupp, D.A. & Rupp, J.C. (1991). Peak vertical ground reaction forces and time to peak force in bench step aerobics and other activities. Research Quarterly for Exercise & Sport, *22*, 370-376.

Michaud, T.J., Rodriguez-Zayas, J.,Armstrong, C., & Hartnig, M. (1993). Ground reaction forces in high impact and low impact aerobic dance. Journal Sports Medicine & Physical Fitness, *33*, 359-66.

Ricard, M.D. & Veatch, S. (1990). Comparison of impact forces in high and low impact aerobic dance movements. International Journal of Sports Biomechanics, *6*, 67-77.

DETERMINANTS OF THE THROWING VELOCITY IN HANDBALL - - A STATISTICAL MODEL

Jerzy Eliasz, Andrzej Wit

Dept. of Biomechanics, Institute of Sport, Warsaw, Poland

INTRODUCTION

Ball velocity is one of the most important factors which has a decisive affect on scoring in team games, like handball, baseball, cricket, water polo, volleyball, soccer etc. (Atwater 1980, Jöris et al.1985, Eliasz et al.1990, Marczinka 1993). Basically scientists are in agreement that the main determinants of the ball's velocity can be divided into three groups: technique of motion, somatic features and motor ability (Pauwels 1978, Muijen et al.1991). However, the technique of motion and the fitness level can be improved by the training process, morphological factors are, in the main part, genetically determined. Thus, the information about the degree of influence of each factor on the ball velocity appears substantial, in order to answer the question: proper selection or proper training has a better effect on ball velocity measured during throwing. Among experienced players it is particularly difficult to make progress in this area without special approach to exercises and training methods. The first step leading to this task is to specify the most important characteristics which effect ball velocity and develop them during training.

The aim of the research was to find the influence of the basic anthropometrical and motor ability parameters on ball velocity during throws in handball where the throwing technique remains consistent. These relationships seem to be very important for coaches, in order to improve the selection quality and the efficiency of training methods.

METHODS

Twelve high-performance handball field players took part in the experiment. The average values of basic parameters of physical characteristics of the subjects were: 89.0±7.8 kg body mass, 1.88±0.05 m body height and 23.3±2.5 years of age.

Anthropometric measurements were carried out according to Martin's method. The following somatic indices were used: length (body height, upper and lower extremity, arm, forearm, palm and fingers of the predominant hand), skeleton width (shoulder, pelvis, palm), musculature (arm and forearm circumference) and adiposity (three skin folds). For each player we used 26 somatic characteristics. In order to assess the **overarm throwing performance**, a standard handball was used (mass 480 g, circumference 58 cm). The subjects were instructed to throw the ball as fast as possible at a target (50 x 50 cm) placed at a distance of about 6 meters. The average linear ball velocity was measured over a 2 meter distance using a special photocells system (Eliasz et al.1990). The muscle strength was evaluated on the basis of **torques developed by main muscle groups under static conditions** The isometric muscle torque stand (locally made) was used to make the measurements, which enabled the direct measuring of torques for flexors and extensors of elbow, shoulder, knee and hip joints and flexors and extensors of trunk (Jaszczuk et al.1987).

The **measurement of the muscle torque under dynamic conditions** were carried out on the CES ARIEL modified in its mechanical part. Subjects performed simulated throws in the sitting position, propelling the bar of the Arm-Leg Station. Each subject executed 3 kinds of tests: maximal speed diagnostic (MSD), isokinetic exercises (IKE) at angular velocities 100, 300 and 500 deg/s, isotonic exercises (ITE) at external torques 10, 30 and 50 N×m. During the **vertical counter-movement jump** performed on a force platform maximal height of the jump and maximal mechanical power of the lower extremity and trunk were measured. The signal (force) was processed on-line using IBM PC.

Statistical methods

The mean value, standard deviation and coefficient of variance were calculated for each parameter. A normality of distributions were examined using the Shapiro-Wilk test. At the next stage the Pearson's correlation matrix and multiple regression analysis were used (α=0.05). The row data were recalculated to values in T-scale and according to the Doolittle method the contribution to throwing velocity was calculated for each factor: motor (M) and anthropometric (A). The best regression subset was assigned using Fisher's discriminating method. The regression hyperplane parameters were estimated, which divided players according to throwing velocity criterion.

RESULTS

Multiple regression analysis has shown that the most important throwing velocity determinants are: range of fingers, shoulder width and length of hand - among anthropometrical factors and isometric muscle strength of trunk flexors, maximal angular velocity of the bar measured in MSD and average mechanical power developed in CMJ - among motor abilities. Expected value of the ball velocity (Y) is stated the following equation:

$$\mathbf{Y = 0.018\ X_1 + 0.733\ X_2 + 0.039\ X_3 - 0.332\ X_4 + 0.006\ X_5 - 2.854}$$

where: X_1 - maximal angular velocity (MSD), X_2 - range of fingers, X_3 - average power (CMJ), X_4 - shoulder width, X_5 - isometric muscle strength of trunk flexors
For these five parameters the multiple correlation coefficient is: R=0.982 (R^2=0.963).
The proportional contribution of these factors in expected value of the ball velocity is:
X_1 = 36%; X_2 = 41%; X_3 = 3%; X_4 = 6%; X_5 = 11%.
After recalculation to T-values the final equation contains two main factors: anthropometrc (A) and motor (M):

$$\mathbf{Y = 0.017\ A + 0.072\ M}$$

R=0.857, R^2=0.735
The proportional contribution of these factors in expected value of ball velocity is 11.9% and 61.4%, respectively.

Using Fisher's discrimination method, according to ball velocity criterion, the subjects were divided into two groups, consisting of nine (mean velocity) and three people (high velocity). It is shown on figure 1. The hyperplane parameters are as follows:

$$\mathbf{0.149\ M + 0.051\ A - 23.821 = 0}$$

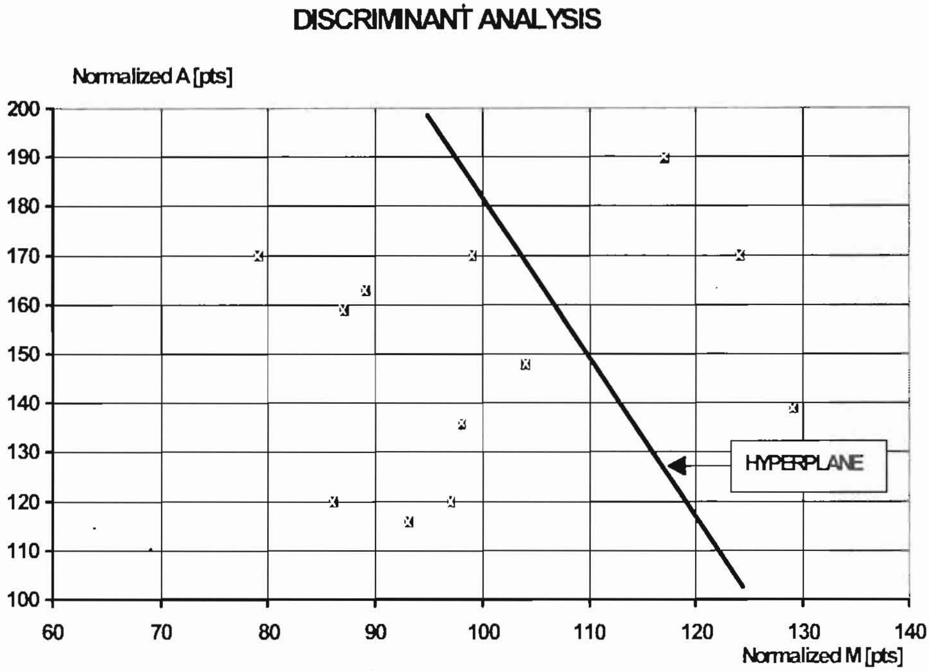


Fig.1. The hyperplane obtained in discriminant analysis separates handball players into two groups of different throwing velocity. The points placed on the right side of hyperplane represent the results of the subjects who throw the ball with high velocity.

The results suggest that motor abilities (especially muscle strength) have a great influence on throwing velocity in handball. Many researchers who have investigated an overarm throw, have indicated that muscle strength is a very important factor influencing throwing velocity (Pauwels 1978, Bartlett et al.1989, Pawlowski and Perrin 1989, Wooden et al.1992, Eliasz 1993). In this work statistical analysis has shown that the muscle strength of trunk flexors (abdominal muscles: abdominal rectus, external and internal obliques) and the maximal arm speed are the most significant velocity determinants. Abdominal muscles are involved in forward bending and trunk rotation (caused by one-side shortening action of external and internal obliques) - the type of motions observed during throwing before release (Atwater 1980, Jöris et al.1985, Eliasz 1993, Marczinka 1993). From a practical point of view there are two main possibilities to improve throwing velocity in handball: (1) development of abdominal muscles strength and (2) by improving the speed of external and internal rotation at the shoulder joint.

Among the anthropometrical features, only the range of fingers and hand length are correlated significantly with the ball velocity in measured throws. All these factors determine the grip quality, which allows the ball to be caught, held and manipulated easily. The influence of these factors on throwing velocity are significantly less than motor abilities. The basic somatic features (body hight, body mass) seem to be more important to the selection of players to specific positions in the game than to general selection for the sport, although it statement still needs verification (Maia et al.1991).

CONCLUSIONS

These results suggest that:

1. The most important throwing velocity determinant is the motor abilities level (if the technique of motion is not taken into the consideration).
2. Among analyzed motor parameters the strength of trunk flexors (abdominal muscles) and maximal arm (shoulder joint) angular velocity have a decisive effect on ball velocity in handball.

REFERENCES

Atwater A.B. (1980). Biomechanics of overarm throwing movements and of throwing injuries. *Exer. Sport Sci. Rev.* 7:43-85.

Bartlett L.R., Storey M.D., Simons B.D. (1989). Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. *Am.J.Sports Med.* 17:89-91.

Dowling J.J., Vamos L. (1993). Identification of kinetic and temporal factors related to vertical jump performance. *J. Appl. Biom.* 9:95-110.

Eliasz J.(1993). Trening siły mięśniowej w piłce ręcznej.*Sport Wyczyn.*9/10:21-28.

Eliasz J., Janiak J., Wit A. (1990): Prędkość lotu piłki podczas rzutów w piłce ręcznej. *Sport Wyczynowy* 9/10:17-23.

Jaszczuk J., Buczek M., Karpiłowski B., Nosarzewski Z., Wit A., Witkowski M. (1987). Set-up for measuring in static conditions. *Biology of Sport* 4:41-55.

Jöris H.J.J., Muijen Van E., Ingen Schenau Van G.J., Kemper H.C.G. (1985): Force, velocity and energy flow during the overarm throw in female handball players. *J. Biom.* 18:409-414.

Maia J.A.R., Vicente C.M., Janeira M.A., Garganta R. (1991). A Discriminant Study of Anthropometric Characteristics of Portuguese Elite Team Handball Players. Second IOC World Congress on Sport Sciences, Barcelona, 26-31 Oct.:251.

Marczinka Z. (1993). Playing Handball. Trio Budapest Publishing Company. I.H.F.

Muijen Van A.E., Jöris H., Kemper H.C.G., Ingen Schenau Van G.J. (1991). Throwing practice with different ball weights: effects on throwing velocity and muscle strength in female handball players. *Sports Train. Med. Rehab.* 2:103-113.

Pauwels J. (1978). The relationship between somatic development and motor ability, and the throwing velocity in handball for secondary school students. W: Shepard R.J. and Lavalle H./Ed./ Physical fitness assessment:principles, practice and application, Springfield, Ill.,Thomas:211-221

Pawlowski D., Perrin D.H. (1989). Relationship between shoulder and elbow isokinetic peak torque, torque acceleration energy, average power and total work and throwing velocity in intercollegiate pitchers. *Athletic Training* 24:129-132.

Wooden M., Greenfield B., Johanson M., Litzelman L., Mundrane M., Donatelli R.A. (1992). Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *J. Orth. Sports Phys. Therapy* 15:223-228.