THE EFFECT OF PERCEIVED FATIGUE ON VOLLEYBALL SPIKE SKILL PERFORMANCE

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All biomechanical studies concerning the volleyball spike have been carried out under non-fatigue conditions (1, 4, 5, 6, 12, 13). No research reports any data concerning the effects of effort on this skill either during match or during experimental conditions.

According to Fidelius (9), the result of technique training is dependent on the quantity and quality of the exercises that are performed and of the number and kind of information that the player is provided during the training. Almost all coaches focus only on the kinematic parameters related to the optimized individual model. As proposed by Bober (3), the investigation of sports technique should provide data which can be converted to useful information in order to ensure its own improvement and development. Even though the performance of a player in a match is a very complex phenomenon, it represents the ultimate goal of the training process (8). Thus, the knowledge of the conditional kinematic variations from the model under effort gives additional information to coaches and athletes. This enhances the coach's awareness of the skill pattern and improves the method of training by providing a sound basis to choose the most rational succession of auxiliary exercises (7), and optimizes the athlete's technique by shaping the system of movements in the course of effort.

Because there are many individual interpretations of the same skill due to either different morphologies or to different learning methods, it is more important to emphasize the maintaining of the individual skill pattern throughout the match than to standardize the spike skill pattern. Ejem et. al. (8) called this relative stable pattern of behavior during a specific time period and with relatively constant results "habitual performance". In this line, the identification of the conditional kinematic critical components of the spike which have deteriorated during effort will give precious feedback to the coach to develop a technical-physical training based on the actual behavior of the athlete (7, 9). In other words, practice should build up the conditions to inhibit the effects of effort. In such a conceptual model, neurophysiological inhibition (2), and methodological individualization of the process of training (7) requires the knowledge of the conditional kinematic variables upon which this study proposed to shed some light.

PURPOSE OF THE STUDY

This study examined the effect of perceived fatigue upon volleyball spike performance. More specifically, this study analyzed how perceived fatigue altered the contact hand angular velocity at ball contact, the height of ball contact, and selected variables related to both.

METHODOLOGY

In order to investigate the effects of perceived fatigue on volleyball spike skill performance, 5 female intercollegiate volleyball players performed a set of spikes in the conditions of non-fatigue (NF) and perceived fatigue (PF). The fatigue conditions were assessed with the Borg 15-point category scale. The subjects underwent individually a set of progressive volleyball drills. At the end of each 5-minute period the subjects were asked to report their ratings of perceived exertion (RPE) and to immediately perform a set of spikes until they achieved 3 good hits. The trials with the reported RPE values lower or equal to 9 were chosen to constitute the NF condition sample, while the trials with the reported RPE values higher or equal to 19 were chosen to constitute the PF condition sample. The spikes performed in the NF and PF conditions were filmed with the LOCAM high speed camera (100 fps) for later computer-aided analysis. A paired t-test was applied to compare the selected variable means of the spike in the conditions of NF and PF.

RELIABILITY OF THE 15-POINT BORG SCALE

The protocol proposed by Skinner et al. (17) was utilized to assess the reliability of Borg's scale. The test began with each subject walking on a treadmill at 3.5 mph (5.6 Km/h) at 0% grade. The grade was increased by 2.5% each 2 minutes until a self-imposed maximum was reached. Fifteen seconds prior to completion of each work load the subjects were asked to numerically rate the intensity of exertion perceived according to Borg's scale. Subjects were given 2 trials separated by 2 days. Based on the test-retest data, the reliability coefficient for the RPE values reported at the end of each 5-minute period at the different percent grades with the treadmill speed set at 3.5 mph (5.6 Km/h) was .95.

SUMMARY OF RESULTS AND DISCUSSION

Variables Related to Hand Angular Velocity at Contact

The variables considered related to the angular velocity of the contact hand were: 1) highest angular velocity of non-contact upper arm extension after shoulder flexion in the suspension phase; 2) wrist angular displacement of the contact hand, from hyperextension before contact until ball contact during the suspension phase; 3) trunk angular displacement, from hyper-extension before contact until ball contact during the suspension phase; and, 4) contact hand distance traveled, in the suspension phase, from ipsilateral elbow and shoulder flexion before contact until ball contact. Table 1 presents the t-value and level of significance between the means in the NF and PF conditions for the mentioned variables.

Hand angular velocity may be increased by completing a wrist snap at the end of the spike which implies a greater angular displacement (8). Alexander and Seaborn (1) stated that another important contribution for spike efficiency is the lower arm pronation which involves the shoulder medial rotation. This lower arm pronation may further increase the wrist angular displacement if the wrist joint does not remain straight. The significant decrease of the contact hand angular velocity in the PF condition may have been due to alterations in the sequential actions preceding the actual contact with the ball. This may have been due to the fact that the wrist joint of the contact hand was kept straighter, that there was not enough wrist hyperextension, or that the lower arm pronation decreased.

The coordinated action of the trunk and flexion of the knees increases the range and speed of the spiking action and creates a sequential facilitation for the transfer of momentum to the upper arms. The significant angular displacement decrease found in the PF condition appears to be related to the decrease in knee flexion. Moreover, a smaller trunk angle with the vertical at the moment of ball contact may also have decreased the trunk angular displacement. Whatever the reason, the results support the hypothesis that a smaller trunk angular displacement impairs spike performance.

The contact hand distance traveled, although non-significant in this study, did show a decrease. It was speculated that the segmental summation of momentum due to the angular displacement variables was more of a contributing factor. Likewise, the upper arm angular velocity of the non-contact arm did

TABLE 1

HAND AND NONCONTACT UPPER ARM ANGULAR VELOCITY (DEG/SEC), CONTACT WRIST, AND TRUNK ANGULAR DISPLACEMENT (DEG), AND CONTACT HAND DISTANCE (CM) TRAVELED FROM CONTACT ARM HYPEREXTENSION TO THE POINT OF BALL CONTACT IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	P
Contact Hand Angular Velocity	NF PF	-1094 -818	-191.7 -244.6	3.69	.005*
Contact Wrist Angular Displacement	NF PF	119 86	14.1 26.5	2.85	.019*
Trunk Angular Displacement	NF PF	16 14	6.2 4.8	2.71	.024*
Contact Hand Distance	NF PF	58 47	9.5 12.0	1.99	.077 NS
Non Contact Upper Arm Angular Velocity	NF PF	-509 -459	-145.4 -118.0	1.25	.242 NS

*Statistically significant at $p < 0.05$

not decrease significantly in this study. Prsala (14) proposed that the greater the downward swing momentum of the non-spiking arm, the greater may be the momentum transferred to the trunk, thus increasing the power of the spike. It was hypothesized that fatigue as induced in this experiment was unable to affect the upper arm extension.

Variables Related to the Height of Ball Contact

Height of hand contact and related variables

The variables considered related to the height of hand contact were: 1) ipsilateral elbow angle of hand contact at ball contact; and, 2) contact upper arm/trunk angle at ball contact. Table 2 presents the t-value and the level of significance between the means in the NF and PF conditions for the mentioned variables.

TABLE 2

HEIGHT OF HAND CONTACT, (CM), IPSILATERAL ELBOW AND CONTACT UPPER ARM/TRUNK ANGLES (DEG) IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	p
Height of Hand Contact	NF	250	7.6	4.87	.001*
	PF	239	8.6		
Ipsilateral Elbow Angle	NF	162	9.6	3.02	.015*
	PF	147	16.9		
Contact Upper Arm/ Trunk Angle	NF	156	15.3	1.85	.097 NS
	PF	152	15.8		

*Statistically significant at $p < 0.05$

The height of hand contact with the ball is dependent on the height of the body COG and the way the player takes advantage of the extension of the contact arm and its angle with the trunk. In the PF condition, the ipsilateral elbow angle at the moment of ball contact showed a significant decrease. This meant that the mechanical advantage of the contact arm level was impaired, thus the linear velocity imparted to the ball also decreased. Whether the reduced extension found in the PF condition was due to a bad timing of ball contact or to the inability to extend the elbow cannot be concluded from this study. It seems more likely that the significant decrease may be related to the overall condition of bad contact timing.

Another factor that also may influence the height of hand contact is the contact upper arm/trunk angle at the moment of contact. This study was unable to show that a decrease in the height of contact was due to a decrease in this angle. These figures do not necessarily indicate that the subjects in the PF condition contacted the ball at the same relative distance from their head. If, for example, the contact upper arm/trunk angle remained unchanged, any decrease in the elbow angle meant that the contact was made nearer the head. Thus, the contact upper arm/trunk angle did not seem to be critical to negatively influence the height of hand contact. This further supports the hypothesis that the lower arm flexion/extension reflected by the elbow angle constitutes the last possibility for the player to adjust for any inaccurate positioning or timing of ball contact.

Height of body COG and related variables

The variables related to the height of the body COG are subdivided into three categories: 1) absolute velocities; 2) angles; and, 3) times. Table 3 presents the t-value and the level of significance between the means in the NF and PF conditions for the height of the body COG and difference in the body COG.

Both the height of the body COG and the difference in the body COG changed from the NF condition to the PF condition. This means that the subjects in the PF condition were unable to contact the ball at the optimal moment and position of the body COG. This may be related to the absence of knee flexion in the suspension phase or to an inadequate take-off timing.

Absolute velocities

The variables considered were the highest vertical absolute velocity of the left lower and right upper arms and trunk before take-off. Table 4 presents the t-value and the level of significance between the means in the NF and PF conditions for the absolute velocities.

TABLE 3

THE HEIGHT (CM) OF BODY COG AT CONTACT AND THE DIFFERENCE BETWEEN THE HIGHEST POINT OF BODY COG IN THE SUSPENSION PHASE AND THE BODY COG AT BALL CONTACT IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	p
Height of body COG at contact	NF	148	3.1	4.80	.001*
	PF	140	5.6		
Difference in the Body COG	NF	1.2	0.8	-2.93	.017*
	PF	3.1	2.4		

*Statistically significant at $p < 0.05$

The significant difference found in the highest vertical absolute velocity before take-off of the left lower and upper arms, and the non-significant difference in the right lower and upper arms for the same absolute velocity are somewhat difficult to explain. Indeed, the forceful flexion of the arms occurs symmetrically and simultaneously just prior to the extension of the legs. They only function differently when the non-spiking arm starts the downward swing and the contact arm starts its forward movement toward the ball. It is interesting to note that the highest mean absolute velocity of the left lower and upper arms were higher than the highest absolute velocity of the right lower and upper arms. Since all the subjects were right handed, it can be hypothesized that the non-spiking lower and upper arms have a greater contribution for the upward momentum. One explanation for this difference may be related to the player's concentration on her contact limb which would impair the freely forceful flexion. As assessed by the significant decrease of the left lower and upper arms vertical absolute velocity in the PF condition, fatigue may impair their relative contribution to the height of the body COG. Two reasons may have caused this decrease: failure of the arm flexion

TABLE 4

THE HIGHEST ABSOLUTE VERTICAL VELOCITY (METERS/SEC) BEFORE TAKE-OFF FOR THE LEFT AND RIGHT UPPER ARM, LEFT AND RIGHT LOWER ARMS AND TRUNK IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	p
L. Upper Arm	NF	5.0	0.6	3.34	.009*
	PF	4.2	0.5		
R. Upper Arm	NF	4.5	0.9	1.73	.118 NS
	PF	4.0	0.3		
L. Lower Arm	NF	7.4	1.0	2.57	.030*
	PF	6.1	1.0		
R. Lower Arm	NF	6.2	1.1	1.71	.121 NS
	PF	5.6	0.8		
Trunk	NF	3.6	0.4	0.39	.708 NS
	PF	3.5	0.9		

*Statistically significant at $p < 0.05$

muscles, or decreased angular displacement from shoulder hyperextension before the beginning of the support phase.

The trunk highest absolute vertical velocity did not show any significant difference from the NF condition to the PF condition. This means that the hip extensors were still able to forcefully extend.

Angles

The variables considered were the smallest angles of the left and right ankles, knees and hips during the support phase. Table 5 presents the t-value and the level of significance between the means in the NF and PF conditions for the angles.

TABLE 5

THE SMALLEST LEFT AND RIGHT ANKLE, LEFT AND RIGHT KNEE, AND LEFT AND RIGHT HIP ANGLES (DEG) DURING THE SUPPORT PHASE IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	p
L. Ankle	NF	118	7.2	4.11	.003*
	PF	112	4.9		
R. Ankle	NF	117	12.1	2.27	.049*
	PF	119	9.8		
L. Knee	NF	137	20.3	1.57	.150 NS
	PF	132	13.8		
R. Knee	NF	129	17.1	1.18	.268 NS
	PF	126	13.8		
L. Hip	NF	143	11.9	-0.72	.487 NS
	PF	145	7.9		
R. Hip	NF	153	13.6	-0.78	.455 NS
	PF	155	10.0		

*Statistically significant at $p < 0.05$

The lowest six angles of the left and right ankles, knees and hips during the support phase were analyzed, and only the left and right ankle angles showed significant differences in the PF condition. The significant decrease in the ankle angles in the PF condition denotes a contractibility impairment of the shank extensors. It seems plausible to assume that the differences found may be related to a longer ankle angular displacement to absorb the body kinetic energy due to failure of the ankle extensors to resist against gravity.

Even though this study showed a significant decrease in the ankle angles, it was unable to show any significant decrease in the knee angles. With the volleyball drills used in this study, the knee extensors, at least during the eccentric contraction, seemed to better overcome the fatigue than the ankle extensors.

As expected, the left and right hip angles did not change significantly. The hip extensors usually are not stressed very much in volleyball skills. In this study, fatigue may not be a factor for the hip extensors to contract eccentrically to stop the downward momentum of the body during the negative sub-phase of the support phase.

Times

The variables selected were the elapsed time from beginning of support phase for left and right thighs and shanks to the initiation of extension, and time of support phase. Table 6 presents the t-value and the level of significance between the means in the NF and PF conditions for the times.

TABLE 6

THE ELAPSED TIME (SEC) FROM BEGINNING OF SUPPORT PHASE FOR LEFT AND RIGHT THIGH, AND FOR LEFT AND RIGHT SHANK INITIATION OF EXTENSION AND TIME OF SUPPORT PHASE (SEC) IN THE CONDITIONS OF NF AND PF.

Variable	Condition	Mean	SD	t(9df)	p
L. Thigh	NF	0.03	0.01	-1.31	.223 NS
	PF	0.05	0.03		
R. Thigh	NF	0.04	0.02	-1.48	.173 NS
	PF	0.06	0.04		
L. Shank	NF	0.13	0.03	-3.21	.011*
	PF	0.16	0.02		
R. Shank	NF	0.11	0.04	-2.58	.030*
	PF	0.15	0.04		
Time of Support Phase	NF	0.22	0.01	-2.09	.069 NS
	PF	0.23	0.01		

*Statistically significant at $p < 0.05$

The elapsed time for the left and right thighs and shanks initiation of extension was longer in the PF condition as compared with the elapsed time in the NF condition. In the same way, the mean time of the support phase also increased. However, only the right and left shank increased significantly.

It is interesting to note that the left and right shanks initiated their extension later than the left and right thighs. These results do not agree with Samson and Roy (15) who stated that the hip, knee and ankle extensors should be extended at the same time. Conversely, these results support the concept of flexion/extension nonsynchronization of the lower joints involved in the push off supported by Vergroesen et al. (18) and Gregoire et al. (10). Gregoire further proposed it is likely that the sequential extension of the hip, knee and ankle joints allows an energy flow in a proximo-distal direction. The increased time of the left and right shanks in the PF condition may be related to this impaired mechanical efficiency of the proximal-distal power delivered to the lower joints.

Even though not significant, the increase in the mean support phase time in the PF condition is mainly related to the failure of the ankle and knee extensors to produce a fast eccentric contraction leading all the low joints to move through a greater angular displacement, or to their failure to produce a fast concentric contraction to lift the body.

The results of this study supported the concept of performance deterioration associated with fatigue as proposed by Bartlett (2). Moreover, the results also supported the hypothesis, as reported by Simonson (16), that performance decrement may reveal fatigue trends. In this study perceived fatigue, as assessed by the subjective perception of exertion, altered an athlete's volleyball spike efficiency. These alterations were found to be negative toward spike performance. Both the angular velocity of hand contact and the height of hand contact decreased significantly. The ball was spiked slower and lower. In this light, there was a marked decrease either in the technical tactical reserve of the spiker or in the reaction index for a defensive player to retrieve the spike.

The technical tactical reserve stands for the elevation of the hand above the net that allows the player to have the time and height, near the zenith of the jump, to choose the proper direction of the spike according to the position of the blocker and of the back defense players (19). Since the height of the women's volleyball net is 224 cm, and the mean height of hand contact in the NF condition was found to be 250.3 cm and 239.3 cm in the PF condition, the technical tactical reserve in the NF condition was 26.3 cm and in the PF condition was 15.3 which represented a 41.8% decrease. In these circumstances the blockers would have more chances to deflect the ball, and the spiker fewer chances to choose the best tactical response.

The reaction index is determined by multiplying the speed of the ball by the reaction time of the defensive player (11). The obtained value indicates the distance that the ball travels before the defensive player has time to react. Keeping the total reaction time constant, any decrease in the speed of the spike decreases the reaction index, which means that the defensive player would have more time to move in the direction of the spiked ball and retrieve it. Therefore, the chances for the attacking team to score would be lower.

CONCLUSIONS

Within the scope and limitations of this study, the following conclusions were drawn on the basis of the results.

1. When assessed with the Borg category rating scale, perceived fatigue impairs spike performance interpreted as the decrease in the hand angular velocity and height of ball contact.

2. When perceived fatigue, players tend to decrease their amplitude of movements during the suspension phase.

3. When perceived fatigue, the players tend to have an inaccurate positioning and timing of ball contact.

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