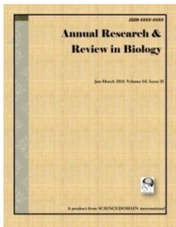

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Evaluation of the Performance of Martial Art Wushu Sportsmen by Measuring the System Complexity

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Authors' contributions

This research was accomplished with collaboration of all authors. Authors AT and MR managed the study. Author AT assessed the research results performed the statistical analysis and wrote the article. Authors MR and FT wrote the protocol and managed the analysis of the study. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: Multiplicity of the degrees of freedom in biological systems is the source of system variability and an indicator of the system health, its flexibility and its ability to adapt with different individual, environmental and functional limitations. Qualitative methods considered by researchers to evaluate the dynamics of nonlinear systems in the last two decades, estimate the level of system variability by quantifying the complexity of movement patterns. The present study investigates the ability of this criterion to evaluate the skill level of sportsmen in performing different maneuvers and to highlight the differences between groups.
Methodology: Sixteen martial art wushu performers, who were invited to Iranian national team, participated in this study. They were divided into two eight-member groups of elite and skilled athletes according to their previous accomplishments in sport. Their postural oscillations, while performing four balancing maneuvers of taolu form of wushu, were captured by a force plate and the complexity of the oscillations in anterior-posterior and mediolateral directions were calculated using the approximate entropy.
Results: The results showed a noticeable difference between the groups in anterior-posterior direction while there was no significant difference in complexity of mediolateral

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oscillations between the two groups. The results also indicated a considerable difference between the maneuvers.

Conclusion: The findings indicated that the athletes in the elite group are more skilled and have more flexibility in performing the maneuvers than the athletes in the other group and this capability results from their ability to better control the effective degrees of freedom in controlling the movements and to coordinate the subsystems to reach a stable and rich balanced position.

Keywords: Sport biomechanics; wushu; nonlinear dynamics; complexity; center of pressure.

1. INTRODUCTION

The modeling of musculoskeletal systems has found widespread application in sport biomechanics to improve, optimize and evaluate the performance of sportsmen [1,2]. Although multilink-multijoint musculoskeletal models have been useful in unraveling the mechanisms involved in performing and controlling the movements, they have major deficiencies. These models limit the degrees of freedom and, more importantly, ignore the interactions between different biological systems; but movement results from an integrated system with a hierarchical control structure, in which the physiological, neural and biomechanical constraints interact with each other. A special maneuver does not result from the function of individual elements but from the common function of these elements; thus the mechanics of a movement cannot be studied isolated without considering the physiological systems involved in motion [3,4]. The variety of the sensory systems and mechanisms involved in postural control, the interactions between the system's elements and also between the system and environment and their mutual impressibility and the variety of applied perturbations, brought the researchers to the conclusion that the movement control results from the interaction of various physiological systems, the task and the environment; and even by identifying all effective factors in movement control, no clear-cut borders can be defined for them [3-6]. These characteristics justify the use of dynamical system qualitative analysis methods to evaluate dynamical systems like biological systems [7]. To perform a movement, nervous system does complex computations, during which the desired path of motion is transformed into appropriate nervous commands to be sent to muscles to move the multilink mechanism. The ability of the nervous system to propose different solutions for a special problem, leads to its flexibility when it is faced with various and unpredictable limitations. For example, the central nervous system uses various combinations of angular changes in joints as well as various ratios of muscular activity in different synergic groups [6], to perform a simple movement; this is known as the movement variability [5]. This problem has also been noted as the problem of the degrees of freedom in movement control and coordination. Performing skillful and coordinated movements requires the dominance over the redundant degrees of freedom and skill acquisition requires timely freezing and releasing of the degrees of freedom [3,4,8]. Multiplicity of the degrees of freedom provides the possibility to benefit from different subsets of degrees of freedom for performing a coordinated, adaptable and optimal movement. Not only multiplicity of the degrees of freedom isn't considered as a drawback for the neuro-musculoskeletal system but also it increases the controllability and adaptability of movement and shows that the movement control system doesn't rely on rigid programs to perform a movement, although it makes the initial phases of skill learning difficult [4,7-10]. In nonlinear dynamical systems – when an attractor is attainable – the non-equilibrium steady state indicates the variability of the dynamical system and this can be seen in the shape of attractor [11]. In high dimensional complex systems like the postural control system [12], system variability is measured from the time series of the outputs of the system and is called complexity. In calculating the complexity, it is evaluated that to what extent regularity has contributed to data generation and to what extent the variability is predictable. Its optimal value lies between complete repeatability and complete randomness [7,10]. The question that how athletes can coordinate the multiple degrees of freedom of the movement control system to do complex maneuvers, has been investigated in the present study from the perspective of nonlinear dynamics. For evaluation of the movement control system, the elements of the system were not separated and the output of the postural control system during several maneuvers of taolu (the exhibition form of wushu) was recorded. The time series of postural fluctuations represent the dynamics of the movement control system, since the dynamics of a system manifests itself in the behavior of all system variables [11]. Quantitative measurement of postural oscillations is done by measuring the displacements of center of mass (COM) and/or center of pressure (COP). Time series of COP displacements, which have been used extensively, due to their high precision and ease of measurement, as a useful tool in research studies on postural control system and diagnostic-therapeutic studies on balance disorders, were also used in this study. Skill means flexibility in performing well practiced movements with selected strategies and fine-tuned adjustments in various environmental conditions, which increase the variability and consequently the complexity of movement patterns. The complexity criterion was used in this study for evaluating the performance of taolu sportsmen in elite and skilled groups so that the ability of this criterion to reveal small performance differences of both groups' members, which lead to point reduction in competitions, becomes clear. This criterion has been used in several studies to investigate the performance of athletes in triple jump [13], basketball [14], ballet dance, and track and field [15]. One of the goals of this study was to find a reliable, but not subjective, tool to show the subtle changes in the phase of skill acquisition by sportsmen and to help the trainers with the evaluation of the skill level of trainees.

2. MATERIALS AND METHODS

2.1 Participants

Sixteen wushu sportsmen of the form taolu, who were invited to Iranian national team, participated in this study. They were divided into two eight-member groups of elite and skilled athletes. Having at least one national championship (gold medal) in professional sport carrier was the criterion to place an athlete in the elite group. Participants had trained two times a day and were physically ready to do the maneuvers of wushu. The average age, height and weight of the participants were respectively, 19.00 (±1.83) years, 169.50 (±1.00) cm and 65.00 (±2.83) kg in the elite group and 18.25 (±0.50) years, 167.50 (±3.79) cm and 63.00 (±3.16) kg in the skilled group; and there was no significant statistical difference between the characteristics of these groups. Table 1 shows the demographic information of participants. Participants were informed about the test objectives before carrying out the tests and all of them signed the written consent form of participation in the study.

Table 1. Subject's physical characteristics

Case ID	Age (yr)		Height (Cm)		Weight (Kg)		Experience (yr)	
	Elite	Skilled	Elite	Skilled	Elite	Skilled	Elite	Skilled
1	20	18	172	165	69	62	9	7
2	19	19	169	172	66	69	8	8
3	18	19	168	166	64	63	7	9
4	21	18	170	168	67	65	9	8
5	19	19	169	169	65	64	8	9
6	18	18	172	171	69	67	8	8
7	20	18	167	163	62	60	9	8
8	18	17	169	164	65	61	7	7
Mean±Std	19±1.83	18.25±0.50	169.5±1.00	167.5±3.79	65±2.83	63±3.16	8±0.83	8±0.75

2.2 Test Protocol

The athletes took first the proper position for each maneuver so that their support foot is on the force plate with the ankle joint axis parallel to the axis passing the origin of the force plate and the maneuver leg is outside the force plate, and then carried out the maneuvers .Center of pressure coordinates (COP) of wushu sportsmen, while performing four exhibition balancing maneuvers. 1) side kick and holding leg in standing position, 2) front snap kick and balance with arms spread sideways (Fig. 1), 3) back kick and holding leg in standing position, 4) backward balance - in anterior-posterior and mediolateral directions, were captured at a sampling frequency of 200 Hz by a Bertec 9090-15 force plate with a Bertec AM-6701amplifier (Fig. 2). Participants stood first in a proper initial posture for doing each maneuver on the force plate and then performed the mentioned maneuvers. The order of maneuvers was chosen randomly for each participant. The coach of the team confirmed whether each maneuver was performed correctly and the incorrect maneuvers were deleted from the study. A minimum of 2 minutes was considered as resting time between maneuvers, which was extended depending on athletes' need. We present here the picture of one of the participants during performing a maneuver:

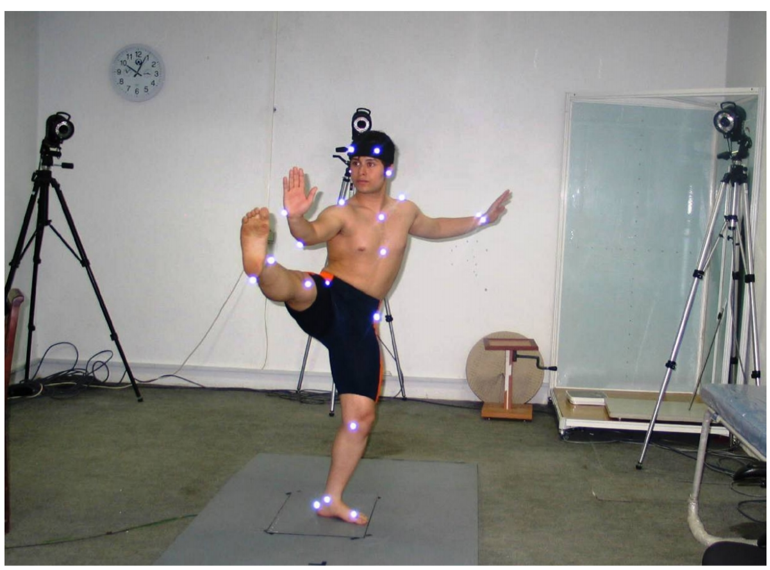

Fig. 1. Front snap kick and balance with arms spread sideways

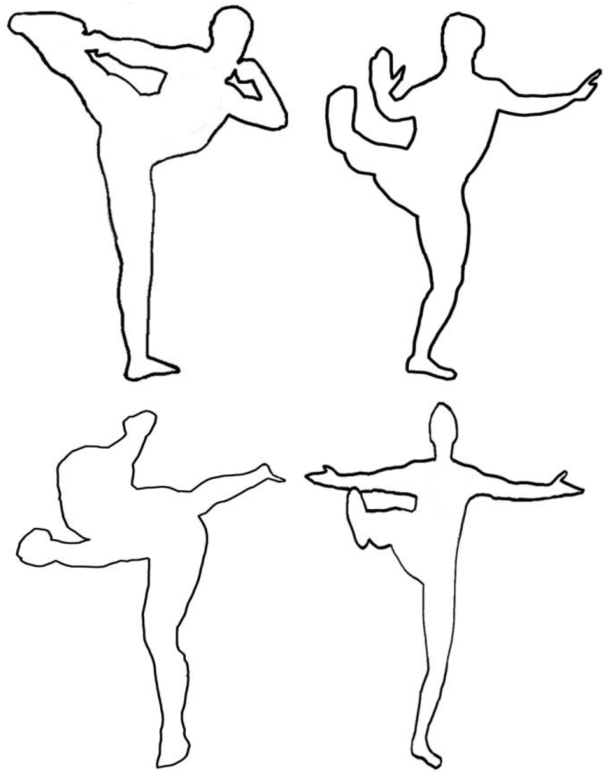

Fig. 2. Selected exhibition maneuvers of taolu form in the sport wushu. (Up-left) side kick and holding leg in standing position; (Up-right) front snap kick and balance with arms spread sideways; (down-left) back kick and holding leg in standing position;(down-right) backward balance

The criterion for entering into the study was the presence in the camp of Iranian wushu national team. The following criteria were the ones for leaving the study:

1. Injury of musculoskeletal system.
2. Inability of the athletes to perform the defined maneuvers in the study.
3. Not winning medals in the selection competitions of Iranian national team.
4. Not participating in doping test or being positively tested for doping.

2.3 Evaluation Criterion

The approximate entropy index (ApEn) was used in this study to calculate the complexity of COP time series in anterior-posterior and mediolateral directions. ApEn is a nonlinear measure of complexity which provides a criterion of the possibility that similar patterns don't repeat in time series. Time series with repeated patterns have relatively low entropy and the more complex systems have higher ApEn [16]. The recorded time series were filtered by the second order low-path Butterworth filter with zero time delay and a cut-off frequency of 10 Hz. Three parameters should be determined as computation inputs for calculation of ApEn: 1) the length of the vectors to be compared along the signal, 2) time delay, and 3) the neighborhood radius. The conservative selection of two data points for the length of the compared runs and 0.2 of standard deviation of the relevant time series as the neighborhood distance yields reportedly good results [7]. The time delay was determined based on the time, when the local minimum of the auto mutual information function of the time series occurred. For all computations, a computation code was written in MATLAB software package version 7.1.

2.4 Statistical Analyses

All statistical analyses were done by SPSS software version 17. The Kolmogrov-Smirnov test confirmed the normal distribution of results and a 4×2 (maneuver × group) post hoc intragroup-intergroup mixed model analysis of variance with 90% level of confidence was used to investigate the differences between maneuvers and between groups.

3. RESULTS

Table 2 shows the descriptive statistics of the results of ApEn calculation in all four exhibition maneuvers of wushu for both groups and for both anterior-posterior and mediolateral directions. The results of ANOVA test and post hoc comparisons have been presented in Tables 3 and 4.

Table 2. Descriptive statistics (Mean (SD)) for the measure of approximate entropy (ApEn)

Group	Side	Maneuver			
		A	**B**	**C**	**D**
Elite	AP	0.39(0.13)	0.67(0.02)	0.54(0.14)	0.58(0.23)
	ML	0.66(0.10)	0.52(0.07)	0.60(0.19)	0.34(0.11)
Skilled	AP	0.28(0.06)	0.51(0.15)	0.57(0.07)	0.50(0.11)
	ML	0.51(0.14)	0.50(0.31)	0.49(0.03)	0.31(0.03)

A : Side Kick, B: Snap Kick, C: Back Kick, D: Backward Balance AP: Anterior-Posterior, ML: Mediolateral

Table 3. Summary of analysis of variance for the measure of postural performance (ApEn)

		Wilks Lambda	F	P	Effect Size
ML	Group	—	1.588	0.254	0.209
	Maneuver	0.194	5.532	0.066*	0.806
	Group× Maneuver	0.766	0.408	0.756	0.234
AP	Group	—	3.896	0.096*	0.394
	Maneuver	0.039	33.079	0.003*	0.961
	Group× Maneuver	0.618	0.824	0.545	0.382

AP: Anterior-Posterior, ML: Mediolateral: less than 0.1 level of significance*

The obtained results indicate that there is no interaction between the groups and maneuvers in anterior-posterior (0.545) and mediolateral directions (0.756); but the main effects of maneuver variable were statistically significant in both directions and for both groups (0.003 in AP and 0.066 in ML direction) (Table 3). The results of post hoc analysis show that the complexity of side kick maneuver in anterior-posterior direction and the complexity of backward balance maneuver in mediolateral direction differed from the complexity of other maneuvers (0.001, 0.018, and 0.000 in AP direction and 0.003, 0.054, and 0.005 in ML one) (Table 4). Statistical findings regarding the main effect of the group variable show a significant difference between the groups in anterior-posterior direction (0.096), but this effect was not significant in mediolateral direction (0.254) (Table 3).

Table 4. The results of post hoc analysis in multiple comparisons

Maneuvers	Side	
	AP	ML
A with B	0.001*	0.394
A with C	0.018*	0.472
A with D	0.000*	0.003*
B with C	0.618	0.676
B with D	0.457	0.054*
C with D	0.895	0.005*

A: Side Kick, B: Snap Kick, C: Back Kick, D: Backward Balance AP: Anterior-Posterior, ML: Mediolateral: less than 0.1 level of significance*

4. DISCUSSION

Obtained results indicate that there is a difference between groups in anterior-posterior direction and the movement patterns of the elite athletes in anterior-posterior direction are more complex in comparison with the skilled athletes. This shows that the elite athletes have more skills in performing the maneuvers than the members of the other group. The same results have been reported by other studies and it has been shown that the complexity of movement in skilled sportsmen is higher than that of beginners [9,13]. The higher complexity in skilled individuals indicates the system multi-stability and ability of movement control system in transitions between different attractors [4], which physiologically means that skilled individuals have higher ability in coordinating the movement while facing various neural, biomechanical and environmental constraints [9]. Knee and ankle joints, which are mechanically simple passive hinge joints in sagittal plane, play a major role in controlling the position in anterior-posterior direction. The low-amplitude low-frequency postural oscillations in this direction are controlled by theses joints by the appropriate sensory inputs and by proper muscular synergies in effective functional muscles like Quadriceps, Hamstring, Tibialis anterior and Gastrocnemius [5,6]. In general, movement control and balance on hinge joints is a complex activity and becomes even more difficult during single support exhibition balancing maneuvers. A small weakness in one of the above mentioned points such as weakness in proprioception of joints, muscle atony, or inability to overcome the internal sources of perturbation and inertial forces prevents the athlete to reach the desirable position or causes his limbs to tremble during the movement. In a similar study using motion analysis and electromyography on maneuvers of wushu athletes, the trembles of limbs during several maneuvers were seen and accordingly, paying attentions to strengthening of muscles, especially Tibialis anterior has been recommended [17]. The results of this study imply that the skilled athletes may have more muscular power or enjoy a better muscular synergy to control the balance in anterior-posterior direction. Of course, electromyographic studies are needed to confirm it. Findings also indicate that there is no intergroup difference in mediolateral direction and this may result from the sufficient skill of the participants to maintain their balance in frontal plane during maneuvers. Therefore, the patterns of COP oscillations in mediolateral direction do not differ between groups and it should also be remembered that in most of these maneuvers, the body moves in sagittal plane. But it doesn't seem far-fetched that we would see significant differences between the complexity of mediolateral oscillations in amateur and professional sportsmen if we compared them with each other. Another important point is the significant difference between the complexity of side kick and backward balance maneuvers and that of other maneuvers in anterior-posterior and mediolateral directions, respectively. Performing one-legged backward balance maneuver is not difficult for athletes with sufficient skills but maintaining it for a while is difficult and, hence, athletes with open arms have to transfer the weight on the supporting leg alternatively from one position to another, to keep their balance; and this results in more regular patterns in COP oscillations in mediolateral direction, which further leads to reduced complexity and lower ApEn in this maneuver in comparison with the other maneuvers. The same argument can be used to justify the lower ApEn of the side kick in anterior-posterior direction in comparison with other movements; of course, the orientation of limbs in the space should be considered for its interpretation. Although in this balancing maneuver, like in the back kick, the limbs have the same distribution around the supporting leg (the trunk of the athlete lies on one side and the other leg is on the opposite side of the supporting leg (see Fig. 2)), with regards to the position of the supporting leg it can be seen that the lateral direction of the athlete's position in this maneuver aligns with the longitudinal axis of the force plate, so the athlete should keep his balance in the lateral direction of the supporting leg. To achieve this, the athlete, like the previous maneuver, should transfer the weight on the supporting leg regularly and alternatively and this will decrease the level of complexity in the recorded time series in the longitudinal axis of force plate. A further point to consider about this study is that the complexities in anterior-posterior and mediolateral directions were not compared with each other. This was due to different mechanical structures of limbs and related constraints for movement control in these directions. This concept is in consistent with a viewpoint in motor control that considers movement as an output of nervous system, which is filtered by body mechanics (mechanics of limbs and joints) [4]; hence, different mechanical structures of the limbs in sagittal and frontal planes cause different manifestations of the integrated movement control system to keep balance in these two directions [18,19]. This study showed the capability of this index (from the set of indices for evaluation of complexity level) to distinguish between two relatively similar groups having only subtle differences with a good precision in comparison to stabilometric indices and this demonstrates the sharpness of that index. The significance level to distinguish between the groups was considered 0.1 in the present study and this was due to small effect size and limited number of available samples, which is also mentioned in the section "study limitations". Had the researchers had a greater statistical population at their disposal, it would have been possible to show the differences between the groups with a significance level of 0.05. This index has also revealed the differences between the maneuvers well and showed that the sidekick maneuvers in anterior-posterior alignment and backward balance maneuver in lateral alignment rely on more rigid neuro-musculoskeletal control system programs. These results, alongside the motion analysis indices, can also help the trainers with the assessment and comparison of the difficulty level of sport activities and the fitness level of athletes and with talent search among the sportsmen at the grass-root level after passing the preliminary training courses.

5. STUDY LIMITATION

The researchers faced the following limitations in performing the tests:

a. There is limited access to elite athletes having gold medals and skilled athletes who have won silver and bronze medals in their sport carrier, and this makes the validation and generalization of results difficult.

b. Lack of two force plates near each other to register the oscillations of pressure center of maneuver leg at the beginning of movement.
c. Inability to register EMG signal of all effective muscles in performing maneuvers.

6. CONCLUSION

This study tried to investigate the movement control system of wushu athletes during balancing maneuvers applying the qualitative evaluation methods of nonlinear dynamical systems, which do not ignore the interactions between various effective subsystems that are the source of variability and adaptability in the movement control system. The findings indicate that the elite athletes enjoy a better ability to control the multiple active degrees of freedom of the movement control system and to coordinate the subsystems for generating rich movement patterns. The obtained results show that these methods, despite computational ease, have profound concepts hidden in themselves, which can reveal the subtle differences of movement control systems and can further be used to improve the conditions of athletes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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