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Movement pattern recognition in basketball free-throw shooting ☆

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ABSTRACT

The purpose of the present study was to analyze the movement patterns of free-throw shooters in basketball at different skill levels. There were two points of interest. First, to explore what information can be drawn from the movement pattern and second, to examine the methodological possibilities of pattern analysis. To this end, several qualitative and quantitative methods were employed. The resulting data were converged in a triangulation. Using a special kind of ANN named Dynamically Controlled Networks (DyCoN), a 'complex feature' consisting of several isolated features (angle displacements and velocities of the articulations of the kinematic chain) was calculated. This 'complex feature' was displayed by a trajectory combining several neurons of the network, reflecting the devolution of the twelve angle measures over the time course of each shooting action. In further network analyses individual characteristics were detected, as well as movement phases. Throwing patterns were successfully classified and the stability and variability of the realized pattern were established. The movement patterns found were clearly individually shaped as well as formed by the skill level. The triangulation confirmed the individual movement organizations. Finally, a high stability of the network methods was documented.

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1. Introduction

The presented study was guided by the fundamental assumptions of dynamical systems theory. These assumptions include: non-linearity, unknown 'action units' (cf. Handford, 2006), the existence of coordinative structures, more complex examination units, and in conclusion, movement pattern recognition.

Movement execution and skill acquisition differ between individuals. Evidence for this assumption is found, for example, in studies by Bingham, Schmidt, and Rosenblum (1989), Button, Bennett, and Davids (1998), Chow, Davids, Button, and Koh (2007), Jaitner (2002), Handford (2006), Schöllhorn and Bauer (1998a, 1998b), and Schöllhorn, Nigg, Stefanyshyn, and Liu (2002). Distinguishing the individuality of the movement pattern is less complicated than detecting the skill level. A clue to detect the skill level of a performer is the extent to which he or she releases degrees of freedom. For instance, Bernstein (1967) proposed that for the beginning of a motor learning process an initial freezing of the degrees of freedom occurs. For the advanced stage he suggested a gradual release and finally, for the expert, a selective control of degrees of freedom. Evidence for the assumption has been presented by Vereijken, van Emmerick, Whiting, and Newell (1992) with participants learning a ski-simulator task. However, there are also contradictory findings, indicating the specificity of the task constraints, for example, in a basketball bouncing task (Broderick & Newell, 1999), in a balance task (Ko, Challis, & Newell, 2003), and in a finger movement task (Ranganathan & Newell, 2008). In a synopsis of empirical studies about this subject Newell and Vaillancourt (2001) concluded a sensitive dependency on the confluence of constraints.

Likewise, functional or compensatory variability as a criterion of expertise is assumed. According to this assumption, expert shooters show an augmented stability on the macro level, and an increased variability on the micro level compared to novice shooters. Their joints compensate for each other in order to achieve the same performance outcome despite different starting conditions and/or initial performance (caused by unexpected perturbations). Typically, this compensation occurs from proximal to distal. The distal articulations exhibit a greater intertrial variability (i.e., Vereijken, van Emmerik, Bongaardt, Beek, & Newell, 1997). Empirical evidence for the phenomenon of compensatory variability is found as an interaction between perceptual and motor components (Bootsma & Van Wieringen, 1990), as a compensation of different launching parameters (Kudo, Tsutsui, Ishikura, Ito, & Yamamoto, 2000; Loosch, 1995; Loosch, 1997), and as compensation between several articulation movements (Button, MacLeod, Sanders, & Coleman, 2003; Robins, Davids, Bartlett, & Wheat, 2008). Button, et al. (2003) found some characteristics of the skill level of basketball free-throw shooting by calculating the function of the hand and elbow angle-measures of the shooting arm: "In summary, the joint-space variability associated with the basketball free-throw shot decreased as a function of increasing expertise" (ibid. p. 268). Furthermore, they found several indications for a more differentiated view on the valuation. For example, an intermediate shooter showed more intertrial trajectory variability than the novice shooters. It is supposed that this participant explored a range of arm positions (ibid. p. 262). Button, et al. (2003) also concluded that the basketball free-throw shot "presents a unique set of task constraints for the performer to solve" (ibid. p. 267).

Special characteristics of the basketball free-throw movement are inter alia the following: it is a full body movement, a precision shooting task and a closed skill. Obviously, the 'ready-to-shoot-position' – a movement phase, where the ball lies in the shooting hand, while the shooter holds it in front of/above the forehead and aims at the basket – is especially significant for the performance outcome of the free-throw action. In a biomechanical investigation of the basketball free-throw action, looking at ten players of the German national team, Loibl (1978) identified the 'ready-to-shoot-position' as the checkpoint of the whole motion sequence (ibid. p.110). Schauer (2006) describes the basketball free-throw in a scientifically based textbook as a two-cycle movement, where the flexion and extension of the shooting arm happen first, followed by the flexion and extension of the knees. The point of return movement between the two cycles is, in fact, the 'ready-to-shoot-position'. He also emphasizes the necessity of carefully coordinating several force impulses for a successful outcome.

Robins et al. (2008) analyzed 30 basketball players with different skill level performing 30 shots from the distances of 4.25 (free-throw distance), 5.25 and 6.25 m from the basket. They calculated the angle measures of the shoulder, elbow and wrist joints. The results showed compensatory adjustments by the expert performers at more distal joints (ibid. p. 476).

Consequently, when analyzing movement behavior, multiple effects have to be expected, because it is as dependent on the individuality as on the skill level of the performer (special kinds of release of the degrees of freedom which are not yet completely explored) and in particular on the constraints of the movement task. Based on the conclusions of Newell and Vaillancourt (2001), a sensitive dependency on the confluence of constraints, various reciprocal effects are possible. But already, the sheer enormity of reciprocal effects between individuality and skill level makes the interpretation of empirical results quite difficult. The compensatory variability which has been shown in empirical studies concerning basketball free-throw shots was detected between the joint movements of the shooting arm. Since compensation is particularly expected in the distal articulations at the end of the movement execution, focusing on those articulations seems reasonable. Nevertheless, the whole kinematic chain consists of at least six articulations (feet, knee, hip, shoulder, elbow and hand joints). It is to be assumed that already at the beginning of the throwing action perturbations occur, which subsequently have to be compensated.

The aim of this investigation is to identify and examine the information which can be gleaned from the movement pattern. We supposed to find characteristics for individuality and skill level. The methodological supposition is to find them in a complex feature which represents the pattern, that is, which contains the invariants of the movement pattern. Such a complex pattern has to be really complex, relating to the defined movement pattern.

Definition: the movement pattern is the basic structure of the movement process. It relates to the whole kinematic chain of the movement in question.

This complexity is the logical issue of the fundamental assumptions of dynamical systems theory. Until now it represented an insoluble methodological problem to relate a dozen items to each other.

The interest of research consists of revealing to what extent the participants' individuality and skill level can be determined from the movement pattern. It should also become quantitatively tangible by identifying a complex feature such as a structural pattern for the chosen criteria task of the basketball free-throw as defined by the foundational assumptions of dynamical systems theory. The movement pattern of expert free-throw shooters should then be characterized by a compensatory interaction of the joints involved, which can be seen when analyzing the kinematic chain (the six joints on the body-side of the shooting arm) while performing the shot. The shooting movement is defined and analyzed over the two cycles: flexion and extension of the shooting arm (parallel to the knee bend) (cf. Schauer, 2006).

2. Methods

The analyses with DyCoN make up the vital methods of the present study, because they are pursuing the central objective of the outlined research project. In order to review the validity of the net analysis results, several preparatory methods are applied. Hence, the following research report will focus primarily on the documentation of the DyCoN-Analysis. DyCoN extends a self-organizing map, a special Kohonen Feature Map (KFM), in which each neuron uses a PerPot-Model to regulate its learning rate and distance. Thus, it allows for faster and more continuous learning. The complex functioning of DyCoN is clearly represented in the literature (see Perl, 2004).

2.1. Sample

The sample should represent a wide spectrum of skill levels, in order to identify the diverse movement patterns, which are presumably responsible for the different degrees of skill level. A wide spectrum opens up when the sample contains the skill levels of novices up to experts and shows a continuous increase in the skill levels. The test persons were sport students of the University of Bremen, talented U19 players from a local team which prepares them for the 1st and 2nd division as well as two coaches. Primarily, but not exclusively, men were examined. Each participant is video recorded and analyzed in a three-dimensional design doing the free-throw shot in a regulation-size court (see Fig. 1).

The score of 20 free-throw shots are calculated corresponding to a fivefold graduated basketball throwing system, by which the quality of the shot can be differentiated very clearly. It was developed by Augste and Lames (2006) and is shown in Table 1. For the present sample which consists of novices, advanced learners and experts, the counting category for "young people" was chosen, as it gives a wide spread differentiation.

The chosen sample consists of $N = 21$ shooters: They are beginner, advanced and expertise players, seven each. The participants are arranged in an order from 01 up to 21 (see Table 2). The number of each participant represents the number of scoring points he or she achieved in the shooting test (i.e., the order of the participants is based on their success in shooting). The numbers are scaled ordinally and will stay the same throughout the present research report. Five of the 21 shooters are women and 16 are men. They are exclusively right-handed (thus shoot with their right hand) and between the age of 17 and 38. The body height of the sample group ranges from 1.58 to 2.01 m. The basketball experiences range from minimal school sports combined with participation in basic basketball events to 13 years of competition experience.

2.2. Analysis

The following analyses have been completed:

2.2.1. Data-acquisition with three-dimensional video recordings

Each participant did 20 free-throw trials as described in Section 2.1.

2.2.2. Calculation of the free-throw score

Calculation of the free-throw score with a test instrument from Augste and Lames (2006) as described in Section 2.1.

2.2.3. Kinematic analysis with SIMI – Motion Reality Systems

Due to the manual tracking of the joint markers, the kinematic analysis has only been taken out for the first five shots of each participant. The resulting data are the angular displacements (φ), angular velocities (ω) and animated stick figures. The kinematic chain is operationalized by the ankle-, knee-, hip-, shoulder-, elbow- and hand joints on the body-side of the shooting arm. Every angle is calculated by the means of three points, one on each leg and one on the apex. A definition of the analyzed body angles can be seen in Table 3.

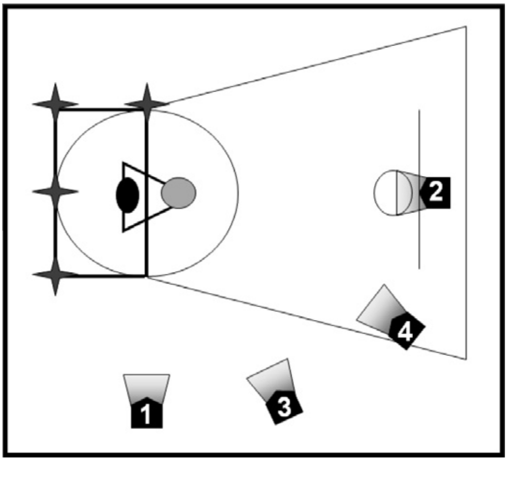

Fig. 1. The experimental setup consisted of four cameras, the shooter on the line in front of the basket and the calibrating system around him.

Table 1
Standard for calculation of the scoring points (Augste & Lames, 2006).

Result of the shot	Young people	Adults	NBA
Swish	1	1	1
Score with touching the rim	0.97	0.96	0.95
Touching the rim inside without scoring	0.74	0.68	0.64
Touching the rim outside without scoring	0.28	0.10	0
Airball	0	0	0

Table 2
The sample with the scored points in the shooting test and the resulting priority chain.

Shooter	Scoring points (according to Augste and Lames (2006) – 'young people')	Category
01	6.14	Novices
02	7.42	
03	10.61	
04	11.13	
05	11.44	
06	12.74	
07	13.02	
08	13.54	Advanced
09	13.98	
10	14.23	
11	14.75	
12	14.80	
13	15.90	
14	16.22	
15	17.40	Experts
16	17.63	
17	17.71	
18	17.74	
19	17.77	
20	17.83	
21	18.78	

Table 3
Definition of the joint angles used for the kinematic analysis (joint angles of the right body side).

Angle/parameter	Apex	1. Point on the legs	2. Point on the legs
Wrist joint	Wrist joint lateral	First knuckle of the little finger	Elbow outside
Elbow joint	Elbow joint outside	Wrist joint lateral	Humerus head
Shoulder joint	Humerus head	Elbow joint outside	Trochanter major
Hip joint	Trochanter major	Humerus head	Condylus lateralis
Knee joint	Condylus lateralis	Trochanter major	Ankle outside
Ankle joint	Ankle outside	Condylus lateralis	Toe

The kinematic analysis is based on the survey of a complex feature in the form of a combination of characteristics of kinematic data. The angular displacements and velocities are measured as well as the relationship between the different joints. In order to relate the twelve attributes to each other, the analysis is carried out with DyCoN.

2.2.4. Objective verbal descriptions of the morphological shooting phases

Three people described the progression of the morphological shooting phases on the basis of the video recordings. The observers could view all four camera perspectives on the computer screen and use the still picture function as often as desired. The starting point of the shooting movement is defined by the initial knee flexion or the initial raise of the ball – as the individual case may be. The end of the shooting movement is defined by the launching of the ball (when the ball loses contact to the hand). The aim of this method consists of constructing, preferably concise verbal descriptions of the shooting movements.

2.2.5. Generating phase-portraits with selected angle-measures

In order to examine the supposition of different individual 'coordinative structures' or 'action units', phase portraits from diverse angle-angle and angle-velocity combinations are made.

2.2.6. Expert rating of the animations and the videotapes

The five analyzed free-throw movements of each participant are rated by seven basketball coaches. In the first round the coaches see the reduced movement view as a stick figure. In the second round they rate the same throwing actions on videotape. The different shooters are presented in a randomized sequence. The basketball coaches classify the shooters using a fivefold graduated rating scale. They also give a verbal explanation of the decision made. The verbal explanations are paraphrased with reference to the 'qualitative data analyze' according to Mayring (2003, 2005) ('Qualitative Inhaltsanalyse').

2.2.7. Pattern recognition with Dynamically Controlled Networks (DyCoN)

2.2.7.1. Training of the shooting data network (neural network of the first layer). The shooting data net constitutes the basis for further analysis – i.e., also for the training of further networks in the hierarchical network structure. The training data of the shooting data network are made of the angle displacements and angle velocities of the foot-, knee-, hip-, shoulder-, elbow- and hand joints from the shooting arm side of each participant. DyCoN does not need as many data as a conventional KFM. Therefore, it has been possible to train the shooting data network exclusively with original data. In consequence, the test data have been represented with a maximum authenticity on the shooting data network.

2.2.7.2. Trajectory analysis. The results of the tests with the specific shooting data sets on the shooting data network (basis network) are trajectories on the network, which represent the complex feature. It bundles the trained data (attributes/isolated features). The similarity of these trajectories, which represent the progression of one shooting action by passing single neurons on the network, offer the possibility of simply comparing the realized shooting patterns of every free-throw movement.

2.2.7.3. Identification of the movement phases. The movement phases of the free-throw shots performed by the present sample are represented on the neural network by single neurons and regions of similar neurons. According to these regions of similar neurons where the respective trajectory passes through, the course of the movement phases can be concluded. Comparing the measurement points, which pass single neurons on the shooting data net, with the actions simultaneously observable in the video sequences, these similarity regions (semantic clusters) could be identified and colored. The clustering is possible with DyCoN innate analysis techniques ('neurons-analysis' and 'similarity landscape-analysis') as well. The comparison with the movement actions in the video sequences, moreover, allows a very direct semantic interpretation and validates the results obtained by the 'neurons-analysis' and 'similarity landscape-analysis'.

The supplemental DyCoN inherent analysis tools 'neurons analysis' and 'similarity landscape analysis' permit an even more detailed insight. The 'neurons analysis' shows the attribute values for every single neuron, whereas the 'similarity landscape analysis' shows the similarity of the network regions and finally the neurons for different similarity resolutions.

2.2.7.4. Transformation of the shooting trajectories on the phase diagram. A special DyCoN-function allows the development of phase diagrams for every shooting action on the basis of the semantically colored network. The phase diagrams show the phase characteristics of the movement progression.

2.2.7.5. Training of the trajectories network (neural network of the second layer). The trajectories network is trained with the trajectories data of the shooting data network. Using Monte Carlo Methods 5000 data sets were generated out of the whole trajectories data of the 105 tested shots. The trajectories network has a lower dimension than the shooting data network.

2.2.7.6. Interpretation of the similarity regions (semantic clusters) of the trajectories network. It is impossible to semantically identify the highly complex information stored on the neurons of the trajectories network through the optical information out of the video films. Therefore, exclusively the DyCoN innate analysis techniques are carried out. The trajectories network is colored as well, according to the analyzed clusters. The clusters get phase numbers from the second layer.

2.2.7.7. Typifying the free-throw shooting patterns. The movement pattern of every single free-throw movement is assigned to a class of basic shooting patterns. The classes are found in the structures of the collected data.

2.2.7.8. Test of intra-individual stability. The test with the trajectories data of the complete free-throw movements on the trajectories network permits to identify the intra-individual stability of the analyzed shots by means of further trajectories analysis.

2.2.7.9. Triangulation. The data drawn from the qualitative and quantitative methods are triangulated in individual case analysis.

3. Results

The results of the present study are presented in the following way: at first the rating scales of the expert rating are displayed. Then, the results of the analysis with DyCoN are depicted in detail. Next, four examples out of the triangulation in individual case analysis are shown.

3.1. Results of the expert rating

The basketball coaches classified the shooters as depicted in Tables 4 and 5. Every shooter is rated by seven basketball coaches.

Table 4
Results from the expert-rating of the reduced movement view as a stick-figure in the fivefold rating-scale. It is denoted in each category how many ratings the participants received from the seven coaches.

Shooter	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
Expert										1			3	1	2	4	3		2	3	5
Very good shooter								1	5	4	2		3	1	3	2	3	2	5	4	2
Intermediate shooter			1				1	1	2	2	2	4	1	3	2	1	1	5			
Advanced learner	1		3	4	3	1	3	5			3	2		2							
Novice	6	7	3	3	4	6	3														

Table 5
Results from the expert-rating of the full movement view by means of the video sequences in the fivefold rating-scale.

Shooter	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
Expert													3			4	2		3	3	4
Very good shooter									1	7	1		3	3	4	3	3	3	4	4	3
Intermediate shooter			1					1	3		2	3	1	3	3		2	3			
Advanced learner	1		2	2	2		3	5	2		4	3		1				1			
Novice	6	7	4	5	5	7	4	1	1			1									

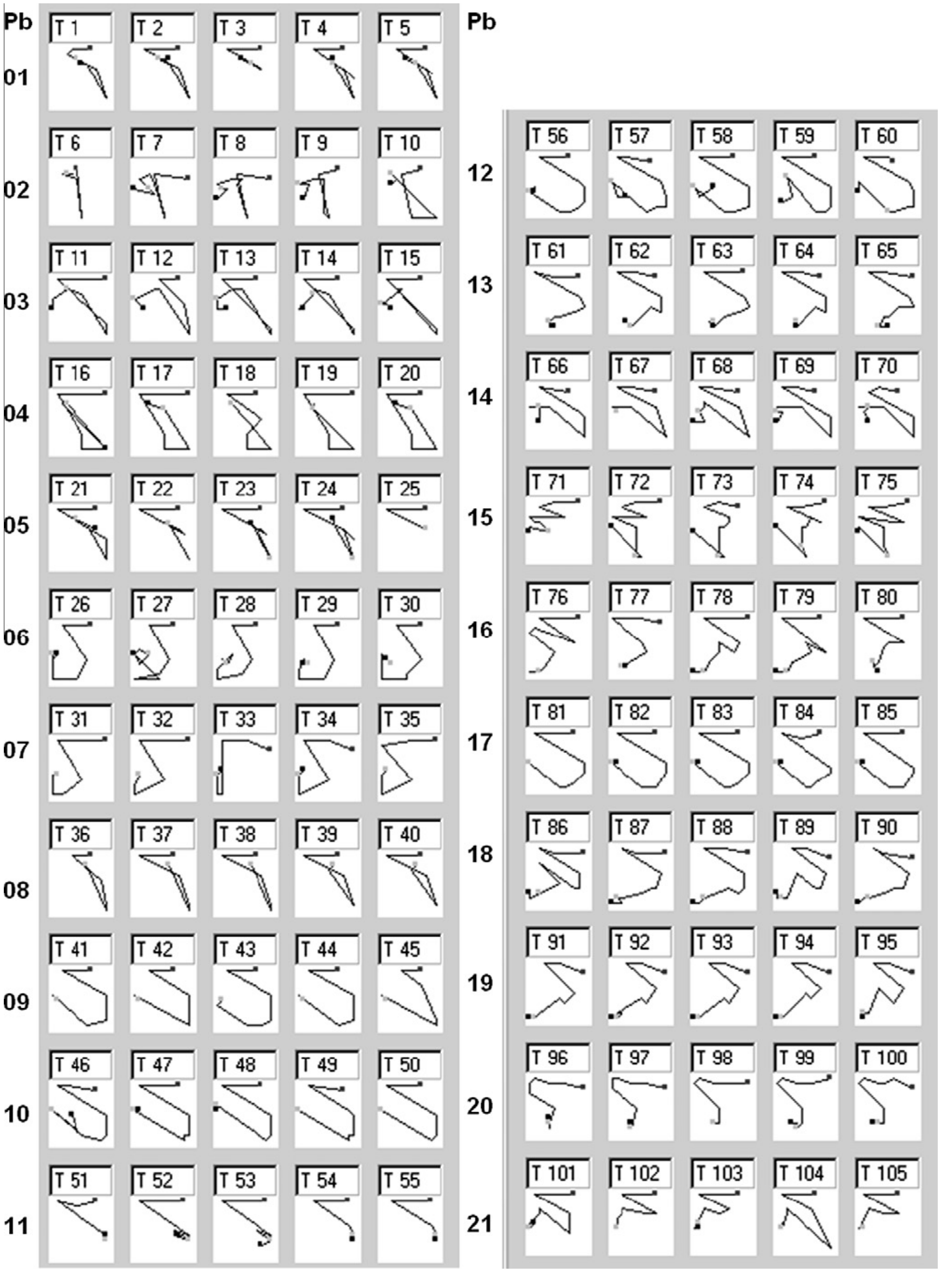

Fig. 2. Trajectories of the shooting actions 1–105 on the shooting data network. All five trajectories in a row represent the free-throw movements of one participant. The trajectories are arranged from those of Participant 01 (T1–T5), a poor shooter rising in skill level, to Participant 21 (T100–T105), an excellent shooter.

The expert rating mostly confirmed the classification which resulted from the shooting test, based on both, i.e., the shooting movement seen in the video sequences as well as the reduced movement view as a stick-figure. Thus, it can be concluded that the observable movement pattern contains crucial information about the skill level of the performer. Nevertheless, there are some ratings which do not clearly confirm the expectation, which is derived from the isolated information about the shooting score and the order of precedence which is resulting from the shooting score. The findings from the neural network analysis can be complemented and verified with a significant amount of qualitative data resulting from the coaches' interviews (for further information see Schmidt, 2010).

3.1.1. Movement pattern recognition with Dynamically Controlled Networks

In a first step of analysis the procedures of shooting are displayed as trajectories on the net presentation. Fig. 2 shows the trajectories of the 105 analyzed free-throws.

Obviously, there is a clear individual imprint in the trajectories' characteristics. The five trajectories representing the five shots of one participant are the closest to themselves. Moreover, there are groups of similar trajectories. For example, the trajectories of the Participants 09, 10, 12 and 17 seem to be overall more similar to each other than to those of the other participants. Whereas, the trajectories of Participant 20 are of a very special kind – they do not pass the net region down right. However, there is no indication to decide which kind of trajectory represents a skillful shot, because in this step of analysis it is not yet clear what meaning the different net regions and neurons have. The next step of analysis, the semantic interpretation provides the essential information.

3.1.2. Semantic interpretation of the shooting data network

By comparing the neurons̀ configuration and the movement actions which are visually noticeable on the basis of the video films, the semantic interpretation (semantic coloring) of the neurons from the shooting data net has been accomplished. Thereby, eight movement phases could be identified, as displayed in Fig. 3.

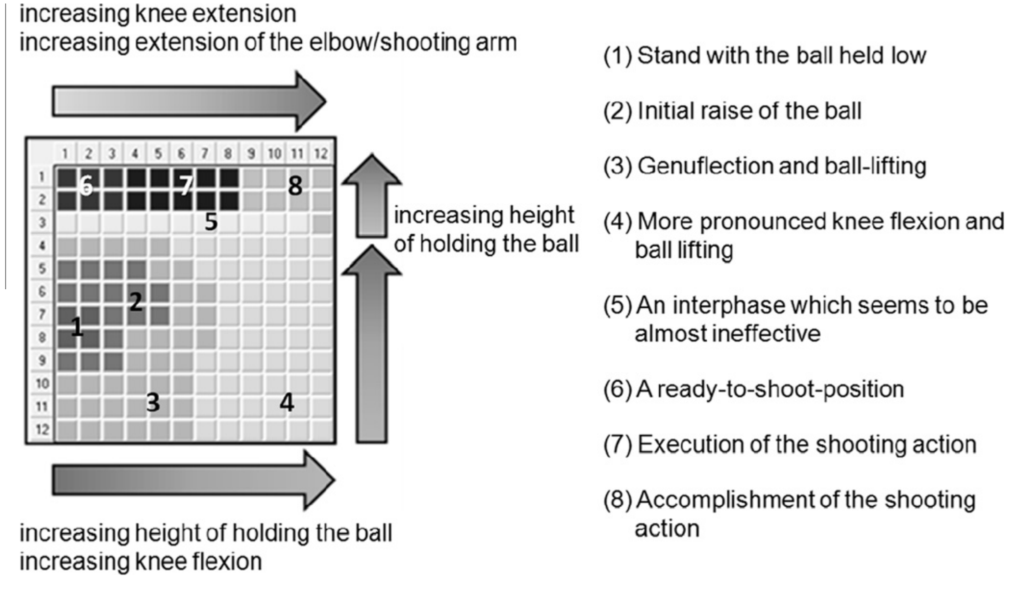

Fig. 3. Coloration of the shooting data network from a semantic point of view. The arrows show the principles of the arrangement within the similarity regions, but also over the different areas. Each arrow refers to the network areas close to it.

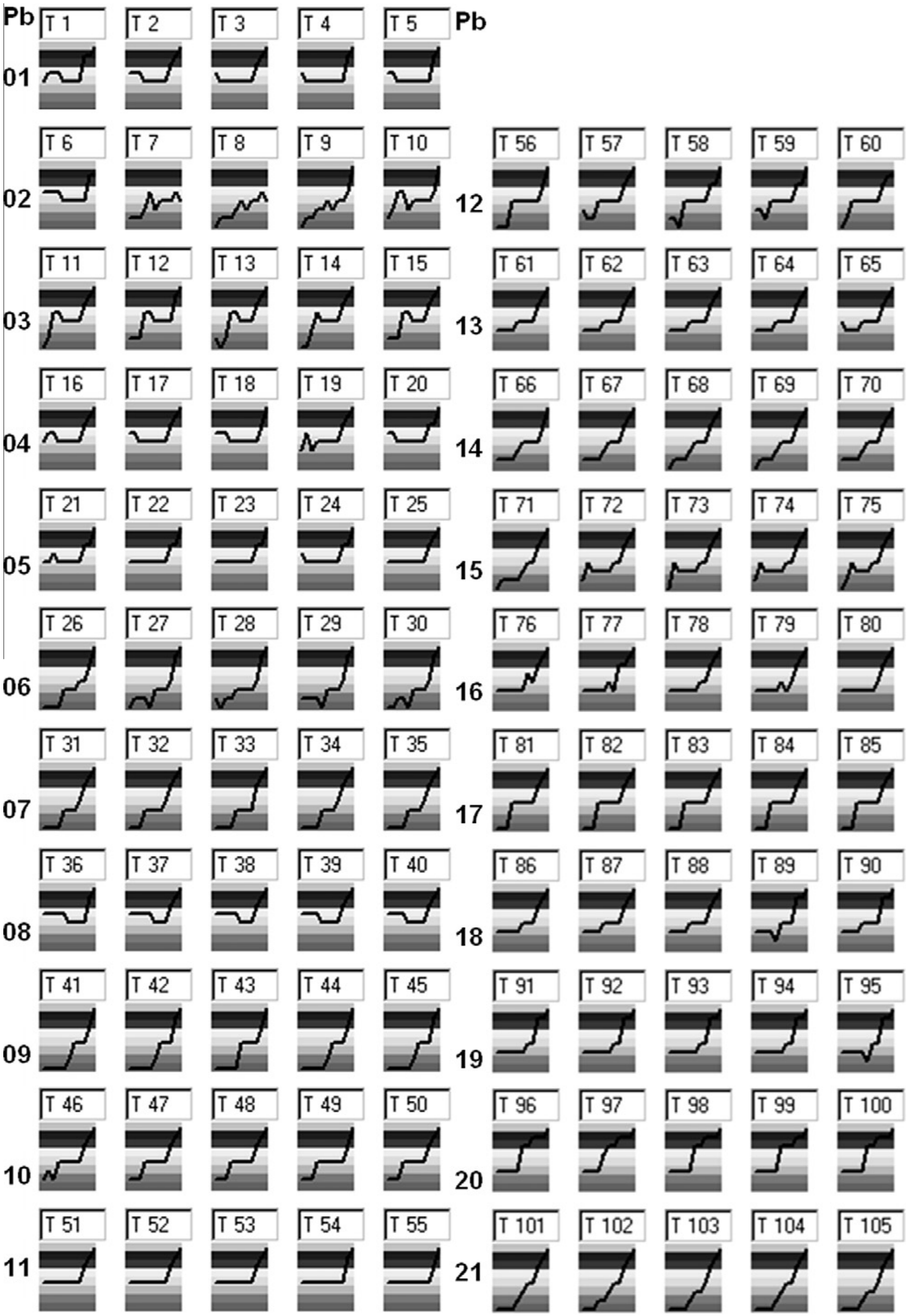

Fig. 4. Phase diagrams of the shooting actions 1–105. The numbering of the trajectories is the same as that of the shots. Thus, five phase diagrams in a row represent the five shots of one participant.

3.1.3. Analysis of the movement phases by means of phase diagrams

On the basis of the semantically colored shooting data network it is possible to depict and recognize in phase diagrams what movement phases the shooters pass through with their shots and how long they remain in the defined phases. Intra-individual similarities as well as inter-individual groupings of similar movement patterns are revealed precisely in the phase characteristics (Fig. 4).

In the phase diagrams the individual imprint becomes even more apparent. In each case the phase diagrams reveal their own structure according to a particular shooter. This result corroborates the assumption of individual characteristics in the movement patterns.

3.1.4. Classification of the shown movement patterns

The concept of hierarchical networks made it possible to further train a DyCoN with the data of the phase trajectories (the trajectories network). The movement patterns of the 105 free-throw shots (highly complex information) are stored on the particular neurons on the trajectories network (Fig. 5).

With 'neurons-analysis' and 'similarity landscape-analysis' specific for DyCoN, this network was area-specifically colored as well. Consequently, a detailed classification of the movement patterns could be carried out (see Fig. 6).

It is particularly noticeable that the free-throw movements from the expert shooters T15–21 in Fig. 6 are exclusively classified into the seventh or sixth cluster. In addition, several shots from intermediate and even novice shooters are found in these two clusters. Solely several shots of the Participants 01–05, 08, 11 and 12 are sorted to the other five clusters. Apparently, the less successful free-throw patterns are very different compared to the intermediate and expert shooting actions. In this case, the different shooting patterns occupy wide regions on the network while the information from the relatively similar patterns of the advanced and expert shooters is stored in smaller regions (only on some neurons).

3.1.5. Test of the intra-individual stability of the shooting patterns

With a trajectories-analysis on the basis of the trajectories network, the intra-individual stability of the found shooting movement patterns is examined. The resulting phase trajectories represent the patterns of the shooting actions over the five shots from each participant (see Fig. 7).

Widespread trajectories (T1–T5) indicate high variability in the movement patterns over the five shots of the participant in question, whereas point trajectories indicate maximum stability (T6, T10, T11, T15, T16 & T17). The shooting patterns of some advanced shooters are not very stable (T08 &

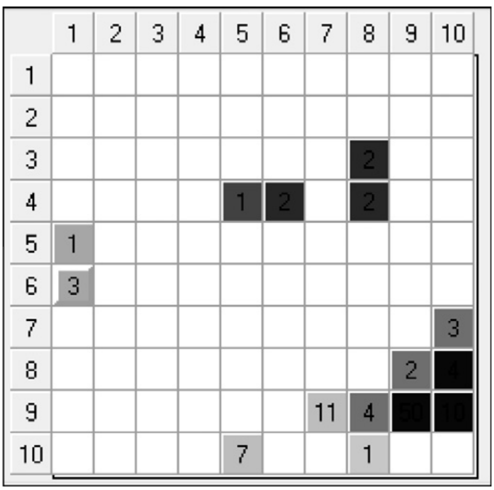

Fig. 5. The 10 × 10 trajectories network. Similar colors/shadows represent similar information stored on the neurons. In this case, similar information corresponds to similar free-throw shooting patterns.

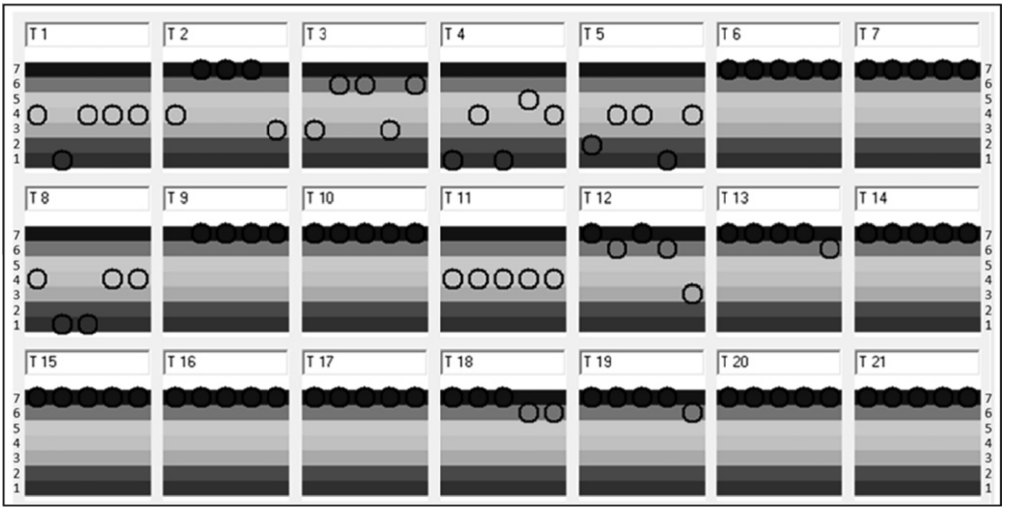

Fig. 6. Classification of the free-throw patterns of the 21 subjects: The colors/shades represent the regions of the trajectories network (compare Fig. 3). Crucial for the interpretation of this graphic is to notice that the used colors each stand for a defined pattern, but the color itself does not provide any information about the quality of the represented pattern. The colors which are near to each other are similar in tendency. The differentiated movement patterns are not equidistant to one another. Notice: The first shot from Participant 09 (T09) cannot be identified; it is a missing data value.

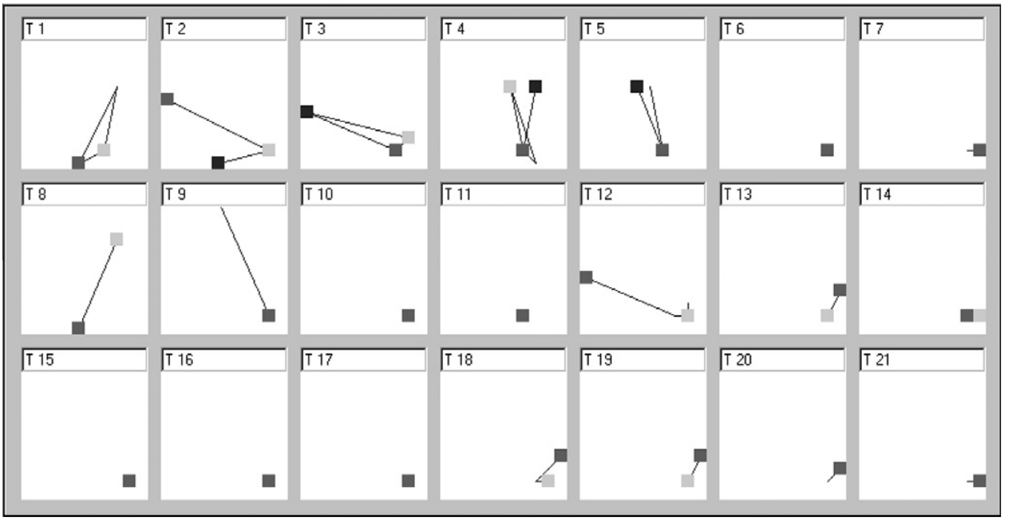

Fig. 7. Test of intra-individual stability on the trajectories network. The numbering of the trajectories corresponds to that of the participants. Notice: The stability value of the shots from Participant 09 (T09) is not certain because the recognition of the first shot failed. The intra-individual stability of his shots are somewhere in between maximum stability and not very stable.

T12). Medium stable movement patterns were observed for advanced and expert shooters (T13, T18, & T19) and submaximal stable patterns were found at all skill levels (T7, T14, T20, & T21). The decision criteria for this categorization are delivered by the distances from ‘neurons-analysis’ and ‘similarity landscape-analysis’.

The test showed an overall increase of intra-individual pattern stability as skill level increases. Nevertheless, maximum stability has been found in all skill levels (novice, advanced, and experts). The five poorest shooters showed a very low stability of their shooting patterns, whereas the four most successful participants' patterns demonstrated medium or submaximal stability.

3.2. Results of the phase-portraits

In the present sample the participants each showed stable structures in different joint combinations, found in very different sections of the participants' kinematic chains. Thus, the assumption of coordinative structures has been confirmed. Single phase-portraits are exemplified in the context of the triangulation (all phase-portraits can be seen in Schmidt, 2010).

3.2.1. Triangulation in individual case analysis

In the following section it is exemplarily displayed how the converging information (data) from the qualitative and quantitative methods develops into further findings. By means of selected case analyses, it is demonstrated which possibilities exist to gain insight by using DyCoN-analyses within a mixed-methods design. The found movement patterns have very individual characteristics. Therefore, the example of single shooters does not represent a typical pattern of a whole skill level. Rather, there are several totally different movement patterns found in the groups of beginners, advanced and expert shooters. Thus, first, the cases of two poorer shooters are depicted. The first (Participant 02) has an unstable movement pattern, as one may expect for a novice shooter, Participant 06, nevertheless, showed a very stable movement pattern. In the following three analyses very different expert shooters' movement patterns are shown. It is interesting to examine in detail how successful shooting patterns are organized.

3.2.2. Exemplary case analyses of the Participants 02, 06, 21, 20 and 19

For comparing different movement patterns, the phase diagrams of the shooting phases provide a useful basis. The diagrams used here display exactly in which phases the single measurement points are situated.

3.2.2.1. Participant 02. This participant has no explicit basketball experience. The five analyzed shots were not successful. This becomes evident in the phase diagrams (Fig. 8) because she almost made no use at all of the launching phases (phases 6–8: 'ready-to-shoot-position', 'execution' and 'accomplishment of the shooting action'). Either they were completely omitted, as in the second and third shot, or at least two of the launching phases were left out. Therefore, the launch was most likely to be uncontrolled.

It is also striking that the movement organization of the first shot differs extremely from that of the following shots. Apparently, Participant 02 actively explores the possibilities of movement organization. She was not successful with her first shot – an airball – so she 'decided' to change something. Her

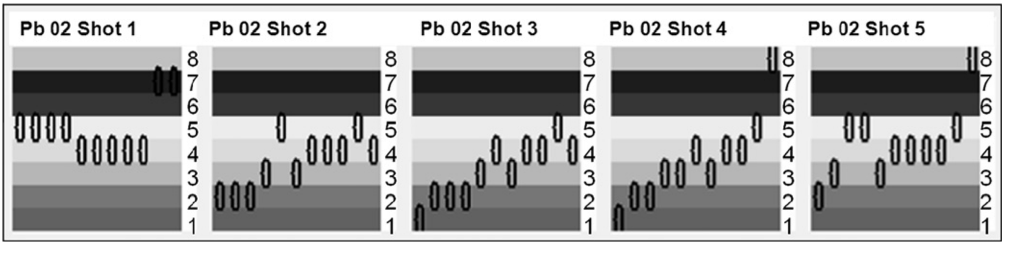

Fig. 8. Measurement points in the constituent phases of the shooting movements from the shots 1–5 of Participant 02 – without explicit experience concerning the free-throw task. The numbers 1–8 represent the movement phases, corresponding to those in Fig. 3. [Outcome of the shots: 1. 'airball' – 2. 'touching the rim outside without scoring' – 3. 'airball' – 4. 'airball' – 5. 'touching the rim outside without scoring'].

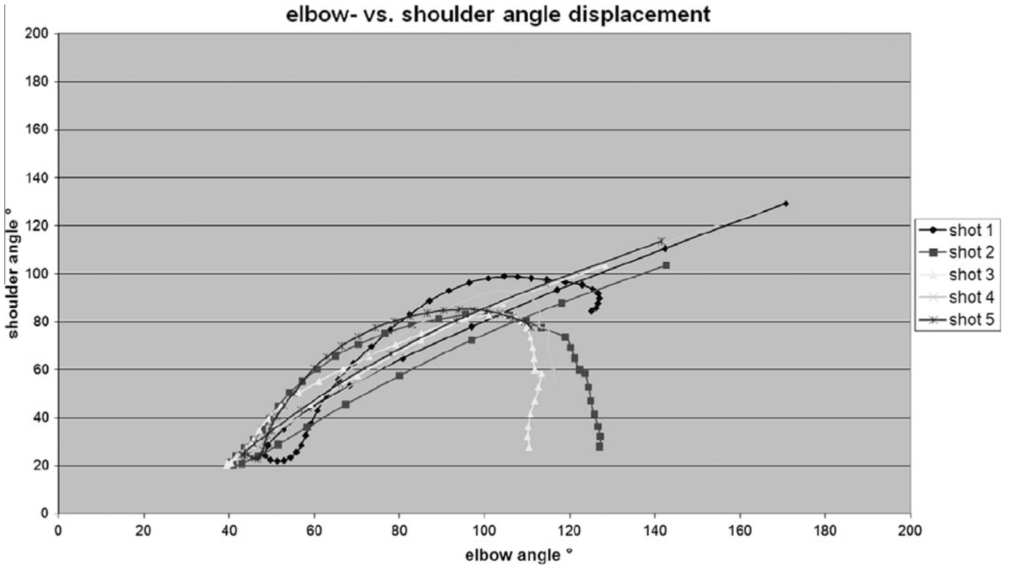

Fig. 9. Phase-portrait of the elbow angle displacement versus the shoulder angle displacement over the five shots from Participant 02 (no explicit experience concerning the criterion task).

second shot touched the rim, which seemed to be better. Consequently, the decision was made that the respective applied movement was not entirely wrong and thus did not need to be changed completely. It appears to be an achievement that she has one measurement point in the eighth phase ('accomplishment of the shooting action') with the last two shots. Nevertheless, the switching between the preparing phases in the last four shots also seems problematic. The shooting pattern is highly variable (see 3.2.3 test of the intra-individual shooting pattern stability). Participant 02 makes use of three different shooting patterns.

Looking at the phase-portrait of the elbow angle versus the shoulder angle may provide more insight into the launching action (see Fig. 9).

At first, both elbow and shoulder joints are flexed to a minimum degree (shoulder approximately 20° and elbow about 40–50°). Out of this position a very fast opening of both joints takes place (see the linear rise). This is the typical proportion between elbow and shoulder joint which develops when performing the push-shot, in the course of which the ball is pushed instead of being thrown. Thus, it is not surprising that the launching phases are not represented in the phase diagrams of the shots from Participant 02.

In the expert rating, all the basketball coaches make the statement that Participant 02 'pushes the ball from the bottom up' (paraphrased) and they all decide that it must be a novice shooter. Thus, the presented free-throw shooting pattern appeared unsuccessful to them.

With this movement, the angular velocity of the elbow from Participant 02 reaches a peak value of more than 1000°/s. When doing this, it is almost impossible to succeed in a precision aiming task. See, for example, Steinhöfer and Remmert (2004), who consider a 'soft shot' necessary for making the basket.

3.2.2.2. Participant 06. The phase progression of Participant 06 (see Fig. 10), a shooter with low to moderate experience, still displays inter-trial instabilities in the shot preparation, phases 1–4, and partly as well in the real launching, phases 6 and 7.

In the first shot, the seventh phase ('execution of the shooting-action') has been omitted. In the following shots the 'ready-to-shoot-position' apparently does not take place. Previous findings (Loibl, 1978) describe this position as an important checkpoint of the whole motion sequence. Therefore,

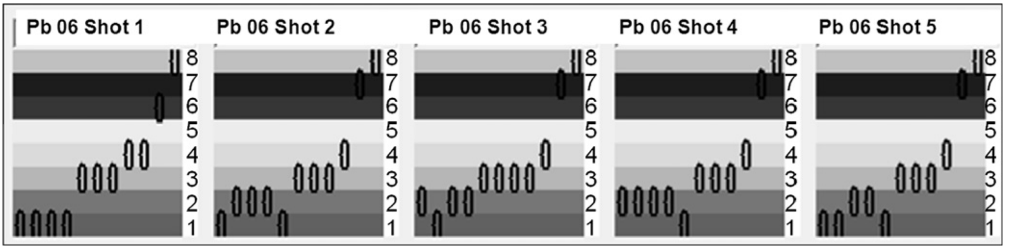

Fig. 10. Measurement points in the constituent phases of the shooting movements from the shots 1–5 of a participant with low to moderate experience concerning the required task.

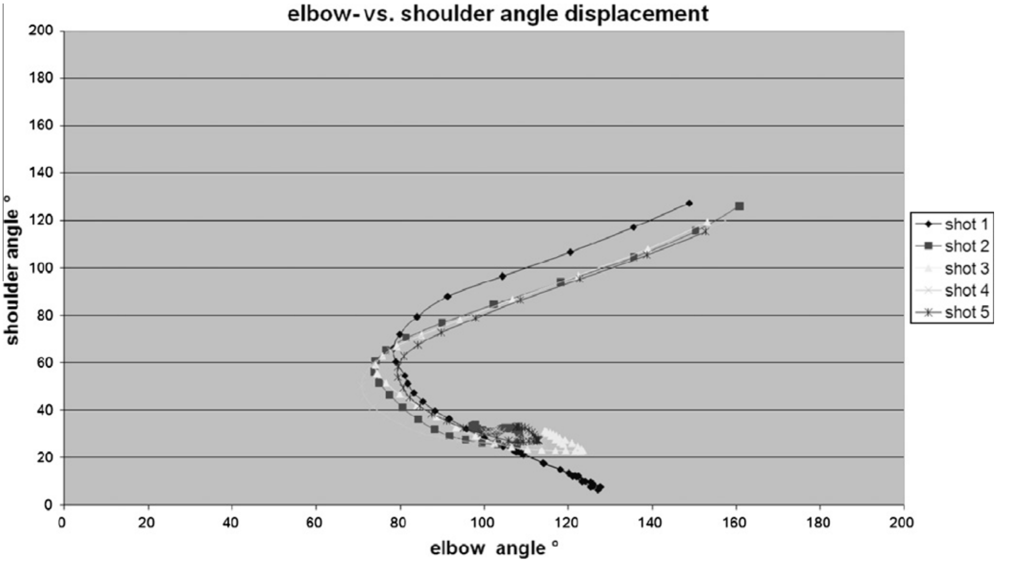

Fig. 11. Phase-portrait of the elbow angle displacement versus the shoulder angle displacement over the five shots from Participant 06 (low up to moderate experience concerning the criterion task).

omitting this phase suggests a quick and, probably uncontrolled launch. This finding is also shown by morphological descriptions of these shots from Participant 06: "With the extension of the knees the extension of the shooting arm begins as well (without an explicit ready-to-shoot-position)." Although, in the objectified morphological description, no explicit push-shot was detected even though the most repeated statement in the expert rating, paraphrased says, 'pushes the ball from the bottom up'. This statement also suggests that there is no 'ready-to-shoot-position' in the shooting action. Further confirmation is indicated in the phase-portrait of the elbow angle versus the shoulder angle (Fig. 11).

The phase-portrait does not show an explicit push-shot. However, the lack of the 'ready-to-shoot-position' – the direct transition from lifting up the ball to the execution of the shooting-action – can be recognized. At the beginning there is only an exiguous opening of the shoulder angle and a shallow transition with a subsequent more or less a steep increase of elbow and shoulder angles by actually opening at the same time. Two of the significant paraphrased statements of the basketball coaches concerning the shooting action of Participant 02 are: 'The extensions of legs and arms take place simultaneously' and 'The power is not best transferred from the feet/legs up to the upper body parts.'

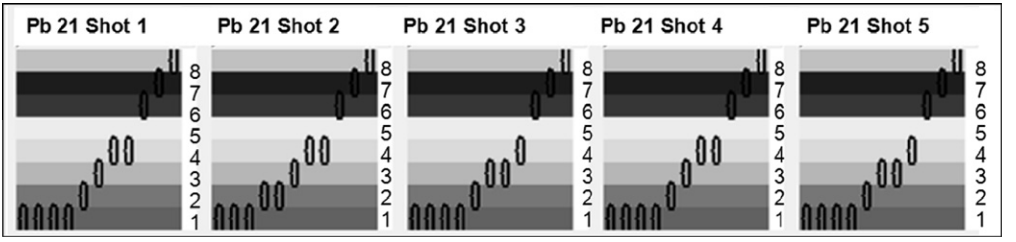

Fig. 12. Measurement points in the constituent phases of the shooting movements from the shots 1–5 of an expert (subject 21).

3.2.2.3. Participant 21. The movement progression of an expert only shows a minor variability in the preparatory movement phases combined with a high stability in the launching phases (for the phase diagrams of Participant 21, see Fig. 12). Looking at the whole sample (N = 21), this launching action, each with one measurement point in the last three phases, was very prevalent, although novice and advanced shooters mostly did not hold this pattern consistently for five shots.

This expert, subject 21, features an evolving progression of the free-throw movement phases which are based on each other. Beginning with a consistent starting position, his shooting movements are built up continuously over all the phases – except over the fifth phase, which has been identified as dysfunctional. In contrast to the phase characteristics of Participant 06, those of Participant 21 are much more similar. In the shooting movements of the expert, Participant 21, the variability takes place in the preparing phases. The 'neurons-analysis' shows for each shot (= trajectory combining eleven neurons), that the variations of the phases are based on clear variations in the attribute values. The shooting actions of Participant 21 were extraordinarily successful: he scored all of the five trials and shots 2–5 were 'swishes' (very precise shots where the ball goes through the rim without touching it). For this reason, it may be supposed, that in the characteristics of the phase diagrams from the shots of Participant 21, a kind of compensatory variability is revealed. Concerning the progression of Participant 21's shooting movement, he shows compensatory variability in the middle part of the movement action and even more during the preparing section of the entire movement, which is a new finding. From previous empirical studies of the basketball free-throw action, a functional or compensatory variability was reported to occur in the distal joints and at the end of the shooting movement. Apparently, by this kind of variability in the starting phases, phases 1–4, this shooter achieves the desired stability in the launching phases, phases 6–8.

In this context it is also interesting that the phase-portrait of the shots from this participant shows an s-shaped function between shoulder and knee velocity (cf. Fig. 13).

In the present sample, such a clearly defined function has only been seen in the movement pattern of Participant 21. There is an apparent coordinative structure between these two joints velocities.

3.2.2.4. Participant 20. Participant 20, an expert shooter, shows a very special kind of phase progression (see Fig. 14).

He rests for a relatively long time (for 4–5 measurement points) in the third movement phase ('genuflexion and ball-lifting'). The transition from the 'genuflexion and ball-lifting' into the sixth phase ('ready-to-shoot-position'), is indicated to happen most likely in an abrupt manner. The transition from the third phase into the real launching phases does not occur by passing through the fourth phase ('more pronounced knee flexion and ball-lifting'). In fact, he does not lift the ball simultaneously to the knee flexion. Participant 20 also shows a very individualized kinematic movement sequence in the objective verbal descriptions of the morphological shooting phases: "With knee flexion in motion and latent pushing forward of the hip, the raising of the ball starts" "The ball is situated at forehead level, while the upper part of the body is upright, the legs are almost completely extended and the heels are raised." Doing this, the pattern of 'more pronounced knee flexion and ball-lifting' (the forth movement phase) was not carried out by Participant 20. He fulfills the criteria (invariants) of the launching phases instead, already at the sixth measurement point.

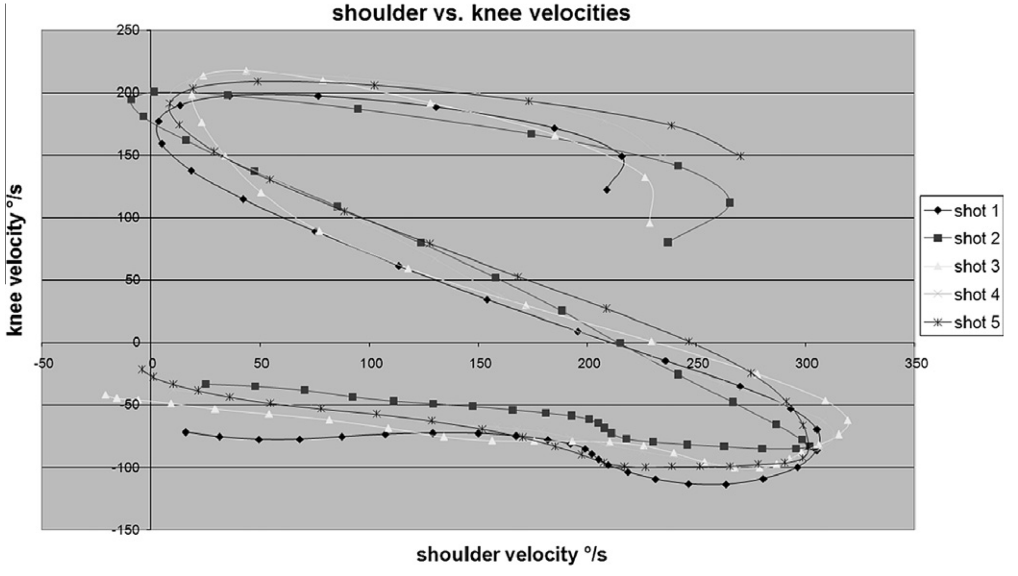

Fig. 13. Phase-portrait of the shoulder joint velocity versus the knee joint velocity from the Participant 21's five free-throw shots.

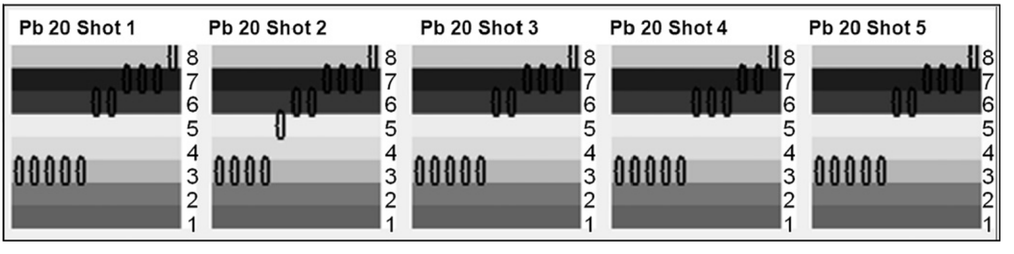

Fig. 14. Measurement points in the constituent phases of the shooting movements from the shots 1–5 of an expert.

Participant 20 always rests for two, in the fourth trial even three, measurement points in the 'ready-to-shoot-position' (phase 6). As we know, the 'ready-to-shoot-position' may serve as an important "check-point of the movement progression" (Loibl, 1978). As a consequence, it may be assumed that Participant 20 controls his movement progression very well. This assumption is confirmed by the intra-individual (inter-trial) velocity of ball displacement over the five shots of Participant 20 (Fig. 15).

In the figure it becomes very explicit that at the specific time, namely frame 31 (0.2 s before ball release), almost the same velocity value (0.24 up to 0.32 m/s [R = 0.08 m/s]) is obtained in all the five analyzed shots. Thus, the shooter managed to channelize the initial variability of the movement in such a way, that a relative constant value of launching velocity is generated.

Participant 20 shows the phenomenon of the two cycles of the free-throw movement very clearly. This becomes obvious in the phase-portrait of elbow versus shoulder angle (Fig. 16).

Until the 'ready-to-shoot-position' is reached (during the first cycle), there is some inter-trial variability in the coordination of these two joints. But in the second cycle, which directly follows the 'ready-to-shoot-position', the movement becomes much more consistent. So this shooter effectively profits from the 'ready-to-shoot-position' as a crucial function of control over his movement. Doing so, he obviously organizes his movement fundamentally differently than Participant 21. This is evident

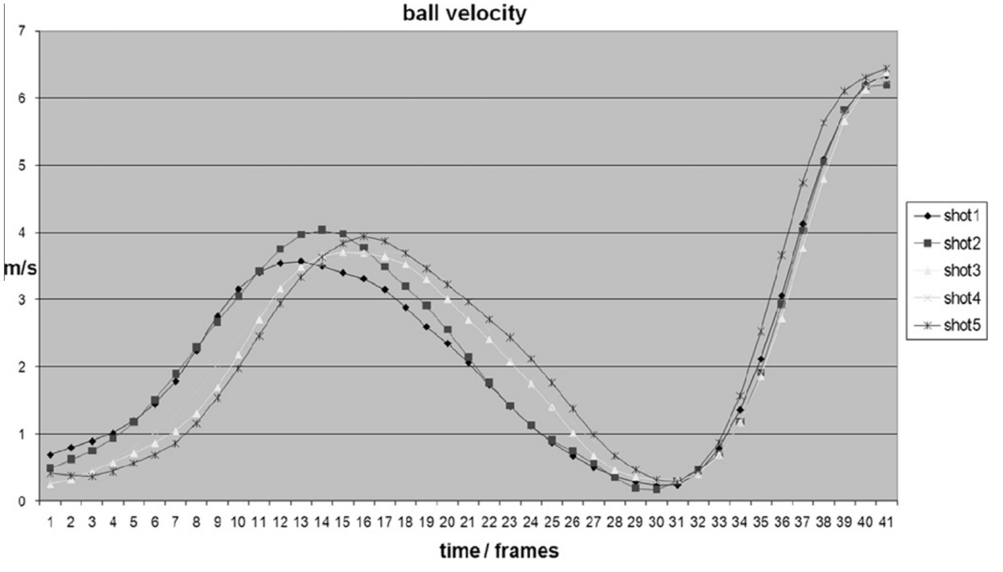

Fig. 15. Track speed of the ball during the five analyzed free-throw shots of Participant 20.

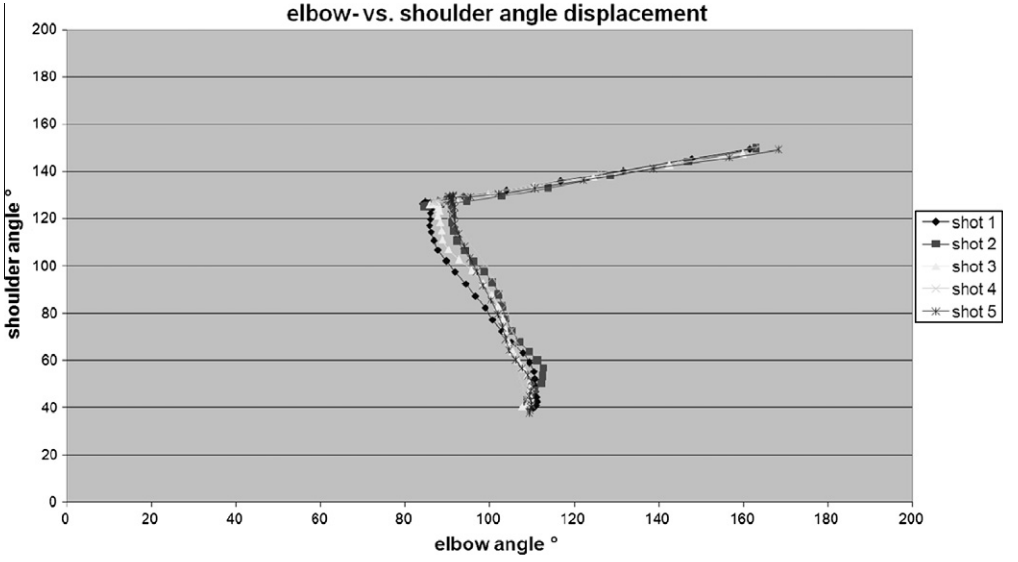

Fig. 16. Phase-portrait of the elbow angle displacement versus the shoulder angle displacement over the five shots from Participant 20 (expert shooter).

in the phase diagrams (compare Figs. 12 and 14) and in the function of shoulder versus knee velocity depicted in the phase-portraits (compare Figs. 13 and 17).

3.2.2.5. Participant 19. On the other hand, Participant 19, also an expert, shows a completely different functional organization of free-throw shooting movement (Fig. 18).

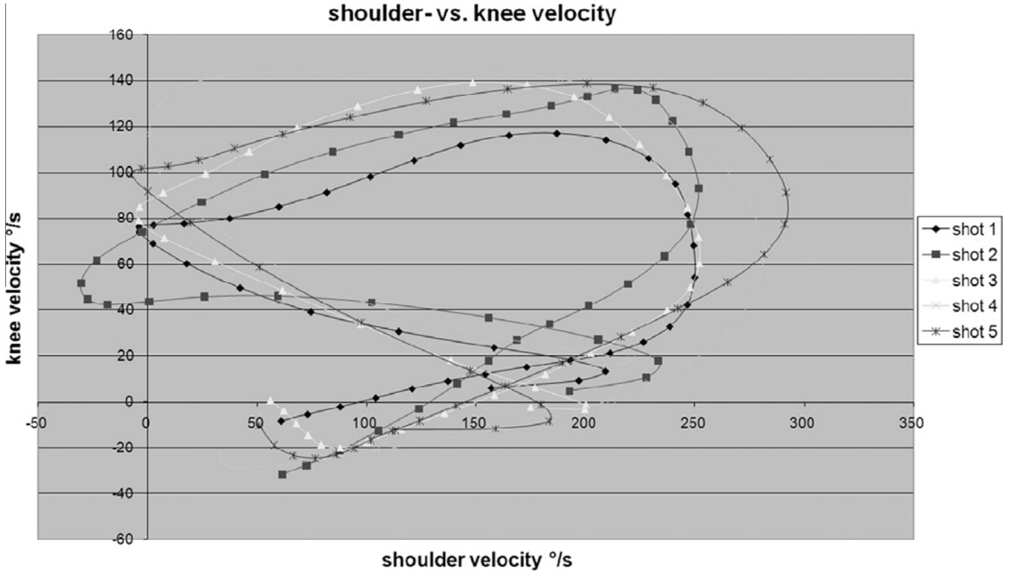

Fig. 17. Phase-portrait of the shoulder joint velocity versus the knee joint velocity from the Participant 20's five free-throw shots.

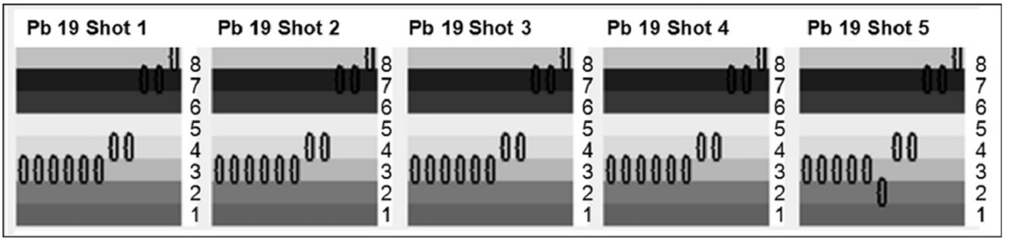

Fig. 18. Measurement points in the phases of the shooting-actions 1–5 of an excellent free-throw shooter. [1. 'score with touching the rim' – 2. 'swish' – 3. 'swish'– 4. 'score with touching the rim' – 5. 'touching the rim outside without scoring'].

Participant 19 reproduces the stability of his movement in the starting position and then he performs, in a classical sense, a ballistic movement where a 'perception–action' determined change is not scheduled anymore.

The shots of Participant 19 are successful in spite of the lack or unclearly shaped ready-to-shoot-position in his movement pattern. In the expert rating the basketball coaches evaluated his shooting action very positively. It seems that the proper ready-to-shoot-position here is substituted by a relatively long period in the seventh phase, execution of the shooting-action. To describe and evaluate the shots of Participant 19, the basketball-coaches used the following phrases (here written as paraphrases): "has a stable standing position"; "the wrist is bent"; "the wrist is remarkably well bent"; "the shooting-arm is (completely) extended"; "stability in the movement (performs always the same movement); "looseness in the movement"; "fluid movement"; "looks very calm"; "good control (of the ball/shot)"; "concentrates on the shot/basket"; "the power is transmitted very well from the feet to the hand to the ball" and "quick launch". Out of these paraphrases a shot is outlined, which is generally characterized by consistency as well as by a consequent execution of the direct shooting action.

In the whole sample, very diverse kinds of movement organization were identified. The experts showed entirely different movement organization 'strategies', which are harmonious (functional) in themselves and which allow for the particular free-throw shooter to solve the movement task successfully. There were also shooting patterns common for several shooters, like the launching with one measurement point in each of the last three movement phases. This launching pattern seems to be advantageous for many people, but nevertheless it is not the only possibility to realize a good free-throw shot, as has been shown.

4. Discussion

Previous movement pattern recognition studies with the basketball free-throw task as criterion often exclusively focused on the launching action without the preparing phase (the second cycle). The considered analyzed movement system consisted of the elbow and wrist joint of the shooting arm (Button et al., 2003) or the shoulder, elbow and wrist joint of the shooting arm (Robins et al., 2008). In the present investigation, the movement organization of basketball free-throw shots was regarded and analyzed as a whole. This procedure was possible by applying neural networks from the type DyCoN, to create a complex feature out of the joint angle measures of the whole kinematic chain. Throughout the diverse analyses, detailed information about the applied movement patterns, as well as about several phases of the entire movement was obtained. Consequently, the analysis with DyCoN proved to be particularly appropriate for the pattern recognition in movement analysis.

4.1. Individual movement patterns and organization types with differing functionalities

As was assumed on the basis of previous studies (Bingham et al., 1989; Button et al., 1998; Chow et al., 2007; Handford, 2006; Jaitner, 2002; Schöllhorn & Bauer, 1998a, 1988b; Schöllhorn et al. 2002), the individuality of human movement was confirmed once more by means of pattern recognition analyses.

By means of several participants, the function of the 'ready-to-shoot-position' as an important checkpoint of the whole motion-sequence, as Loibl (1978) pointed out, has been shown as well on the basis of the complex feature as in the triangulation of qualitative and quantitative data. Explicitly, using the example of Participant 20, it could be shown how the initial variability of the movement has been channelized after assuming the 'ready-to-shoot-position'. This is a finding which has already been established by Bootsma and van Wieringen (1990) on the basis of strokes in table tennis performed by highly skilled players. They exhibited a higher inter-trial variability at the beginning of the stroke motion than at the time of ball contact. Wollstein and Abernethy (1988) presented a similar finding on the basis of a squash forehand stroke performed by highly skilled players. Their participants exhibited relatively consistent intra-individual stroke specific and velocity specific foreswing movements, whereas the backswing movements varied significantly. In contrast to the cited studies, this phenomenon in the present study could be depicted by means of a complex feature and by several complementary data. Interestingly, this checkpoint has a very diverse relevance for the individual movement organization.

In fact, several very different kinds of movement organization have been observed, which obviously have their own functionality. The three most successful shooters showed considerably different movement organizations with different functionalities. Consequently, the individual imprint on the movement pattern in this study has been shown related to its own, obviously appropriate functionality, which fits well with the personal constraints of the athlete in question.

Basketball free-throw shooting is a widely artificial movement – an unnatural movement that has to be learned. The more interesting it is to find such deep individual imprints. Accordingly, a typical textbook technique which every athlete should aim for cannot be concluded.

4.2. Movement variability as an indicator of the skill level

Newell and Vaillancourt (2001) pointed out that the relation of movement variability and skill level in principal is determined by the confluence of constraints. They depicted the essential roles which in particular play the task demands. Thus, the findings of the present study have to be regarded as relevant only for the basketball free-throw shot and should be compared to other studies, where the basketball free-throw movement has been analyzed.

With the test of intra-individual stability of the shooting patterns, the stability of the applied movement patterns for the five shots has been detected. The finding of an overall increase of intra-individual pattern stability with increasing skill level is approved by the structure outlined by previous findings: The five poorest shooters showed a high variability in their movement patterns, thus the very beginners did not apply stable shooting patterns. Button et al. (2003) found a high variability in the elbow-wrist angle-angle function of basketball free-throw novice shooters. So, this finding of Button et al. (2003) has been confirmed with the present study regarding the whole kinematic chain. Nevertheless, Participant 06, also a poorer shooter, but with some experience in free-throws, showed maximum stability in the movement pattern. In this case, it is supposed that he is freezing the degrees of freedom for better control of his movement, like Bernstein (1967) assumed for the beginner in learning movement tasks. In the present study, maximum stability has been found in the three skill levels of novice, advanced and expertise shooters. In the sense of the dynamical systems theory it is supposed that in the learning process of a movement skill those stable states may represent attractors (Kelso, 1995). Until one has found the best fitting attractor to cope with the requested movement task, several phase transitions accompanied with fluctuations may occur. In many cases a higher intra-individual, inter-trial stability has been found particularly by the more successful shooters. Nevertheless, the four most successful shooters showed medium and submaximal stability in their movement patterns, which is interpreted as a kind of compensatory variability (cf. the case studies of the Participants 19, 20, and 21).

The instabilities which have been expected as functional or compensatory variability, occurred related to the phase progression in the preparatory phases (phases 1–4), respectively in the first cycle of the whole shooting movement (as, e.g., by Participant 21), whereas the phases which complete the movement are consistent over the last four measurement points. This is a new finding, however, it does not contradict the proximal–distal phenomenon, because rather than representing a comparison of the isolated angle measures, the found variability is based on the complex feature of the movement pattern. Admittedly, the proximal–distal phenomenon does not seem to characterize the skillful free-throw movement sufficiently. In fact, it has been shown that functional movement organization may have individually different regions of stability, respectively coordinative structures or action units.

Differences between men and women could not explicitly be worked out because the sample was not paralleled relating to men and women.

5. Summary and outlook

In the present study the free-throw movement has been analyzed over two cycles and over the whole kinematic chain. With the hierarchical concept of Dynamically Controlled Networks a complex feature of the basketball free-throw was operationalized for the very first time out of the articulation angle features of the whole kinematic chain of the participants' shooting-arm-side. Thereby, fundamental findings about the organization of free throw movement have been discovered. Such *individual* movement organization can also be supposed for other human movement skills. In this regard further research is needed.

Tests with DyCoN are proving the assumption of individual characteristics in movement patterns. It has been clearly shown that the movement organization is individually configured. Moreover, an identification of the skill level as well as a differentiated analysis of the movement phases has been possible to be carried out.

The triangulation provided additional insight into the coherency of the movement organization effectuating a basketball free-throw. By training several comparison networks and embedding the net analysis in a mixed approaches design of qualitative and quantitative data (triangulation), validation of the applied methods took place. A high stability of the DyCoN-networks was documented (for more details see Schmidt, 2010).

With further analysis, it is also possible to carry out a classification of the skill level on the basis of the identified movement pattern.

5.1. Classification of the skill level

For the purpose of typifying the shooting patterns according to the skill level, the trajectories network is calibrated with 20 obviously good and 20 obviously bad shooting patterns. Thus, data of unknown free-throw patterns can be tested according to their quality.

The classification of the skill level is a method which is possible to carry out and which is used to classify the free-throw data. The technological possibilities with the DyCoN exist and are reliable. But in the present study there are not enough data from expert shooters in order to calibrate a network sufficiently to make statements about movement behavior.

However, the employment of the last analysis has to be improved by generating additional data from more free-throw players and by developing a new training adjustment also recognizing the quality of rarely trained patterns by characterizing them with relevance and quality values. This way individually styled movement patterns are recognized as such.

5.2. Outlook

The movement organization turned out to be very individually different. With only seven expert shooters it is difficult to make statements on the functionality of movement organizations. Recommendations for individuals have to be developed under consideration of their own approaches. To get more differentiated information about the movement patterns of expert shooters, it is necessary to carry out further investigations with data exclusively from expert shooters. A new training adjustment also recognizing the quality of rarely trained patterns remains to be developed.

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