Sonification of Group Behavior for Analysis and Training of Sports Tactics

Oliver Höner, Thomas Hermann and Christian Grunow

***Abstract*— This paper presents a new application for auditory display, the use of sound to assist the analysis of tactics and tactical training in sports games. For a pilot study we have set up a system for the video recording and processing (i.e. tracking of the players and the ball) of tactical training cycles in handball. An auditory display was designed to meet the requirements for supporting and extending visual analysis of tactics, e.g. it allows to identify those players that deviate from a nominal tactical position, and it allows to value the degree of deviation. Sound examples for tactically correct and deviating group behavior in game situations are provided and discussed for the example of the 6:0-defense. We also discuss our intended psychophysical experiment for the validation of the method. For technical reasons, the display is not yet applicable in real-time but we aim towards an online interactive player feedback for tactical training.**

***Index Terms*— Interactive Sonification, Sports Games, Analysis of Tactics, Tactical Training, Data Analysis**

I. Introduction

Tactical phenomena are resounded throughout the land in the everyday discussions about sports games like handball, soccer, or basketball. For instance, after a lost game, many spectators may have observed, 'that the coach had chosen the wrong tactics'. In addition, 'in particular the young players were not well enough trained in tactics'; and 'the defense did not have their best day, because they have been too far away from the attackers'. At Bielefeld University, a cooperation has started between the Neuroinformatics Group and the Sport Science Group in order to provide a more profound basis for systematic analysis of such situations that go beyond the subjective everyday observations. In this project, a camera is used to track the location of all players and the ball in specific game situations, and the technique of sonification is used to support the analysis of the data.

II. Tactics in Sports Games

Given the task of observing tactical phenomena from a scientific and systematic perspective, the first step is to classify the role of tactics for the result of the game. According to Hohmann's structural model of complex performance in sports games [1], tactical abilities are one of the major factors of playing ability (besides physical condition and technique), which are responsible for the effectiveness and success in sports games.

Tactics represents a non-observable factor of playing ability, and implies short-term, situation-dependent problem solving processes under the constraint of the own playing ability, represented by the physical, motoric and psychological premises [1]. If tactics is seen according to this definition, as "planned action", then tactical actions can be discerned according to their function (e.g. offensive vs. defensive actions) and the number of involved players. As a consequence, in sports games a distinction is drawn between offensive and defensive tactics, and – according to the number of players that are directly responsible for the tactical behavior – between individual, group and team tactics [2].

The big sports games are characterized by extreme situational complexity, severely higher than in e.g. individual sports like cross-country skiing or cycling. For this reason, tactics is denoted a very high relevance for performance. The degree of relevancy for tactical performance is expected to become even more important in future, with the increasing condition and technical skills of top level players.

Different types of data acquisition are applied for the systematic and scientific observation of tactical processes in sports games. For instance, the quality of tactical decisions of single players can be analyzed via laboratory tests, where a subject has to solve simulated decision situations. Such decision tests can be extended by integrating the cognitive processes of the individual decision making into the analysis, e.g. by accessing methods like eye-tracking experiments, 'thinking aloud' protocols, spatial and temporal occlusion techniques, etc. [3]. For the analysis of group- or team tactical behavior, however, such decision tests are not practicable. To analyze this kind of team play, the commonly applied technique in sport science is game observation.

III. Game Observation

The observation and analysis of tactical group behavior in sports games is a rather complex process, both in sports game research and in practice. In top sports, it is an essential procedure for obtaining game relevant information about team play, both of the own team and the opponents.

On the highest level, two methods of game observation can be distinguished, which are rather complementary than concurrent [4]. The personalized analysis of subjective impressions comprises all kinds of observations, made for an analytical purpose but without a fixation of the observations. In contrast, standardized systematic observation relies on previously determined features that can be observed as objective as possible. This, however, systematically causes a fixation on the observation of the considered features. A common practice for the latter kind of game observation is the use of technical auxiliaries, since the perceptual load, the high temporal density of interactions and the differentiated action alternatives are typically exceeding the capacity of the observer (see [5], p. 37, also [6], p. 194).

Most of these techniques (e.g. video recordings) base on visual presentation of the information, which is in real time neither accessible to the coach (who usually follows the game) nor to the players. Visual observation is in principle limited by the properties of visual perception. It is extremely selective due to the limited temporal resolution and the perceptional focus. This motivates us to investigate alternative methods like for instance the auditory presentation of the data for supporting team play analysis.

IV. Sonification of Group Behavior in Sports Games

In extension to visual aids for analyzing sports games, this study develops an auditory display for the sonification of the players' activities. So far training in sports is very much related to the indirect advice of the coach – the communication channel between the coach and the players (given by his/her voice) is not broad enough to give a detailed feedback to all the individual players in real-time due to the speed of the game. A direct auditory feedback here is expected to help overcoming this limitation by providing a sound from which every player can infer the effect of his behavior with respect to the tactics of his team.

In the domain of communication in sports games, sound is specifically useful since (a) the visual channel of the players is already blocked, (b) the data type (time-variant patterns) matches the listening capabilities of our auditory system, (c) human listeners are very well able to interpret multi-stream mixtures of sounds. For instance, a symphony can be well experienced as 'a whole', integrating all the different instruments, while at the same time listeners keep attention to any musical instrument playing musically wrong or dissonant notes.

For this reasons, sonification for Sports Science offers not only a promising method in the context of technique training [7], but also diverse possibilities for the analysis – and relying thereon – the training of tactics. From the view of sonification, there are in principle no limitations with respect to the tactical situations. But it must be admitted that it will not be easy to create a nominal behavior for the case of very complex tactics (e.g. many different variants in offensive/defensive tactics), which is required if the approach is taken to use deviations from a nominal behavior as an input for the auditory display. For this reason, we will focus our attention to a clearly structured group tactical situation.

To validate the use of sonification for analyzing tactical behavior of sport teams in defense constellations we conduct a pilot study with the example of a 6:0-defense in handball. We will firstly establish a theoretical model for "optimal" behavior with nominal positions for each defender depending on the position of the attackers and the ball. Then, game situations will be recorded by a video camera located above the center of the sports hall. A tracking system (semi-)automatically follows the players and the ball and delivers (x, y)-coordinates at a frame rate of 25 Hz (within the pilot study, this analysis has to be done offline for technical reasons). The obtained data are then compared to the tactical expectations, obtained from employing the theoretical model. Deviations between the nominal and actual coordinate vector are used for the synthesis of the multi-stream auditory display, which will be optimized for fast detection of malpractice of the whole group and further allow to identify the specific players.

V. Pilot Study: Sonification of 6:0-Defense Behavior in Handball

A. *Nominal-Model for Optimal Defense Behavior*

A precondition for the analysis of tactical misbehavior is the knowledge of the correct behavior. In the case of the chosen situation of a 6:0-defense, a model behavior would describe the nominal positions of all 6 defenders as a function of the attackers position, the ball position and the time.

Construction of a nominal-model for optimal tactical behavior is a generic problem of sports game research. Even within relatively clearly structured defense systems (like the 6:0- instead of a 3:2:1-defense) the trainers' opinions about how to play it show variations. Three different approaches are taken in order to obtain a good basis for such a nominal value model, namely (a) computer simulation, (b) expert interviews, and (c) empirical analysis of data from correct behavior.

Our first approach (a) bases on a computer simulation of defense behavior in handball by Erdnüß [8] that computes a defense behavior on the basis of if-then rules extracted from trainer knowledge. Erdnüß intends to use her simulation for teaching defense behavior. Her simulation visualizes the trajectories of all defenders according to the played defense system and parameters like the step-out width to attackers in possession of the ball, see Fig. 1. For this application she has

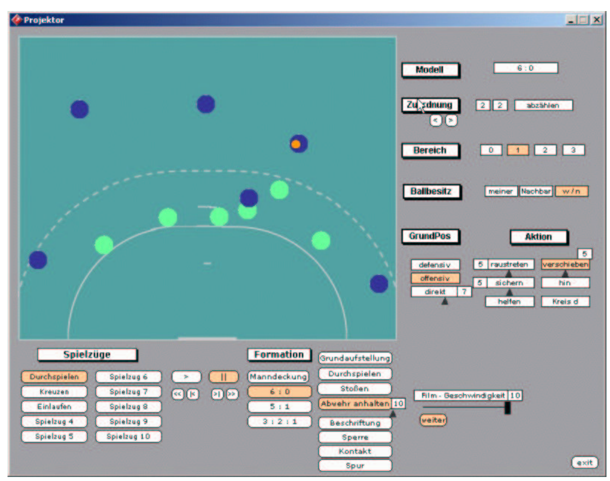

Fig. 1. Simulation of the Defense Behavior, Screenshot of the simulation program from Erdnüß (2003).

programmed standardized offense behaviors like for instance the "crossing" of the attackers on position 2 and 3.

The next approach (b) bases on interviews with experts (Volker Mudrow, the coach of the multiple German master TBV Lemgo and Renate Schubert, former coach of German national female junior teams). They were shown diagramed attack situations, simular to those used within the first approach, and asked to position the defenders dependent on the attackers' position and the ball position.

The last approach (c) computes the nominal positions from recorded real defense situations that were performed correctly. For this, the positions of the team of a 6:0-defense are used that are rated by coaches as successful. The data will then be used to average an empirically correct nominal behavior.

B. Video-Recording and Tracking of Players and the Ball

For the pilot project, we use a video camera to record defense situations. This leads to all sorts of problems generally encountered in video-based game observation, like the question about the best camera position, the tracking of players and the ball, removal of any distortions introduced by the optics, calibration, etc. The main cause for most of these problems lies in the big size of the handball field, compared to the relatively low ceiling of most sports halls. Although it is not required to observe the whole handball field, but only a 12 m long and 20 m wide rectangle, the angle is practically so large that extreme fish-eye lenses are necessary. The camera position was chosen to be downwards from the center of the rectangle, so that the z-position has an influence on the recorded positions as small as possible.

The sports hall we used had a height of 8 m, and the viewing angle of 120° was reached by a combined use of a semi-fisheye lens and a Fresnel lens. Figure 2 shows a typical camera view that obviously catches the whole 20 m width. While close to the image center, distortion effects are small, the distortion cannot be neglected far outside: the straight lines on the floor appear quite curved on the video. The spatial distortions are

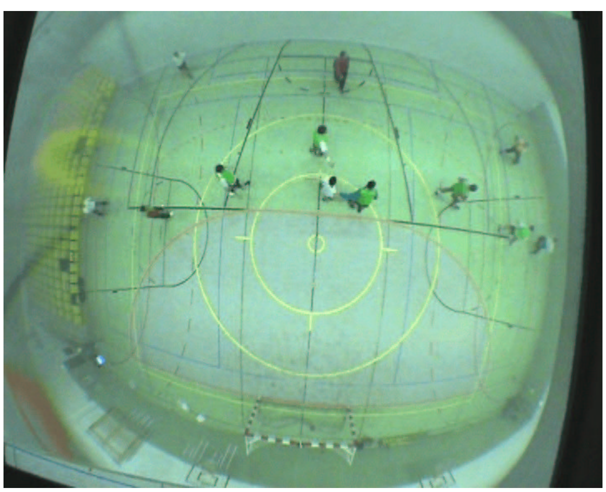

Fig. 2. The 6:0-defense recorded by a camera located above the field

removed by a calibration procedure in OPTIMAS from Media Cybernetics. For calibration, a regular grid of objects is put above the floor in 1.9 m height. The recorded positions are taken as reference data for the equalization procedure.

The top view offers the advantage of non-overlapping players compared to a side view. But here we encounter the problem that the players are rather small in the images: using a resolution of 720×576 pixels, each pixel represents a width of about 3 cm, so that a player's head is about 7×7 pixels large. The head positions are regarded as body center locations of the player, no orientation can be analyzed so far. To enhance the contrast of the small head area, the players are equipped with black bathing caps. When the heads of the players in the video to be tracked show enough contrast to the background, this facilitates the tracking procedure using our image analysis software MOTRANS [9]. This software enables us to track the positions of the players and the ball (semi-)automatically with 50 Hz (50 semi-frames per second). Tracking is currently done as a separate step, so that the current system is incapable of providing real-time auditory feedback.

C. Comparison between Nominal and Actual Positions

It is of crucial importance for the analysis of tactical behavior, what kind of deviations between the actual and the nominal model shall be regarded.

In this pilot study, the deviation is simply computed by the Euclidean distance between the tracked coordinates and the model coordinates of each player. This distance measure assumes an equal importance of deviations in all directions. Alternative distance measures could use different functions for the individual players. For instance, for the inner defenders the horizontal deviation is much more important than the vertical deviation, since any horizontal error offers a free shot. So a complete data set contains the 6×2 attackers coordinates (x,y), 6×2 defender coordinates, the 2 ball coordinates and the 6-dimensional distance vectors according to the model, and represents a 32-dimensional data point. To keep the model simple, any influences of position errors of neighboring defenders are neglected.

The relevance of deviations from the nominal position of a defender depends on his relative position to the ball. The ball position can therefore be used as a variable in the computation of the deviation. In Figure 3, the yellow light cone shows that defenders in close vicinity to the ball are regarded as very relevant, whereas errors of a defender on the other side are much less relevant. Such additional variables can be used to determine more features of the auditory representation and increase the amount of information that is portrayed by sound.

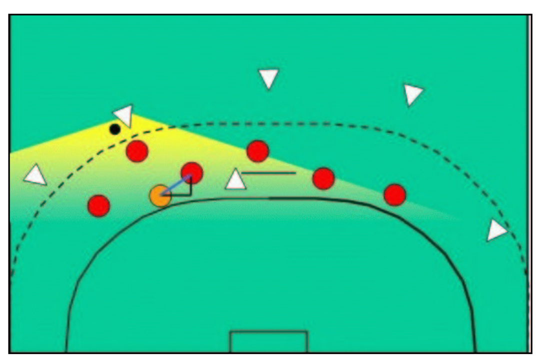

Fig. 3. Euclidean Distance (blue line) between an actual position (orange circle) and a nominal position (red circle) of the left-central defender. The intensity of yellow represents the relevance of the position.

However, for this pilot study, further possible extensions are omitted.

D. Sonification Design

The sonification shall provide the coach with two sorts of information: which player shows a deviating behavior from his nominal trajectory and in what degree. While visual inspection of the video would give a perceptual bias towards the player that the eyes focus on, the sonification has the potential to increase the awareness of the whole team behavior, rather than the behavior of a single player. These ideas inspire an auditory display that is a superposition of different auditory streams, one for each player, that merge together to a soundscape. Similarly to an orchestra piece, where the listener can both listen to the musical piece as a whole and to individual instruments, but at the same time remains attentive to any occurring misplay of any instrument, we expect the listener to make use of the same listening skills for the interpretation of the auditory display [1].

To support the identification of the individual players, different strategies are possible, like assigning different pitch, harmony, rhythm or timbre to them. We adopted to assign timbre to the players, since most listeners are more sensitive in discerning sound sources than in distinguishing musical attributes like harmony or pitch. Practically, we selected the domain of percussion sounds, since on the one hand these sounds have a short transient (attack phase) and are thus suited for the fast game situations faced in this context. On the other side, this domain offers a rich set of very well differing sounds, think of base drum, hi-hat, rattle, cowbell, etc.. Next, we need to determine how these sounds shall occur in the display according to the actual distance vector of errors. We assume that errors smaller than a threshold of about 20 cm are negligible for the tactical behavior. Below this threshold, the instruments are not played at all. A perfect tactics according to the model will thus be the sound of silence. Any deviations will be audible by the superposition of the instrument sounds.

As a first version, the instruments play a repetitive pattern whose rate is determined by the deviation, so that large deviations stand out in the display pretty well. In the context of model-based sonification [11], the data/rate connection can be achieved by using the model element of *Auditory Infomation Buckets*, first introduced in [12]. To support the identification of the associated player the sounds are assigned to the left (players 1-3) resp. right (players 4-6) audio channel, as seen from the perspective of the goal keeper. Sound examples are presented for some situations where the 6:0-defense is not stepping out enough towards the ball possessing attacker on our website [13], The applied sonification design uses the percussive instruments and both a level and rate mapping for the player's auditory stream. The isolated player samples are also provided on the website.

So far we have not used any other auditory variables like the pitch (resp. speed-up). These remain free for further extensions like the relevance discussed above. E.g. the sound level may be controlled by the importance of the player for the tactics. As an alternative approach we think about using musical motifs for each player that complement in such a way that the obtained sound for the optimal team behavior is harmonic, consonant, a nice and well sound. The more the players deviate from the tactics, the more the sound gets out of tune, resulting in out-of-tune sounds or wrong notes played by the instrument. In the selection of what note in the pattern for each player, and in the manner of misplay, lots of information can be put about the details of deviations. For instance deviations in the horizontal position could result in tuning errors while deviations along the vertical position could result in rhythmical errors. The higher complexity of musical motifs which are about one bar long with about 4-8 notes, together with the difference in timbre let assume a better identification of the corresponding player. The disadvantage, however, is that the latency increases since the playing parameters are on average for half a bar be determined in advance. Practical experiments will show if this is acceptable or even superior to the actually applied display. In all the discussed variants, however, the association from a player to an auditory stream must be learnt. However, such learning is acceptable, since it needs only be done once. Beyond the direct goals that the sonifications are tuned to, the sonification may offer the chance to detect typical patterns in the overall activity of the team, features which are so far more or less unobserved and unused for the analysis of tactics and game observation.

Obviously, the demonstrated sonification on the website is already able to transport the intended information. It can be perceived if a player or several players deviate from their nominal position, and to what degree. However, in order to assess this, perceptual studies are required.

E. Experimental Evaluation with Handball Coaches

We plan to conduct a cognitive psychological experiment to validate the use of sonification for understanding/analyzing tactical misbehavior. In this experiment we will show recorded scenes of a 6:0-defense to skilled handball coaches and ask them to value the tactical behavior as correct or wrong. In addition, the coaches are asked to identify the player(s) that behaved wrongly.

Experimental factors are the scene type (correct play vs. wrong play) and the presentation type (visual, auditory, combined audiovisual), which will be varied randomly. We act on the assumption that all three presentation types lead to a correct classification of misbehavior. In addition we assume that the visual and auditory information will complement so that the coaches will perform best in the audiovisual condition.

VI. Perspectives

The pilot study and the following experimental evaluation will provide the basis for the consideration of auditory display for tactical training. We are aiming at a real-time game observation that can be used for online feedback, and so as an interactive component for the training of tactics.

A prerequisite for this interactive use is the solution of the real-time video-tracking problem. An extension/optimization of the MOTRANS system used here is one candidate for

[1] see [10] on auditory perception.

this. A promising alternative are computer vision based game analysis systems which work on the basis of probabilistic models for player recognition, and that are able to deliver the overall constellation of the players [14]. Another possibility for obtaining the required data are non-vision systems, like for instance the Cairos system developed by the Fraunhofer Institute for Integrated Circuits [15] that uses miniaturized microwave emitters and receivers located on the corner of the field to measure the positions accurately.

The coach needs – in order to take profit of this new form of tactical training assistance – a clear idea about the optimal defenders' positions in relation to the attackers position and the ball position. An advantage of the approach presented here lies in the fact that for the application in tactical training no generally valid model for tactical behavior is needed, but that the system can easily be adapted to the specific needs and ideas of the coach. For instance, if a coach wants to tune the defense to a certain opponent, e.g. a team which frequently plays the "crossing", he just needs to provide nominal values for the defenders positions for them to cope with the attack. Afterwards, a series of "crossings" can be played against the 6:0-defense. The online-computed sonification can then be played to either all players in the sports hall, or to the individual players, allowing them to perceive how far their actual behavior deviates from the expected behavior. Even further, the online-training system could provide automatically generated signals when a certain threshold is exceeded, e.g. playing a verbal acclamation.

The long-term goal is to establish and investigate the use of real-time feedback systems involving human group behavior in an auditory display system for the purpose of training and improving coordination. Such real-time monitoring systems have various applications beyond tactical analysis and training in sports, e.g. for rehabilitation or for teaching choreography, or to be invented interactive auditory team games.

ACKNOWLEDGEMENT

We thank Arthur Steinmann for helping with the MOTRANS system and calibrating the radial distortions and Till Bovermann for test listening, good comments and help with the Pd synthesis. We very much thank Sandra Erdnüß for her assistance on the computer simulations!

REFERENCES

[1] A. Hohmann, *Zur Struktur der komplexen Sportspielleistung*, Hamburg, Czwalina, 1985.
[2] K. Roth, *Taktik im Sportspiel*, Hofmann, Schorndorf, 1989.
[3] O. Höner, *Entscheidungshandeln im Sportspiel Fußball - eine Analyse im Lichte der Rubikontheorie*, Sport und Buch Strauß, Köln, in press.
[4] A. Hohmann, M. Lames, and M. Letzelter, *Einführung in die Trainingswissenschaft*, Limpert, Wiebelsheim, 2002.
[5] M. Lames, *Systematische Spielbeobachtung*, Philippka, Münster, 1994.
[6] P. Wagner and K. Willimczik, "Beobachtung", in *Sozialwissenschaftliche Forschungsmethoden in der Sportwissenschaft*, R. Singer and K. Willimczik, Eds. Czwalina, Ahrensburg, 2002.
[7] A.O. Effenberg, "Zum Potential komplexer akustischer Bewegungsinformationen für die Technikansteuerung", *Leistungssport*, , no. 5, pp. 19–25, 2000.
[8] S. Erdnüß, "Modellierung und Simulation des Abwehrverhaltens im Hallenhandball", in *16th Collective Congress of the German Society of Sport Science*, Münster, 2003.
[9] Y. Jacobfeuerborn, D. Pollmann, A. Steinmann, D. Stössel, and B. Zeltwanger, "Motrans - ein automatisches bildverarbeitendes bewegungsanalysesystem", in *Sport und Informatik VI*, W.-D. Miethling and J. Perl, Eds., pp. 237–247. Sport und Buch Strauss, Köln, 1999.
[10] Al Bregman, *Auditory Scene Analysis: The Perceptual Organization of Sound*, MIT Press, Cambrigde Massachusetts, 1990.
[11] Thomas Hermann, *Sonification for Exploratory Data Analysis*, Ph.D. thesis, Bielefeld University, Bielefeld, 2 2002.
[12] Thomas Hermann, Mark H. Hansen, and Helge Ritter, "Sonification of Markov Chain Monte Carlo Simulations", in *Proc. of 7th Int. Conf. on Auditory Display*, Jarmo Hiipakka, N. Zacharov, and Tapio Takala, Eds., Helsinki University of Technology, 2001, ICAD, pp. 208–216, Laboratory of Acoustics and Audio Signal Processing and the Telecommunications Software and Multimedia Laboratory, `http://www.acoustics.hut.fi/icad2001/proceedings/index.htm`.
[13] Thomas Hermann, "Sonification for exploratory data analysis – demonstrations and sound examples", `http://www.techfak.uni-bielefeld.de/~thermann/projects/index.html`, 2002.
[14] G. Lashkia, N. Ochimachi, E. Nishida, and S. Hisamoto, "A team play analysis support system for soccer games", `http://kopernik.eos.uoguelph.ca/~zelek/vi2003/papers/S2/S2_lashkia_31.pdf`, 2003.
[15] Fraunhofer Institut für Integrierte Schaltungen, "Cairos-projekt", `http://www.iis.fraunhofer.de/ec/app/sport/cairos/index_d.html`, last seen 2003.

Oliver Höner, born in 1972 in Bad Oeynhausen, studied at Bielefeld University and received 1998 his final degree in Education, Sport Science and Mathematics. Since 1998 he is a member of the Sport Science department and in August 2003 he received Ph.D. with the thesis "Entscheidungshandeln im Sportspiel Fußball - eine Analyse im Lichte der Rubikontheorie" from the Faculty of Psychology and Sport Science, Bielefeld University. Today he works as a post doc in the Sports Science department (movement science group) and takes part in research projects on tactics in sports games, psychological aspects of instrumental physical activities, meta-theoretical and methodological foundations of the sport science. Since 2001 he has an additional occupation as soccer coach with the UEFA A-Level-License.

Thomas Hermann received a Masters in Physics 1997 from Bielefeld University working on femtosecond laser pulse analysis and frequency conversion. Afterwards, he joined the Neuroinformatics Group of the Faculty of Technology, Bielefeld University, where he started the research on sonification for exploration and process-monitoring of high-dimensional data. In 1998 he became a member of the Graduate Program "Task-Oriented Communication". He received a Ph.D. with the thesis "Sonification for Exploratory Data Analysis" in June 2002 and is currently continuing his research with a focus on interactive human-computer interfaces (e.g. audio-haptic controllers) and techniques for multi-modal data exploration.

Christian Grunow is sports student at the department of Sport Science, Bielefeld University. He is currently pursuing his Masters of Science in Sport Science with a thesis on analysis of tactics in handball, with a focus on the use of auditory display. Since 2000 he has an additional occupation as handball player in the 2nd German division.