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Biochemistry and Psychology of Chess and Classical Physical Exercise: Concurring or Conflicting Evidence?

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Abstract

Chess is a competitive sport in the classical meaning of the word. One of the most important factors for chess and sport competence is the accumulated time of training. In order to obtain a high level of competence, chess players and athletes alike must spend up 10 years of specific training.

In chess and classical sport energy needed for brain activity is first derived from glycogen stores in brain, muscles and liver and later from adipose tissue. Both, chess and classical sport rely on shared energy from glycogen and fat. When the brain needs additional energy, muscles and liver share energy with the brain. When muscles need additional energy, brain complies with the request of muscles. Energy expenditure, O2 uptake and CO2 production during chess games are similar to those obtained during a marathon. Mental and physical fatigue begin with similar metabolic states: deprivation of glycogen. During competitive chess, athletes must be in good physical condition.

Mental profiles of chess players and other athletes correlate with processes such as attention, conflict control, memory, motivation and recognition.

In chess there exists no gender-specific excellence; glycogen availability, however, is less developed in female chess players.

In chess and in classical sports, the brain, spinal cord, nerves and muscles cooperate in complete harmony. The brain commands everything: in chess the figures, in sport the cellular receptors (baro-, lactate-, gluco-, metabo-, chemo-, thermo-, respiratory-) "send" signals via eyes or metabolic changes to the brain. The brain then decides, what to do: in chess, the player moves a figure; in sports, muscles react according to demand.

Physical exercise or chess must be defined by a motor activity completely controlled by the central nervous system (CNS) in combination with a specific competence. In chess as well as in physical exercise, physical stress prepares brain to cognitive stimulation.

With respect to biochemical, physiological, neuronal and psychological aspects, chess is equals classical physical exercise and must be recognized as sport.

Keywords: Biochemistry; Psychology; Chess; Brain

Introduction

Classical definition of sport

The DOSB (national sports organization of Germany) expresses in its preamble: "The exercise of sport must have to its own end a specific motor activity depending on the kind of sport. This specific motor activity does not exist especially for mental games [1]".

Despite this exclusion of chess as sport, the German Chess Federation (DSB) has been accepted for more than 50 years as a member in the German Sports Federation (Deutscher Sportbund) and therefore also by the actual DOSB [2]. The membership in the DOSB entitles the DSB to receive financial support by the German Treasury.

In summary, the membership of the DSB in the DOSB is not clear as crystal, since a definite and widely accepted definition of "Sport" in Germany does not exist.

In spring 2014, the DOSB cancelled the financial support of the DSB with the argument, that chess as a mental game does not have as a purpose its own motor activity.

Common biochemical, physiological, neuronal and psychological fundamentals of chess and classical sport athletes are discussed to characterise chess as comparable with physical sport to secure the membership of the DSB in the DOSB.

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CNS Control of Physical Exercise

How much of physical exercise is physical and how much mental?

The is involved in every aspect of sport performance and is used to its fullest extent for maximal physical adaptation and performance.

To initiate skeletal muscle contractions voluntarily, action potentials arise in the motor cortex of the brain and are propagated down the spinal cord along upper motoneurons that synapse onto the lower motoneurons. Axons of the lower motoneurons leave the CNS and provide motor signals to particular groups of skeletal muscle fibers via neuromuscular junctions. Lower motoneurons and particular muscle fibers they innervate are called motor units [3]. The total number of fibers in man was never solidly estimated; On the basis of estimation of the muscle fiber numbers [4-8], an extrapolation with anthropometric data [9] results in circa 18×10^6 muscle fibers in man.

In addition to inducing contractions, CNS monitors the performance of muscles: Sensory receptors located in muscles, tendons, and joints in conjunction with afferent neurons, i.e. barosensors, chemosensors, metabosensors, thermosensors, respiratory sensors [10] send feedback information in form of action potentials to the CNS concerning muscle length, limb position, rate of movement, and contraction tension. This permits stimulation of maximally $18x10^6$ muscle fibres to be continuously and appropriately modified so that the actual performance matches the intended performance.

An interruption of this afferent sensory pathway, for example by a spinal cord injury, will result in a complete loss of kinaesthetic sense, i.e., a complete loss of muscle functionality.

Psychology of Physical Exercise

Lately, a growing interest in cognitive sport psychology and systematic study of mental processes in sports performers has been observed [11]. Mental processes of cognition usually expected in chess players have been studied in all sport specialities [12-14]. The mental processes include intelligence [15], expertise [16,17], perception [18], memory [19], anticipation [20], attention [21], mental imaging [11], judgement and decision making [22]. The most important factor for acquiring athletic skill in any sport discipline is the accumulated duration of special training [23].

Athletic Skill

Athletic skill is present, when players have a learnt ability to select and perform the correct technique as determined by demands of the situation. Decision making is the fundamental element of skill. When compared with less-skilled competitors, adult athletic experts are better at anticipating opponents' intentions based on partial information or advance cues, and can more consistently pick up minimal essential information needed for successful anticipation. Experts typically exhibit more effective visual search strategies and are faster and more accurate at recognizing and recalling typical patterns of play from memory [12].

Decision Making

Decision making depends on a step-by-step pattern from perception, evaluation, and selection to execution [24]. Knowledge bases and cognitive strategies underlying effective performance develop gradually as a result of extensive task-specific practice. Only experienced athletes are able to discriminate task-relevant from task-irrelevant information [14] and encode a greater number of alternative strategies faster. Experts dismiss many events as being highly improbable and attach a hierarchy of probabilities to remaining possibilities. They pick up task-relevant information to predict the best options available to the athlete.

Anticipation and Prediction

When compared with their less-skilled counterparts, adult experts are better at anticipating opponents intentions based on partial information or advance cues, and can more consistently pick up the minimal essential information needed for successful anticipation. Experts typically exhibit more effective visual search strategies and are faster and more accurate at recognizing and recalling typical patterns of play from memory [14,25].

Memory

The ability to recall athletes` positions from memory in offence and defence in a team play is dependent on memory [14].

The ability of elite players to recall both structured and unstructured patterns of play increases with age. Experienced adults demonstrate less error in recalling key player positions from typical patterns of play when compared to inexperienced players [26].

Mental Imagery

Action execution, imagery and observation are functionally equivalent for the brain [27]. They are based on the same action-specific and effector-specific motor representations [28]. Imagining the performance of a skill with no related overt actions is the most prevalent form of mental rehearsal used in athletics. World-class athletes and coaches use imagery thoroughly.

Imagery improves athletic performance when used alone and in conjunction with other cognitive techniques to improve learning and acquisition of motor and patterns of movement. Mental imagery also enhances the transfer of an acquired skill from practice to performance. It is most effective when combined with physical practice [29].

Conclusions

Expert performances and differences between experts and non-experts in physical sport depend on experience [30]. The skilled performers' superiority over the less skilled and novices is based on cognitive skills essential for effective anticipation and decision making processes. These skills include memory, anticipation, prediction, advance visual cue utilization, pattern recall and recognition, visual search behaviour and knowledge of situational probabilities, which together are referred to as "game intelligence" [31].

Significance of Motor and Mental Activity for the Definition of Sport

All competitive athletes - whether in football, dart or chess - must meet two requirements to compete successfully: First, they need a specific, long learned mental expertise in football as a team-sport, dart and chess as individual sport [32].

Secondly, all competitors need muscles for the physical part of the exercise.

When the corresponding mental expertise is available, the specific muscle fibres are activated according to the commands of the brain.

The muscle in itself is a “dumb” organ. It cannot work on its own, it cannot interpret metabolic signals coming from its receptors or events, it does not know, when to accelerate or to slow down. A muscle without control by the CNS is a muscle as bad off as after a spinal cord injury with a complete interruption of signalling from the CNS.

Balance of Energy Resources of Man during Mental and Physical Exercise

Three principal energy resources are available to humans for energy-dependent processes such as physical and mental stress situations: Creatine-phosphate and ATP present in cells, glycogen derived from blood glucose present in cells of muscle, liver and brain and some other organs [33], and fatty acids from adipose tissue.

The most important energy resources for daily occurring tasks as well as for mental and physical exercise is glycogen in brain [34], liver and muscle [35].

In man, glucose from glycogen in cells of liver, muscle and brain is available for glycolysis on demand within seconds [36]. A decrease of glucose in the blood by physical or mental stress leads to hydrolysis of glycogen delivering additional glucose [37]. When glucose in blood increases by nutrition, insulin enters the brain [38], liver and muscle to start glycogen-synthesis. During routine tasks of the day and In times when humans rely on anaerobic glycolysis for rapidly available fuel during short periods of intense mental and physical exertion, or when oxygen is limited [39], muscle and brain cells rely on anaerobic glycolysis. Anaerobic glycolysis produces energy 100times faster than aerobic respiration [39-42]. When glucose stores in muscle and brain are lowered, energy is gained from glycogen in liver and ß-oxidation of fatty acids in adipose tissue [40]. When energy is needed for continuously enduring physical exercise, even brain glucose is made available for muscles [43].

Spirometric analysis is applied in traditional sport, medical diagnosis and therapy [44] and in chess tournaments, where the respiratory exchange ratio is raised (>0.89) at the start of a chess competition and decreases during the game to 0.75, indicating that energy expenditure switched from carbohydrate to lipid oxidation [45]. The changes in substrate oxidation are caused by high cognitive demands and bring new insight into adaptations to mental strain.

Energy Expenditure of Brain and CNS for Mental and Physical Exercise

In chess as well as physical exercise, a series of metabolic, physicochemical and physical signals are on the way in order to move a hand. First of all, the activation pattern of motor cortex neurons does two things--it specifies for the peripheral motor system both what to do and how to do it [46]. The signals move from the brain cortex through the spinal cord to nerves to muscle cells.

There exist not only one signal during a physical movement of an extremity, but many more. When one biceps muscle is in motion during the execution of a chess move, then ca. 250000 muscle cells receive signals [4]. When half the 640 muscles of man are in motion during a marathon, then signals must reach 10 million muscle fibers. Signals are sent back from every muscle cell in motion to the brain, coming from baro-, lactate-, gluco-, metabo-, chemo-, thermo-, respiratory-, etc-receptors. The brain evaluates the signals and if needed, sends new signals, and so on and so on…. during every second of the whole marathon, or chess game!

The brain is an expensive tissue [47]. Grey brain matter needs double the energy of the rest of the brain [48] because of the high signalling-related energy demand in grey matter [49], for which 75% of the energy is necessary. With this level of energy expenditure, brain uses more energy than the human leg muscle during a marathon [50].

Physical Exercise during Competitive and Professional Chess

The laws of chess have been defined by the FIDE and were adopted at the 79th FIDE Congress at Dresden (Germany), November 2008 and came into force in July 2009 [51]. The FIDE specified, that during official chess competitions chess must be carried out using a physical chess board and 32 figures, which must be moved by the players. Additionally chess players must activate a special chess-clock after moving a chess piece and must personally write down the specified chess notation.

The involvement of physical exercise for chess tournaments is very evident. A professional chess expertise is obtained only after numerous hours of training. Gobet estimated [52], that after 50000 hours of training a very good chess player remembers at least 300000 chess positions so that he is able to recognize and then to compare and to act [53]. Training time is one of the most effective prognostic factor for achieving very good chess expertise [54] and not intelligence [54]. At least 5000-10000 hours of chess training time during the first ten years must be invested to reach professional chess competence [55,56], and this as early in life as possible [57].

In order to remember 50000-300000 chess positions, one has to assemble chess figures on the board at least two or three times per position. In summary the player positions at least 2-3 million chess figures in those ten years.

Chess games might last up to 7 hours (own experience). The actual chess Bundesliga (first division) of Germany for example carried out the last 3 games on three consecutive days (April 2014).

A very exciting form of chess is “blitz” chess, where the players have only 5 minutes time to complete the whole game, which might last for more than 50 moves. Many championships are carried out in blitz chess including world-championships. If a blitz chess tournament with 20 players is carried out during one evening, each player must move at least 1000 chess figures in addition to 1000 activation of the chess clock by finger pressure.

The first study of autonomic excitability and metabolic load of high-class chess players during an 18 day tournament was carried out in 1980 [58]. It was concluded, that the autonomic excitability and circulatory parameters (heart-rate, HR) during the competition of the chess players were completely comparable to other sportsmen of similar athletic performance. Later studies confirmed these observations on human circulatory parameters [59-61].

An increase in HR is the physiologic response of the human body to a change in physical or mental balance. In chess, the change of HR is connected to physical exercise and to specific events during the chess game and it reflects reactions, such as a blunder made by the opponent, by fluctuations subsequent to the move, by a sacrifice, a difficult defence, or even by the winning move [58,60]. These observations demonstrate that fluctuations of HR constitute a broad marker integrating a series of physical and mental variables.

Stress can be defined as the brain's response to any demand. Mental stress during physical exercise is a common experience for involved athletes, since it is intrinsically linked with an additional increase in HR. Mental stresses include normally occurring events, for example anxiety, anticipation and unexpected events [62,63], and cognitive exercises [62,64,65].

Physical Exercise to Improve Chess Expertise

HR measured during chess tournaments may include peaks in excess of 220/min with a single maximum of 223/min [59]. Not surprisingly, the peak HR is reached in the time pressure phase towards the end of the sixth hour of play [58]. The player's adrenaline level can reach eight times its normal value [59]. This sympathoadrenal response in chessplayers during chess-competitions closely resembles that during strenuous physical exercise [66]. Players experiencing HR in excess of 200/min and big increases in catecholamines are prone to make simple mistakes caused by extreme physical pressure. Players who are in good physical condition are able to cope better, having much lower HR, hardly any catecholamine increase and make fewer errors. Therefore chess expertise alone is insufficient to compete in chess tournaments. Chess players additionally need a corresponding physical fitness in order to endure exhausting chess plays.

The benefits of regular, but moderate physical exercise are well-established. The American College of Sports Medicine [67] states that physical exercise improves stress responses such as HR, blood pressure and release of stress hormones to physical and mental stress situations.

Exercise training is effective in improving physical skills [68], and it is also effective in reducing reactivity to psychological stress in terms of cognitive and somatic anxiety, behavioural anxiety during the anticipation of the stressor, and speed of HR recovery after stress.

Physical exercise and mental performance are closely and structurally related in natural conditions. Cognitive processes like trial and error [69] direct behavioural adjustments and sometimes result in behavioural novelties which allow the organism to cope with environmental pressures. Under long-lasting environmental changes, these behavioural adaptations can become hereditary [70]. There exist some brain-structures which are under genetic control and might evolve under selective pressures. These include brain size, the ratio of various brain structures to the whole brain, number and density of neurons in various parts of the brain and variations of neuronal circuitry.

Based on evidence from human and animal studies, there exists a genetic correlation between acute physical aerobic exercise and improvement of cognitive function and deceleration of deterioration of mental processes [71]. Fitness training with laboratory animals selectively enhances angiogenesis, synaptogenesis, neurogenesis in the hippocampus [72] and upregulates a number of neurotrophic factors. Aerobic exercise has significant positive effects on a large range of other cognitive functions including auditory and visual attention, motor control, spatial cognition and cognitive speed and spatial memory [73]. The largest positive effects were observed for executive control processes such as cognition, planning, scheduling, memory and multitasking [74].

Physical exercise facilitates neuroplasticity and enhances the capacity to respond to new demands with behavioural adaptations. Studies suggested that combining physical and cognitive training might result in a mutual enhancement of both interventions. Moreover, maintenance of neurocognitive benefits induced by physical exercise may be secured by increases in cardiovascular fitness [75]. Physical exercise may also prepare the brain to respond to cognitive stimulation [76]. A cognitive training then induces neuronal changes in specific networks associated with the trained skill.

Especially chess players will benefit from these resources, since the image obtained by a mental decision process is an exact match to that obtained by moving chess figures on the chess board. Consequently, chess training with computers would largely eliminate physical exercise and therefore preparation of the brain to cognitive stimulation.

Physiology and Biochemistry of Chess

Brain energy resources during chess

Brain energy sources are glycogen located in brain, liver and muscle and some other organs, and from adipose tissue located outside of the brain.

Glycogen stores in brain are small compared to liver and, especially muscles. Brain glycogen turns over rapidly [77] and contributes significantly to normal brain energy metabolism [78]. Glycogen is located almost entirely in astrocytes [79], the multitudinous cells in brain, which are distributed throughout the brain and mostly concentrated in fiber bundles and white matter [80,81].

Energy expenditure during chess

Neural information-processing of information is metabolically expensive. Although the human brain contributes only 2% to the body's weight, it accounts for 20% of its resting energy metabolism [82].

Most of the brain's energy is used for signalling processes, particularly Na+ transport. The brain has small energy reserves, and the safety margin between energy that can be generated and energy required for maximum activity is small. The supply of energy from glycogen limits the activity of neurons [83].

Since anaerobic energy from glycogen is obtained 100 times faster than aerobic energy, the brain is able to function in competitive chess at maximal performance only through anaerobic glycolysis. When lactate coming from anaerobic glycolysis is exhausted, the brain "talks" to adipose tissue and energy coming from ß-oxidationof fatty acids will be available [45].

Mental and Physical Fatigue

Fatigue is defined as the difficulty initiating or sustaining voluntary activities. Fatigue is considered a safety mechanism to prevent changes in metabolism that could result in irreversible damage to muscles and brain. Fatigue decreases the efficiency in performing tasks. Mental fatigue especially represents a potential failure to complete mental tasks [84,85].

Some metabolic causes of fatigue are decreases in creatine-phosphate in muscles, depletion of glycogen stores in brain, liver and muscle, hypoglycaemia in the body [86].

Mental fatigue is characterized by a slower cognitive performances and an impaired selective attention, due to reduced availability of fast energy from anaerobic glycolysis. The high level of mental effort introduces a greater level of impaired conflict control, which is of elemental importance for chess players confronted with continuously developing and changing conflicts throughout the game. Selective attention processes activate the anterior cingulated cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) [87] where structures of chess cognition are located [88]. General fatigue is associated with ACC and DLPFC [89,90]. Fatigue will therefore cause deteriorated cognitive performances through impaired functions in these brain regions with reduced attention and conflict control [86,91].

Chess Expertise

Mental profile of professional chess players

Expertise in chess enables the player to perform as an expert in a cognitive domain [92,93], which taps many cognitive processes [94], that are associated with intelligence, mental speed, spatial abilities, working memory [95-98], anticipation and transfer [99,100], perception [101,102], motivation [103] attention [104] and recognition [105].

Chess practice

Serious study alone is the strongest predictor of chess skill [54]. Chess players at the highest skill level expended about 5000 hours on serious study alone during their first decade of serious chess play.

A strong correlation exists between the number of hours, chess players have dedicated to chess and their current rating [52]. Unrated players reported more than 8000; rated but untitled players reported close to 12000; Fidemasters reported almost 20000 and the International Masters reported 28000 hours of dedication to chess.

Decision

Since expert chess players search less on the chess board than lower grade chess players, yet still manage to find strong chess moves, research attention has shifted from investigating search processes to the role of pattern recognition processes in move selection. Skilled players use their knowledge of chess configurations to recognize plausible moves for limited searching [106].

This result suggests that better players have a larger visual field on the chess board from which they can extract chess relationships and the experts are more likely to concentrate on relevant squares on the board [107].

In summary, experts rely on a rich network of chess patterns stored in long time memory (LTM) structures to give them a larger visual span when encoding chess positions more quickly than non-experts [108]. Within the first second of exposure to a new position, experts examine salient squares and simultaneously extract chess relationships critical to choosing good moves.

Memory [109]

The template theory [97] states, that human cognition comprises three main modules: a visuo-spatial imagery system, a short-term memory (STM), where information is briefly stored, and LTM, which consists both of structures indexing the information and the information itself. LTM consists of declarative knowledge (the 'what'), encoded as schemata, and of procedural knowledge (the 'how'), encoded as productions. Perceptual and conceptual information that can be used as units are called chunks, and constitute the building blocks out of which knowledge is constructed. These considerations are strengthened by the observation [96], that expert chessplayers find only a few chunks in random chess positions.

They encode chess information far more quickly and accurately than non-experts and it is estimated, that it takes about ten seconds to learn a new chunk in the LTM [110].

Skill does not reside in differences in STM capacity or encoding speed, but in the number of complex units such as chess positions held in LTM [111,112]. These complex units give access to information coming from the LTM such as what move to play, what plan to follow, and what evaluation to give to the position.

Based upon computer simulations with the computer program MAPP, it was calculated, that one needed to acquire from 10,000 to 100,000 patterns to reach master level in chess [110]. Computer simulations with the computer program CHREST show that at least 300,000 complex units are required to reach grandmaster level [52].

Intelligence

Does chess need intelligence? [55]

In contrast to contrary claims [102], world-class chess players have no exceptional intellectual abilities [113]. This finding has been confirmed several times [55,114].

Recently, the role of intelligence in chess was extended and specialized [115,116]. Six variables were identified:

- The age entering the chess club
- The number of tournament games
- The emotion expression control
- the numerical intelligence
- The actual age and finally
- The chess-related performance motivation

which account for ca. 60% of the variability of the ELO-rankings (derived by the ELO-formular used to calculate the relative skill of chess players from results achieved in official chess tournaments), showing that playing strength in chess can be best predicted by domain-specific practice.

It is concluded, that expert chess players display significantly higher selective intelligence than controls and their playing strength is related to the selective intelligence level. In addition, by using the extended expert–novice paradigm (comparing experts with novices of different intelligence levels) it has been found that both, expertise and intelligence have an impact on the performance in expertise-related tasks [115]. It is presumed, that expertise in chess play does not stand in isolation from selective intelligence [116,117].

Chess and Gender

There exists no gender specific intellectual performance in humans for chess playing despite several different opinions [102,118-124]. Since both women and men use glycogen from brain liver and muscle for fast energy during physical stress and during chess playing, mental fatigue occurs earlier in women [125,126], because their body glycogen content is lower if compared to men due to hormonal conditions [127-131] and chess demand for fast energy for women is equal to men. This would indeed lower speed of conflict control at an earlier time point for women during a chess game.

Nevertheless, the regional, national, continental, World and Olympic Championships in chess are open for men and women and are often carried out with both men and women In addition, special women-leagues exist in many countries, mostly with the aim to establish and support regular chess playing by women.

Definition of Sport

Sport is a regulated form of physical, neuromuscular and mental activity organized as a contest between two or more participants for the purpose of determining a winner by fair and ethical means [2,132].

The criteria by which the DOSB limits its acceptance of membership (see Introduction) cannot be applied for this purpose [133]. A specific motor activity is by no means an end in itself, but always has been beyond that means for reaching higher-ranking purposes. During the evolution of mankind, physical activity was absolutely necessary for survival. In modern times, physical activity in the form of sport is carried out for countless purposes including amusement, competition, entertainment, health, money, socialisation and so on.

Therefore this definition of sport is suggested: (Table 1)

1. Organized conductance of sport
2. Rules
3. Temporally and locally limited in scale
4. Use of technical tools
5. Physical, mental and neural activity
6. Conservation and promotion of health
7. Usefulness for education
8. Gratification of human play instinct
9. Game
10. Body and mental training
11. Teamsport
12. Availability for professional sport
13. Competition
14. Orientation toward maximum performance

Administration and Organisation	Sport (Soccer)	Chess	References	
			Sport	Chess
Member of DOSB	+	+	[1]	[1]
Organized conductance of sport	+	+	[1]	[1]
Rules	+	+	[1]	[1]
Temporally and locally limited scale	+	+	[2]	[2]
Use of technical tools	+	+	[2]	[2]
Body and mind				
Physical activity	+	+	[1]	[51]
Mental activity	+	+	[1]	[1]
Conservation and promotion of health	+	+	[1]	[1]
Useful for education	+	+	[1]	[1]
Gratification of human play instinct	+	+	[1]	[1]
Game	+	+	[1]	[1]
Physical and mental training	+	+	[1]	[1]
Teamsport	+	+	[1]	[1]
Professionalism				
Availability for professional sport	+	+	[2]	[2]
Competition	+	+	[1]	[51]

Orientation toward maximum performance	+	+	[1]	[1]
Energy				
Glycogen from brain	+	+	[34]	[34]
Glycogen from Liver	+	+	[35]	[35]
Glycogen from muscle	+	+	[35]	[35]
Adipose tissue	+	+	[40]	[40]
Brain, nerves				
Control of activity	+	+	[3]	[3]
Signaling by brain, spinal cord and nerves	+	+	[3]	[3]
Cardio-respiratory system				
HR	+	+	[67]	[58]
Blood pressure	+	+	[67]	[58]
VO2	+	+	[44]	[58]
Respiratory quotient	+	+	[44]	[45]
Hormones				
Catecholamines	+	+	[66]	[58]
Mental Performance				
Anticipation	+	+	[20]	[99]
Attention	+	+	[21]	[87]
Conflict control	+	+	[22]	[106]
Decision	+	+	[22]	[106]
Expertise	+	+	[16]	[116]
Images	+	+	[11]	[112]
Intelligence	+	+	[15]	[115]
Memory	+	+	[14]	[101]
Motivation	+	+	[15]	[103]
Perception	+	+	[18]	[101]
Prediction	+	+	[25]	[30]
Recognition	+	+	[12]	[30]
Training time	+	+	[23]	[54]

Table 1: Summary of concordance between chess and classical sport.

Conclusion

Competitive chess is equal to classical sport with regard to physical, mental and neuronal activity, effects on conservation and promotion of mental and physical health as well as on professional, educational and recreational human needs.

During chess and physical sport, brain commands every muscle action, which moves a finger, a leg or arm, etc. The expert athlete has gained a specific mental and more or less a physical skill by a specific training period of many years. In brain, prior to the initiation of any muscle contraction, a series of neuronal signals occur as a consequence of corresponding signals arriving from muscle cells in the brain and which are expressed as mental procedures such as anticipation, prediction, conflict control, and finally decision. The decision is supported by a correspondingly specific memory including mental images. As a result of the cooperative expert work of brain and muscle, a deciphered physical movement results such as a specific movement of a chess figure on the chess board or of a thrown javelin.

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