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# Higher psycho-physiological refinement in world-class Norwegian athletes: brain measures of performance capacity

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**This study tested the hypothesis that the degree of psycho-physiological development is related to performance level in world-class athletes. We compared physiological and psychological patterns of 33 Norwegian world-class athletes to patterns in 33 average performing athletes. The subjects were matched for gender, age, and type of sport. Electroencephalography activity was recorded to measure brain integration; skin conductance was recorded to measure habituation to a loud stimulus; and paper-and-pencil tests were given to assess self-development, moral development, and frequency of peak experiences. A factor analysis (varimax rotation) reduced the eight variables to three factors that together accounted for 65.3% of the total variance: (1) physiological integration – brain integration and habituation rates, (2) self- and moral development, and (3) peak experiences. A MANOVA conducted on the factor scores showed a significant main effect for the experimental group collapsing across the three factors ($P < 0.0001$). Individual ANOVAs showed significantly higher values for development ($P = 0.021$) and physiological integration ($P < 0.0001$) factor scores for the world-class athletes. The above measures can be seen as different expressions of an underlying dimension – human development. These data support the concept that higher psycho-physiological growth underlies higher performance.**

Athletes, who compete at the highest level, invest in general around 1000 training hours a year in order to be prepared for upcoming challenges. Typically, at the top level of any sport there are many athletes who have the physical fitness and the physical skills for being a winner. In this scenario, it is psychological skills and capabilities that determine who will be able to best cope with the pressure of competing at the elite level (Hardy & Gould, 1996).

One study on mental links to excellence concluded that athletes had their technical and physical skills honed to perfection for years before becoming world champions, but they had not yet learned how to hold their best focus in important competitions (Orlick & Partington, 1988). These athletes said that it was not until their focusing skills were refined that their dreams of winning became a reality. Jimmy Conners, an athlete known for his mental toughness, has often stated that professional tennis is 95% mental (Weinberg & Gould, 1995). Thus, it is important to illuminate the mental aspect that appears to give athletes the competitive edge.

## Self-development

The research reported here is part of a comprehensive investigation of the relationship of self-development and high performance in world-class athletes and top-level managers (Harung et al., 1996, 2009; Harung, 1999). Sense-of-self underlies how we make meaning of daily experiences, and is reflected in our success of planning, thinking, and acting. Levels of self-development are characterized by an increasingly expanded awareness, and range from ego-centric (pre-conventional), to socio-centric (conventional), to world centric (post-conventional), to ego transcendence (unitive level and peak experience) perspectives on life (Loevinger, 1976; Loevinger et al., 1985; Cook-Greuter, 1999, 2000). Measurements of stages of self-development also directly reflect increases in cognitive complexity and flexibility, that is, in more efficient brain functioning.

With self-development there is an enhancement of a person's capacity to make meaning of experience and to perform consciously. This ability can be illustrated by contrasting the personal characteristics of conventional development (about 80% of today's adult population; Torbert, 1991; Cook-Greuter, 1999, 2000) with post-conventional development (about 9% of adult population): from path following to path finding; from dependence to greater autonomy; from narrow craft perspective to more holistic comprehension; from unilateral control to collaboration; from reactive to proactive and preventive; from short-term to long-term perspective; from ambivalence to feedback to embracing feedback; from resistance to innovation; from win–lose to win–win interpersonal strategies; from focus on problem solution to focus on process and problem finding; and from extrinsic motivation (winning, money, power, fame) to intrinsic motivation (self-improvement and searching for meaning or peak experiences; Loevinger, 1976; Cook-Greuter, 2000; Rooke & Torbert, 2005).

The later the stage of individual development, the more sources of input (internal and external) a person can incorporate, digest, and orchestrate to their advantage (Cook-Greuter, 1999, 2000). This progression also applies to the peak or ego transcendent experiences – which are glimpses of higher consciousness lying beyond the above self-developmental stages (Alexander et al., 1990; Harung et al., 1996). Our former research with 22 world-class performers in a wide range of professions reported, "an association between world-class performance and more frequent experiences of an expanded, alert, and settled state of consciousness, even while engaged in dynamic activity" (Harung et al., 1996). Peak experiences bring with them such qualities as inner silence and deep relaxation amidst dynamic activity, ease of functioning and effortless action, playfulness, inner happiness, broad awareness combined with sharp focus, frequent luck or fortunate coincidences, reliable intuition, and sustainable performance on a high level (Maslow, 1971; Harung et al., 1996, 2009; Alsgaard, 2008).

To get a comprehensive picture of self-developmental, we also measured related psychological and physiological variables that are robust, well documented, and simple to administer. First, moral development in athletes is a highly relevant topic as the many recent doping scandals in the United States and in professional cycling indicate. Second, peak experiences have been found to relate to mature self-development and to peak performance (Maslow, 1968; Harung et al., 1996, 2009). Third, the speed of habituation to a loud sound (i.e., the time needed to start ignoring an irrelevant sound) indicates the athlete's ability to remain focused on what is relevant for success in his or her performance. Fourth, as we shall see, the integration of the electrical brain wave activity using electroencephalography (EEG) also correlates to top performance.

## Brain patterns in skilled performance

EEG has been recorded in high-performing athletes. EEG recording is non-invasive, relatively non-interfering with the sports event, and has excellent time resolution (millisecond recordings). Most research has been conducted on self-paced sports, such as rifle and pistol marksmanship (Hatfield et al., 1982), archery (Salazar et al., 1990), and golf putting (Crews & Landers, 1999). That research focused on EEG activity over temporal leads, which are responsible for adding details of experience. Before pulling a trigger, releasing an arrow, or hitting the golf ball, left temporal activity was lower, suggesting "economy" of effort – decreased intentional demand and less cognitive interference with motor planning and execution. While expert marksmen had lower cortical activation during target shooting, relative to controls marksmen, there were no cortical differences between groups during a spatial and verbal task (Haufler et al., 2000). Thus, brain changes in athletes are reported *during challenge* with which they are highly practiced.

The above research is task specific. Brain differences are seen during sports but there were no differences between trained athletes and controls during cognitive tasks. Another study looked at non-specific changes in brain functioning during training. Alpha EEG, a signature of restful brain activity, was recorded in frontal, central, parietal, and temporal areas over 3 months of training (Kerick et al., 2004). This study reported widespread increases in alpha at all sensors over the training period. Increases in global alpha are consistent with the idea of "efficiency of movement," "minimal effort," and "economy of effort" reported in skilled performers (Hatfield et al., 2004).

## Brain Integration Scale

The Brain Integration Scale, which is used in the present study, is also a measure of non-specific brain functioning. The Brain Integration Scale includes three brain measures calculated from EEG recorded during paired reaction time tasks (Travis et al., 2002). These three measures are

(1) *Broadband (6–40 Hz) frontal (F3–F4) coherence*, a measure of coordinated functioning of frontal executive brain areas;
(2) *Higher alpha and lower gamma frontal and central EEG power*, a processing style characterized by inner directedness (alpha EEG) and less absorption in outer boundaries (gamma EEG);
(3) *More appropriate cortical preparatory response*, a measure of efficiency of applying mental and motor resources to the task. This is quantified by the difference in the amplitude of the late con-

tingent negative variation (CNV) at frontal and central sites during a simple and a choice paired reaction-time task.

High levels of brain integration are correlated with higher levels of moral reasoning, greater emotional stability, and decreased anxiety (Travis et al., 2004).

### Speed of habituation to a loud stimulus

The skin potential response is an automatic marker of stimuli that are novel, significant, or deviant. The response itself has survival and performance value. However, once the stimulus is no longer novel, the body does not need to continue to respond. This is habituation. Habituation of response allows the body to conserve resources and to allocate attention to other tasks that are more salient.

### Moral development

Gibbs details four stages of moral reasoning: (1) unilateral and physicalistic – rules determine your behavior; (2) exchanging and instrumental – a consideration of consequences determines your actions; (3) mutual and pro-social – concern for the integrity of the individual determines your actions; and (4) systemic and standard – concern for the larger societal consequences and benefits of your actions. More abstract levels of moral reasoning emerge developmentally and parallel growth in cognitive development, and in self-development (Gibbs et al., 1990, 1992).

Moral development and sport have received attention due to considerable unethical behavior amongst athletes (Shields & Bredemeier, 2001; Long et al., 2006). Shields and Bredemeier write "At one time it was widely believed that sport was valuable because it develops the character of its participants, a belief that is no longer so widely shared" (p. 598). They report on several studies that show that the level of moral reasoning in professional basketball players was lower than in non-athletes. For instance, Long et al. (2006) studied elite team players and found that they generally were associated with low levels of moral reasoning.

### Survey of Peak Experiences

This measure has been developed over 25 years based on ego transcendence experiences that are beyond the endpoint of development – self-actualization – normally described by modern social sciences (Alexander et al., 1990; Harung et al., 1996). Maslow (1968) and Harung et al. (1996) reported that peak experiences are associated with peak performance. Ego transcendence – in our model – involves the experience of "Transcendental Consciousness", the most basic and expanded level of the mind, a state of "restful alertness" and "inner wakefulness" (Maharishi Mahesh Yogi, 1963, 1969; Cook-Greuter, 2000; Travis & Pearson, 2000).

### Self-development as the causal variable

A number of authors write that higher levels of self-development are a predictor of enhanced performance, leadership ability, and quality of life (e.g., Torbert, 1991; Harung et al., 1996, 2009; Rooke & Torbert, 2005). Extensive research shows that self-development is rare after the age of 17–20 (Piaget, 1972; Loevinger et al., 1985; Chandler et al., 2005); that such growth is generally not affected by higher education, which frequently involves competitive sports (Loevinger et al., 1985; Cook-Greuter, 1999); and that adults end up at a wide range of growth stages (Loevinger et al., 1985; Rooke & Torbert, 2005). Of course, sport activity may cause a developmental shift in children and even in adults. Yet, in conclusion, self-development appears to be the causal variable that may be a key inner factor underlying outer success in any field of life, all other factors being similar, i.e., in sport physical fitness and technical skills being similar.

In this study, we apply several psychological and physiological measures to peak-performing and average-performing athletes. We studied athletes because their competitive performance is a reliable classification of their level of excellence. By constantly breaking performance boundaries, world-class athletes may play an important role in bringing individuals and society in general to higher levels of accomplishment.

We hypothesized that athletes who have excelled in competition, in comparison to athletes who have not reached the top, should have higher scores on the Brain Integration Scale and on a measure of habituation to irrelevant stimuli; higher score on self-development and moral development; and more frequent peak experiences. We also carried out an in-depth interview of both groups, but this research will be reported later elsewhere.

## Method

### Subjects

The National Olympic Training Center (Olympiatoppen) in Norway and the Norwegian School of Sport Sciences (Norges Idrettshøgskole) selected 59 athletes who met three criteria: (1) placing among the 10 best performers in major competitions (Olympic Games, World Championships, World Cup, or similar) for at least *three* seasons; (2) normally being active on the top level within the last 5 years, and (3) at least 25 years of age. Out of this group, 33 individuals agreed to participate in the study. They were the world-class performance group and included 10 females and 23 males, average age of 34.0 ± 1.2 years.

The authors then selected 33 control athletes who had been active in training and competition at the senior level for at least three seasons, but did not normally place amongst the top 50% in the Norwegian Championships. This group, called the comparison group, also contained 10 females and 23 males, average age of 34.8 ± 1.3 years.

In addition to age and gender, the world-class and comparison athletes were matched for type of sport: (1) endurance sports (e.g., cross country skiing, orienteering,[1] biathlon, and long-distance running) (2) technical sports (e.g., down-hill skiing, shooting, and offshore boat racing), and (3) team sports (soccer and handball). Seven world-class athletes competed in cross country skiing and seven in orienteering. Three top performers competed in kayaking; two competed in running, skating, soccer, and free style swimming. One participated in combined Nordic, Tae Kwando, offshore boat racing, shooting, biathlon, handball, down-hill skiing, and rowing.

### Procedure

Athletes came in for 2 h of testing. First, they completed a consent form. They continued filling out the three psychological tests while physiological sensors were applied. Thirty-two EEG-active sensors were applied using the BIOSEMI ActiveTwo system (http://www.biosemi.com). Linked ears signals were also measured for calculating an average ears reference offline. Brainwaves were digitized on line at 256 points/s, with no high- or low-frequency filters, and stored for later analyses using Brain Vision Analyzer. To measure skin potential, an Ag/AgCl sensor was attached to the palm of the hand, using the saline and Unibase recipe recommended by Fowles et al. (1981). This sensor was referenced to a sensor on the forearm after first abrading the site, and using EC2 crème. Following application of sensors, the athletes were given three computerized tasks while their physiological and performance data were recorded.

### EEG protocol

EEG was recorded during two paired reaction-time tasks, CNV tasks. CNV is an event-related potential occurring between a warning stimulus (S1) and a second imperative stimulus (S2) requiring a response (Walter et al., 1964). Early CNV, measured in the 500–800 ms window after S1, reflects automatic, orienting processes (Tecce & Cattanach, 1993). Late CNV, measured in the 200 ms window before S2, reflects proactive preparatory processes, including mobilization of motor (Brunia, 1988; van Boxtel & Brunia, 1994), perceptual, cognitive, and attentional resources (Tecce & Cattanach, 1993). Different patterns in late CNV amplitudes during simple and choice tasks differentiated self-development levels in previous work (Travis et al., 2002).

The first CNV task was a 3-min paired simple reaction-time task – a warning asterisk (150 ms duration, 1 cm in height) in the center of a computer screen, followed 1.5 s later by a continuous computer-generated tone (1200 Hz, 85 dB). Subjects were asked to press the button in their right hand as soon as they heard the tone. The second CNV task was a 5-min paired choice reaction-time task – a one- or two-digit number (150 ms duration, 1 cm in height), followed by a 1.5-s blank screen and then another one- or two-digit number (150 ms duration, 1 cm in height). Subjects were asked to press a left or right hand button to indicate which number was larger in value.

[1]Orienteering is a complex sport that involves both mind and body to the fullest extent. The purpose is to, as fast as possible, navigate (using map and compass) and run through a course consisting of a number of predefined check-points (controls).

Data were also recorded during the Connor's Continuous Performance Task-Identical Pairs task, a vigilance task. These data are presented elsewhere.

### Skin potential habituation protocol

Skin potential responses were counted in the 3-s windows following the 16 90 dB tones during the simple reaction time task. This interval is the recommended window for calculating skin conductance response (Levinson & Edelberg, 1985). Trials to habituation comprised the number of skin potential responses before the subject stopped responding to three consecutive tones. The criterion for "no response" was a skin potential response $<0.02\,\mu$m. Fast habituation rates reflect higher neural efficiency. The efficient physiology responds initially to any novel stimulus, but then stops responding, once the stimulus is recognized as being non-threatening or irrelevant.

### Psychological test instruments

#### *Self-development*

Subjects were administered the SCTi-MAP – the expansion of Loevinger's (1976; Loevinger et al., 1985) Sentence Completion Test by Susanne Cook-Greuter (1999, 2000) – which includes sentence stems that tap more mature developmental stages. The SCTi consists of a set of 36 sentence beginnings such as "Raising a family . . .," A good boss . . .," When I get mad . . .," that the subjects are to finish as they like. The SCTi is based on the projective use of language, that is, on its automatic and unconscious properties in revealing people's reasons, thoughts, and feelings most readily. The SCTi takes up to 45 min to complete and up to an hour to assess.

Highly trained and certified raters (1 year certification course) next analyze each SCTi for developmental clues that make up each individual's underlying meaning-making system, that is, of a person's stage of self-developmental. Cook-Greuter (1999) found that for SCTi the Pearson correlation for inter-rater reliability of trained raters was as high as $r = 0.79$–$0.84$, while Cronbach's $\alpha$ coefficient was as high as ($r = 0.95$).

#### *Moral reasoning*

Gibbs' Socio-Moral Reflection Measure – Short Form (SMR-SF) – presents moral statements and asks subjects to describe *why* a moral act may be important to them. For instance: "Keeping promises is important because . . .", or "Helping one's friend is important because . . ." Gibbs has written an extensive reference manual to aid in categorizing responses into moral maturity levels (Gibbs et al., 1990, 1992).

The SMR-SF can be group administered as a pencil-and-paper test, takes 15–20 min to complete, and can be scored in 25 min. A scorer can gain competency in 25–30 h of self-study. Gibbs's SMR-SF has high test–retest reliability ($r = 0.88$), and high Cronbach's $\alpha$ coefficients ($r = 0.92$). Scores on the SMR-SF are highly correlated with scores on Kohlberg's Moral Judgment Interview ($r = 0.70$; Gibbs et al., 1992), which is much more intensive to administer and to score.

#### *Survey of peak experiences*

The peak experience instrument consists of four questions on higher development derived from Eastern and Western traditions (Harung et al., 1996):

(1) *Experiences of Transcendental Consciousness (TC) during rest with eyes closed:* "During practice of relaxation, meditation, prayer, or any other technique – or when you have relaxed or had a quiet moment – have you then experienced a completely peaceful state; a state when the mind is very awake, but quiet; a state when consciousness seems to be expanded beyond the limitations of thought, beyond the limitations of time and space?"
(2) *TC during waking activity:* "Have you experienced that while performing activity there was an even state of silence within you, underlying and coexisting with activity, yet untouched by activity? This could be experienced as detached witnessing even while acting with intense focus."
(3) *TC during sleep:* "During deep sleep, have you ever experienced a quiet, peaceful, inner wakefulness? You woke up fresh and rested, but with a sense that you had maintained a continuity of silent self-awareness during sleep?"
(4) *Luck or fortunate coincidences:* "Have you experienced that your desires are fulfilled in a way that seems to be caused by coincidence or luck? You may have experienced that the circumstances arrange themselves to fulfill your desires without your direct action."

For each question the subject is asked to indicate frequency of the experience – ranging from "never to my knowledge" (0) to "all the time" (11). In addition, for each question the subjects were asked to write down sample descriptions of such experiences, using their own words – this to bring out particulars of the glimpse and to aid the scorer in assessing if the experience was appropriate and/or genuine.

### Data analysis: psychological tests

The Survey of Peak Experiences was scored using standard templates. Loevinger's Sentence Completion Test and Gibbs's moral reasoning protocols were sent to trained scorers.

### Data analysis: physiological measures

#### *Brain Integration Scale*

The data were analyzed as in our earlier work (Travis et al., 2002). Broadband (6–40 Hz) frontal coherence and alpha and gamma power at frontal and central sites were calculated during the EEG recorded during the choice reaction time task. Movement artifacts and eye-movement artifacts, as identified by large wave forms at the Fp1 and Fp2 sites, were manually removed from these data before conducting a FFT in 2-s bins. From the 31 2-s bins in the choice trials, an average of 23 (world class) and 21 (controls) artifact-free bins were used in the final analysis. Late CNV was calculated during the simple and choice reaction time tasks. Simple-choice difference scores were calculated. For the present study, these values were added to the normative database, converted to $z$-scores, and summed to yield a single value representing the Brain Integration Scale score for each individual.

#### *Skin potential analysis: habituation*

The number of responses was counted before three consecutive non-responses to the loud sound during the simple task.

### Statistical analyses

A factor analysis was performed on the single stage score from the SCTi, the single variable from Gibb's social reflection questionnaire, the single variable from the Brain Integration Scale, the single variable from the habitation rate, and the four variables from the peak experience questionnaire. This yielded eight variables with 66 subjects, which is greater than the minimum of five subjects/variable needed for a stable factor analysis (Hair et al., 1992). The variables loading sixty or more on each factor were converted to $z$-scores and combined into a factor score. MANOVA and individual ANOVAs were conducted on the factor scores.

## Results

A factor analysis was conducted with a varimax rotation to maximum variance between variables. Factor analysis groups different measures according to their patterns of correlation. Factor analysis is often used as it is here, to explore the relationships between different measures. Three variables resulted from the factor analysis, accounting for 65.3% of the variance. These three factors were (1) *peak experiences*: Three of the four variables on this instrument (luck, the fourth variable did not load uniquely high on any of the factors). (2) *Physiological integration* with scores on the Brain Integration Scale and rate of habituation to loud stimuli, and (3) *development* with scores on the self-development and moral reasoning instruments. The rotated component matrix is presented in Table 1.

Three factor scores were created by transforming the measured variables into $z$-scores and summing the measures, weighted by their factor loadings. Conversion to $z$-scores standardizes scores on measures that may be in different units and different magnitude. A MANOVA was conducted on these three factor scores. There was a significant main effect for world-class performers collapsing across the factor scores (Wilk's Lambda $F(4,48) = 13.0$, $P < 0.0001$).

Individual ANOVAs were conducted. There were significant differences between the world-class per-

Table 1. Component matrix (varimax rotation) for the eight psychological and physiological variables

| Variables | 1. Peak experiences | 2. Physiological integration | 3. self development |
|---|---|---|---|
| Brain Integration Scale | 0.038 | **0.793** | 0.032 |
| Habituation to loud stimuli | 0.075 | – **0.734** | 0.005 |
| Self-development | 0.341 | 0.011 | **0.747** |
| Moral reasoning | – 0.123 | 0.387 | **0.449** |
| TC during waking | **0.753** | – 0.113 | 0.140 |
| Luck | 0.339 | – 0.002 | 0.494 |
| Transcendental consciousness (TC) | **0.723** | – 0.224 | 0.066 |
| TC during sleep | **0.765** | 0.191 | 0.050 |

The eight variables loaded on three factors, called (1) peak experiences, (2) physiological integration, and (3) development. Luck did not load on a particular factor. The variables are in bold that loaded on individual factors.

formance group and the comparison group for development factor scores ($F(1,55) = 5.6$, $P = 0.021$) and physiological integration factor scores ($F(1, 55) = 32.7$, $P < 0.0001$). Figures 1–3 present the result of the factor analysis with Brain Integration Scale scores, habituation rates, and self/moral development scores for the two groups. These are raw scores for better interpretation of group differences.

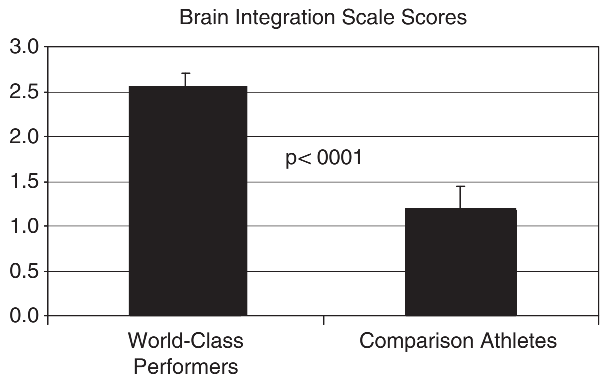


*Fig. 1.* Brain Integration Scale scores for the two groups. The world-class performance group had significantly higher scores on the Brain Integration Scale ($P < 0.0001$).

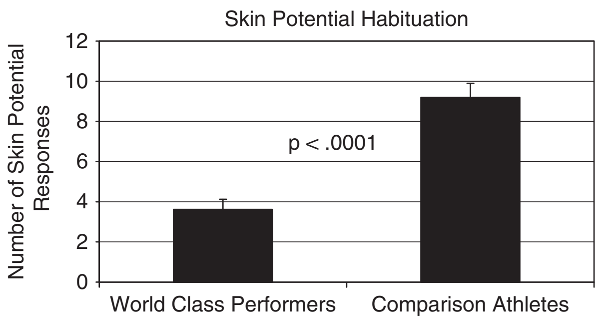


*Fig. 2.* Rate of habituation to loud tones. The world-class performance group habituated more quickly to the loud tones ($P < 0.0001$).

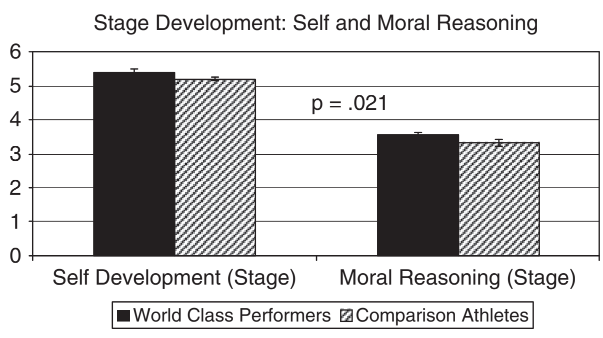


*Fig. 3.* Self-development and moral reasoning. The world-class performance group had significantly higher levels of self-development and moral reasoning ($P = 0.021$).

Table 2. Means (standard deviation) for the three components of the Brain Integration Scale for the two groups

| | 6–40 Hz frontal coherence | Alpha/gamma ratio (frontal and central) | CNV (frontal and central) |
|---|---|---|---|
| World class | 0.321 (0.085) | 2.65 (0.24) | – 4.14 (0.53) |
| Comparison | 0.210 (0.194) | 1.4 (0.32) | 0.56 (0.09) |

These differences were all at the $P < 0.01$ significance level.
CNV, contingent negative variation.

An examination of the Pearson correlation table revealed that the Brain Integration Scale score significantly correlated with moral reasoning ($r = 0.306$). Also, self-development correlated with two variables on the Survey of Peak Experiences (TC during waking $r = 0.284$; and TC during eyes closed resting, $r = 0.302$).

An analysis of the three components of the Brain Integration Scale revealed significantly higher values for the world-class performers in the three components of the Brain Integration Scale. As seen in Table 2, 6–40 Hz frontal EEG coherence, alpha/gamma power ratio and CNV difference scores (minus means greater preparatory response during the simple trial) were higher in the world-class athletes compared with the control athletes. Figure 4 presents the averaged CNV wave forms at Fz (thicker, solid line) and Cz (thinner, dotted line) for world-class and control subjects. These two leads are displayed because CNV is a frontal–central component. These data were filtered with a 0.01–15 Hz filter before averaging. The two stimuli are represented by solid vertical lines at 0 and 1500 ms. It is evident that the world-class athletes had higher late CNV amplitudes – 200 ms before the second stimulus – before the simple trials, when they knew the correct response; and lower preparatory response during the choice trials, when they did not have sufficient information to make a decision.

## Discussion

The world-class performance athletes had significantly higher scores on the Brain Integration Scale, more rapid habituation to a loud stimulus, and higher levels of self-development and moral reasoning than the control athletes. All these measures give different angles into how athletes may be able to excel.

### Brain Integration Scale

Earlier studies report the impact of efficient brain functioning on skilled performance in athletes (e.g.,

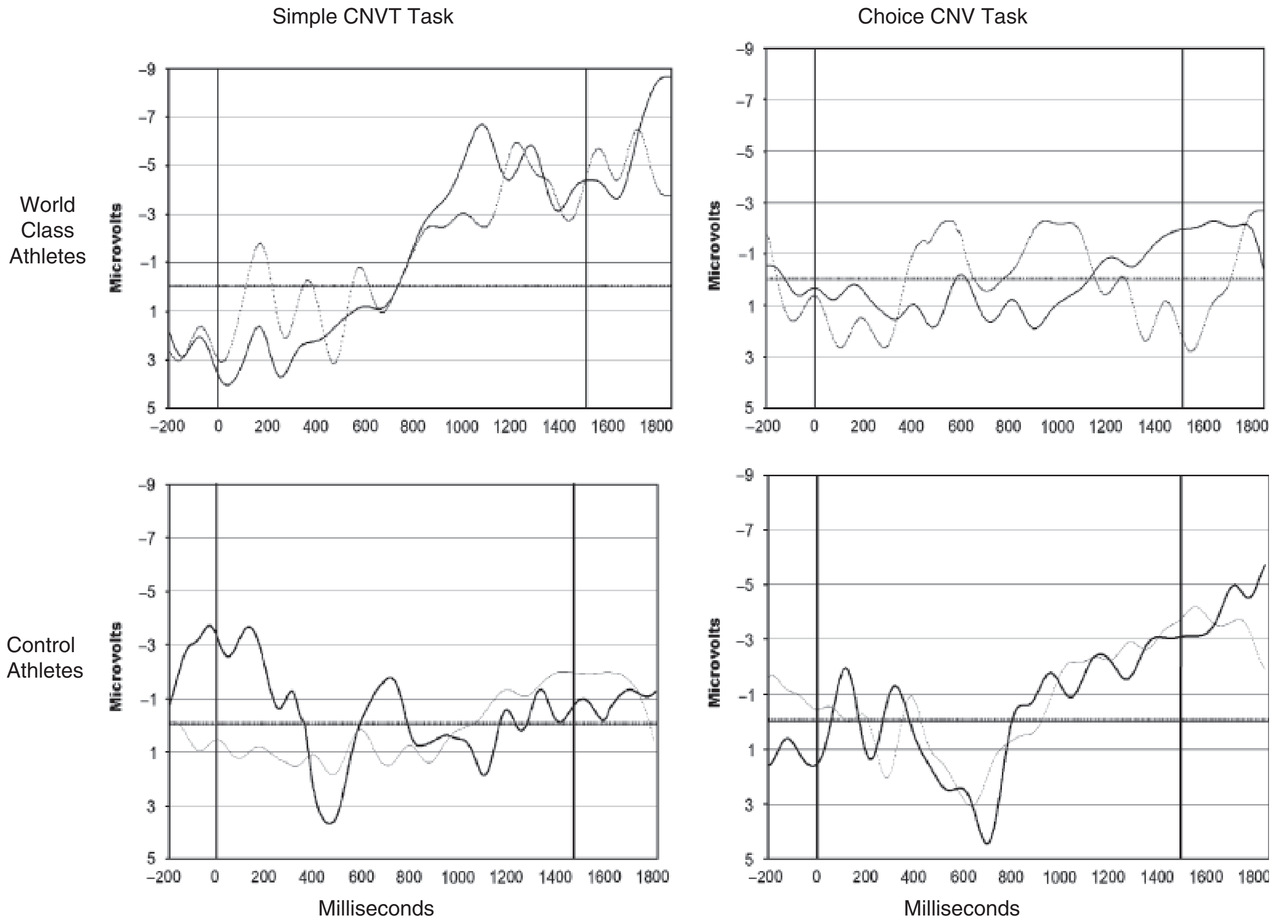


*Fig. 4.* Continungent negative variation (CNV) for the simple (left column) and choice CNV reaction time tasks (right column) at Fz (thicker, solid line) and Cz (thinner, dotted line). The two stimuli are represented by solid vertical lines at 0 and 1500 ms. It is evident that the world-class athletes had higher late CNV amplitudes – 200 ms before the second stimulus – before the simple trials, when they knew the correct response; and lower preparatory response during the choice trials, when they did not have sufficient information to make a decision.

Hatfield et al., 2004). The Brain Integration Scale specifically includes frontal coherence, global alpha power, and brain preparatory response. The frontal cortex is reciprocally connected with nearly all other cortices, with subcortical structures, and with brainstem nuclei (Fuster, 1993). This extensive neural connectivity supports the executive role that the frontal cortices play in generating and guiding goal-directed behavior. EEG coherence is associated with information exchange (Petsche et al., 1997; Pfurtscheller & Andrew, 1999) and functional coordination (Gevins et al., 1989) between brain regions.

These three components of the Brain Integration Scale can be argued to be important for athletes:

(1) Higher EEG coherence in frontal executive system could tie perception, planning, strategizing, motor functioning, and endurance into a perfectly sequenced performance.
(2) Alpha power suggests the athlete remains at the balance point – being calm and alert at the same time – to be most adaptable to changes in the environment, or changes in the behavior of teammates or the opposition.
(3) Better match between task demands and brain activation, as quantified by the CNV during simple and choice reaction tasks, translates into more efficient brain functioning. Brain areas involved in a task will be primed and activated *only* when needed and for as long as needed, and relaxed when that is most appropriate. Fewer resources will be wasted. Because the brain will function more economically this could co-vary with high performance.

## Habituation to loud stimuli

Frontal areas control habituation to stressful stimuli. Higher frontal coherence would be expected to lead to faster habituation as was seen in these data. Faster habituation by world-class athletes may explain the frequently described experience in our study of “the tunnel." In the tunnel, which is often related to peak performance, the athletes are able to focus only on factors relevant to their successful performance, and exclude irrelevant input, e.g., irrelevant thoughts of the past, present, and future, and irrelevant input from the environment.

### Consideration of higher moral reasoning

Frontal areas are also specifically active during moral reasoning tasks. The finding of higher moral reasoning in world-class athletes in this study is contrary to research with US athletes that reports *low* levels of moral reasoning in professional athletes (Shields & Bredemeier, 2001; Long et al., 2006). First this paradox could reflect differences in the US and Norwegian national cultures, the OECD (2007) reports that the salary differences in Norway are the lowest in 20 OECD countries, while it is highest in Hungary and United States, which might influence motivation in athletes. Second, other researchers focused on team sports, while the athletes in this study played primarily individual sports. Third, Long et al. (2006) examined athletes that were only 15–18 years old (an age range where moral development is still taking place), while we studied athletes of $>25$ years of age (because this is the age limit when development of both the self and the brain with few exceptions has peaked).

### Self-development

Frontal areas are central for neuronal implementation of a "self-model" – one's self-concept and sense of personal identity (Vogeley et al., 1999; Ben Shalom, 2000; Keenan et al., 2000). World-class performers had higher levels of self-development than controls. World-class performers from a number of countries reported more frequent peak experiences than control athletes (Harung et al., 1996). Mature growth is reported to lead to higher performance (e.g., Harung et al., 1996, 2009; Rooke & Torbert, 2005). The advantage of mental maturity for top performance is well summarized by the world-class cross country skier Thomas Alsgaard (2008) who won 11 gold medals in Olympic Games or World Championships. Alsgaard says that the basis of his success is not physical capabilities that he is born with – compared with others he does not have a bigger heart, or bigger lungs, or more enduring muscles. In contrast, the basis of his success is the way of thinking – "so that one always manages to do the right things in the right way at the right time" (p. 12).

Summarizing, sport conducted at the highest level is comprised of a lot of expectations and high levels of perceived stress. Therefore, it is of vital importance that the athletes are able to cope with this situation (Pensgaard & Roberts, 2000). The ability to stay calm and focused becomes essential and any elevated tension – either psychological or physiological – might interfere with a fine-tuned technique. Thus, the combination of more rapid habituation to a loud stimulus and higher levels of self-development, which correlate with low levels of anxiety, seems particularly useful at the highest level of competitive sport. Also, a high score on the Brain Integration Scale and rapid habituation both reflect efficient mind–body coordination, the essence of high performance in any sport.

This matched study of professional athletes highlights the importance of brain functioning on outer success. More integrated brain functioning underlies faster habituation, higher self-development, and higher moral reasoning. Both mind and body of these athletes were tuned to success and appeared to be the edge that enabled them to excel in their sport.

## Perspectives

Brain integration may be the next frontier of training for excellence in sports. The hand moves; but who moves the hand? Brain functioning underlies how we make meaning of daily experiences; how we perceive the world; and how we respond to challenge. Higher brain integration supports higher levels of self-development, higher ethical values and behavior, and a higher quality of life. Methods for enhancing brain integration may therefore be critical for becoming a champion. Inner development could give the added edge for outer performance. The Brain Integration Scale may provide an objective measure to allow athletes and coaches to monitor growth of inner development, and by inference performance potential, as the athletes actualize their athletic career game plan.

**Key words:** self-development, brain integration, peak experiences, world-class athletes.

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