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MUSCLE MEMORY AND THE SOMAESTHETIC PATHOLOGIES OF EVERYDAY LIFE

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ABSTRACT
Memory is a cherished cognitive skill that contributes enormously to human flourishing, yet it sometimes proves detrimental. Much of the memory we productively employ in everyday life is implicit memory that results from habit. The paper first demonstrates the important somatic dimension of implicit memory that gives rise to the popular notion of "muscle memory" by articulating six different forms of implicit memory in which the body plays a central role. The paper next focuses on some problems relating to these forms of memory and deriving from flawed habits of somatic perception and performance. I then explain how these problems of muscle memory can be treated by disrupting such memory through heightened, explicit consciousness involving methods of somaesthetic attention and reflection.

Key words: somaesthetics, muscle memory, implicit memory, habit, awareness

Muscle memory as implicit memory

Muscle memory is a term commonly used in everyday discourse for the sort of embodied implicit memory that unconsciously helps us to perform various motor tasks we have somehow learned through habituation, either through explicit, intentional training or simply as the result of informal, unintentional, or even unconscious learning from repeated prior experience. In scientific terminology, such memory is often designated as "procedural memory" or "motor memory" because it enables us to perform various motor procedures or skills in an automatic or spontaneous fashion, without conscious deliberation of how the procedure should be followed and without any explicit calculation of how one identifies and achieves the various steps involved in the procedure and how one proceeds from step to step. Paradigmatic of such muscle-memory motor skills of performance are walking, swimming, riding a bicycle, tying one's shoes, playing the piano, driving a car, or typing on a keyboard. To be precise, these motor skills should be described as sensorimotor, because they involve coordinating sensory perception with the movement of action. Moreover, because these skills apparently rely on schema or patterns deeply embedded in an individual's central nervous system, the core engine of memory in so-called muscle memory is not simply the body's muscles but instead also involves the brain's neural networks.

The term "muscle memory" is nonetheless deeply entrenched, perhaps because it serves some key rhetorical functions. Muscle suggests body in contrast to mind, as muscular effort is frequently contrasted to mental effort, or as muscle men are typically opposed to men of thought. Because of this common brain/brawn opposition, muscle memory conveys a sense of mindless memory.[1] Such memory is mindless, however, only if we identify mind with mindfulness in the sense of explicit, critically focused consciousness or deliberate, reflective awareness. Procedural or performative tasks of implicit motor memory often require and exhibit significant mental skills and intelligence, as, for example, when a good pianist plays with spontaneity yet also with aesthetically sensitive mindfulness. In demonstrating that intelligent mind extends beyond clear consciousness, muscle memory also makes manifest the mind's embodied nature and the body's crucial role in memory and cognition.

The idea that our normal somatic skills of performative muscle memory are intelligently deployed without explicit thought or deliberation has played an important part in the cognitive rehabilitation of body and habit in contemporary philosophy, a project we can trace back to pragmatists like William James and John Dewey and to phenomenologists like Maurice Merleau-Ponty. In celebrating the body's effectively purposive yet unthinking spontaneous performance in perception, speech, art,

[1] Here I should note that another meaning of muscle memory refers to the phenomenon that when a person suspends a sustained weightlifting program for a prolonged period and then resumes it, his earlier trained muscles are able to return to their previous levels of size and strength more quickly and easily than was necessary to reach those levels originally, as if the muscles recalled their prior levels.

and other forms of action, these philosophers recognize that such intelligent spontaneity is not mere uneducated reflex but rather the acquired product of somatically sedimented habit, which often goes by the name of muscle memory. Because the somatic self is essentially expressed through this purposive intelligence while the term body is too often identified with mere physicality, I use the term soma to designate the living, sentient, purposive, perceptive body that forms the locus of the transdisciplinary project of somaesthetics.[2]

The performative procedural skills of muscle memory comprise only one of the different kinds of implicit memory that are deeply grounded in the soma. Though the habits and skills of such memory are typically very welcome and useful, we also develop bad habits of muscle memory, many of which go unnoticed not only because of their implicit character but also because their detrimental effects are usually not so extreme as to call our conscious attention to them. Such habits of muscle memory (though undetected and seemingly benign) impair our somaesthetic perception and our consequent experience and performance. Their remedy requires a disruption of implicit memory so that it can be improved through reconstruction. After exploring the soma's role in diverse modes of implicit memory, this paper analyzes a cluster of everyday problems that arise from such memory, and then suggests how such problems can be treated through methods of heightened body consciousness that render the implicit more explicit.[3]

Six forms of muscle memory

1. Perhaps the most basic implicit memory is that of oneself, the implicit sense of continuing personal identity. When I awake in the morning, even before I open my eyes, I have the implicit memory (as an implicit feeling) of being the same person that went to sleep the night before. I do not need to recall explicitly that I am the same person, nor do I even explicitly recognize or thematize the feeling of sameness; but this implicit feeling of being the same abides with me and provides a narrative ground or core for my sense of self and for my perception of the world. This implicit body memory or feeling of continuity was recognized by William James, who construed it as the foundational factor not only for personal identity but also for the unity of consciousness and thus essentially for the coherence of a person's thinking.

This implicit feeling of being the same self as one was before (even if only a split second before), James argues, is essentially a bodily feeling. As he puts it in *The Principles of Psychology*, our thoughts are united as being ours because "as we think we feel our bodily selves as the seat of the thinking. If the thinking be *our* thinking, it must be suffused through all its parts with that peculiar warmth and intimacy" with the implicit memory of being the same body, "the feeling of the same old body always there," even though the body is, strictly speaking, always changing [8]. This implicit memory of feeling the same body, James insists, helps "form a *liaison* between all the things of which we become successively aware" and thus serves to organize and unify the complexity of experience through its relation to "the objective nucleus of every man's experience, his own body," which he feels implicitly as "a continuous percept" [9].

2. If one basic mode of implicit memory is the self-memory of being the same person, of remembering implicitly who one is[4], a second crucial mode is remembering *where* one is; and very often this memory includes implicitly recalling how one gets from where one is to where one wants to go. We have all had experiences of walking a familiar route, say from one's office to the bookshop a few blocks away, and suddenly realizing one has arrived at one's destination without ever having thought about or explicitly remembered the path taken. Similarly when we arrive at the bookshop we implicitly remember its familiar feel and layout without consciously recalling it to memory. These implicit memories of location are, of course, deeply grounded in the soma, which essentially determines one's location and sense of place, one's perspective on the world and one's coordinates of direction in it.

We know the world largely because we inhabit it through our soma. Because, as a body, I am also a thing among things in the world, that world of things is also present and comprehensible to me. Because the soma

[2] For initial formulations of this project, see [1 – 2]. For elaborations and critical discussions of somaesthetics, see, for example, [3 – 6], and [7].

[3] My account of these methods relies on my professional practice as a somatic educator and therapist in the Feldenkrais Method, from which I have also been able to study some of the somaesthetic pathologies I discuss in this article.

[4] Such implicit memory of knowing who one is in terms of knowing one is the same person now as in the past does not, as implicit memory, require that one remembers who one is in terms of an explicit descriptive identity of being a certain person with a particular name, age, gender, and profession. The formulation of such descriptive terms involves, of course, explicit thought, but on the basis of implicit memory of self one could recall these descriptions if one were asked.

as subjectivity is affected by the world's objects and energies, it incorporates and implicitly remembers their regularities, thus recalling features of spaces and places without needing to engage in explicit recollection or reflection. To see any place (or any thing), we must see it from some point of view, a position that determines our horizon and directional planes of observation, that sets the meaning of left and right, up and down, forward and backward, inside and out. One's body, of course, supplies this primordial point, the center or origin of coordinates, by being what locates us in space and gives that lived space its directionality. Moreover, it also gives us our sense of the volume of space, since this sense relies on our experience of moving through space, an experience and ability that depends on the body's powers of locomotion.

As a holistic sensorimotor subjectivity, the soma is essential to spatial memory in yet another way. Unlike some other perceptual dimensions, our sense of space does not directly depend on a specific sensory organ but is instead essentially the product of multisensory representations that build up a spatial map through a learning process, implicit or explicit. In the implicit learning process, where the forming of a spatial map does not involve special attention or explicit conscious effort, it is through the soma's unreflective perceptions of space that a space is learned and remembered. Not only can we remember spaces we have inhabited and how to negotiate our ways through them through implicit memory without consciously reflecting on representations of those spaces in explicit thought. But we can also first come to know and learn to remember a space through implicit means, without consciously making an effort to remember, without engaging our explicit, voluntary attention to learn the space. Experimental studies have confirmed what we know from ordinary experience: that while explicit, focused attention facilitates the forming and stabilizing of a spatial map, such maps can be formed and stabilized (though not as powerfully) through the sort of unreflective ambient attention that an animal has just by moving through or inhabiting space [10].

The soma's potent role in understanding and remembering space is highlighted and heightened by its asymmetries. The body's front is different from its back, its top is different from its bottom; and these asymmetries are reflected in differential capacities of memory. Studies show that it is hardest to retrieve spatial memory of left and right (dimensions that are symmetrical in the body) than the asymmetrical dimensions of front/back and top/bottom. For the upright observer, the head/foot axis is the easiest for recalling spatial information, because it is also "correlated with the only asymmetric axis of the world, the axis created by gravity." But when reclining, observers remember information fastest on the front/back axis, which roughly correlates with the axis of what can be seen versus not seen [11].

We sometimes distinguish place from mere space, to characterize the former as a particular landmark with value or meaning (a home, school, stadium, mall, or parking lot). Place in this sense helps define the more abstract concept of space as a general area through which movement is possible (and where places represent distinct points where one might pause in that movement). Similarly, we can distinguish memory of space and place, the latter being easier and very useful for the former. For example, we implicitly remember to turn right at a certain point because we implicitly remember the corner café as the place where we need to turn right. The body plays a central role in such memory through its remembered feel of certain places (the smell of the coffee, the need to navigate one's path around the outdoor tables, etc.).

Certain places leave such strong somatic imprints of feeling that it is involuntarily evoked whenever we enter them. My life as department chair was so pressured that each time I entered that office, even during vacation, I shivered with memories of hectic work and stress so that it was impossible for me to relax or think about anything but my administrative duties, even when I was in principle free to do so. My muscle memory of that place was automatically triggered, shortening my breath and tensing my posture; though, it also provided implicit recall of where all the necessary tools could be found to perform my job. And while we're in my office, it's worth mentioning another sort of memory (implicit or explicit) that could be grouped with memory of space and place – situational memory.

My chairman's office was a place of repeated situation types, for example, interviewing a job candidate or meeting individually with junior faculty members to discuss their progress toward promotion and tenure. Implicit somatic memory of such situations allowed me with smooth spontaneity (i.e. without the awkward hesitancy of deliberative thought) to offer the appropriate greeting and comfortable chair to my interlocutor, to assume the appropriate posture, tone, and demeanor that such situations call for, where one must be kind and encouraging but at the same time represent the impersonal authority and responsibility of one's executive position. There are countless situations in which the soma enacts such implicit situational memory. Sports provide excellent examples; experienced athletes spontaneously recognize (through implicit somatic memory) those situations in which they should pass the ball and to whom and at what speed and trajectory they should pass it.

3. A third form of implicit memory with deep bodily grounding might be described as interpersonal or more broadly as intersomatic – so as to include non-human companions like animals. We develop ways of being with and reacting to certain other bodies, and these modes of relationship are incorporated into our muscle memory as habitual attitudes or schemata of action that are spontaneously recalled and repeated in the presence of those other bodies, with the appropriate contextual variations. Did you ever notice that though you have shared with your spouse or long-time lover countless beds in countless bedrooms, you always seem to lie together in the same orientation, on the same side? You do not have to think about which side of the bed you should take; and if, for some reason, you find yourself lying next to your lover on the non-habitual side, it will probably feel odd or perhaps even awkward. Similarly when walking hand in hand or with their arms around each other, couples spontaneously take up their habitual positioning. These habitual postures are assumed without thinking about them and they establish a feeling of comfortable familiarity that typically escapes explicit recognition but nonetheless pervasively influences one's experience. The same sort of intersomatic attunement is developed between horse and rider or between a person and her pets.

Because emotions are grounded in the body, our implicit somatic memories have an affective dimension. We carry these implicit intercorporeal memories and corresponding somatic attitudes into our encounters with new people, which is why we often have an immediate, visceral feeling of comfort or discomfort when we meet someone new who is implicitly perceived as suggesting positive or negative memories. We develop such intersomatic patterns of interactions already from infancy, as Daniel Stern has shown in his extensive studies of infant interpersonal relations, and these early schemata of interaction powerfully integrate motor, cognitive, and affective dimensions [12]. By means of such somatic patterns and attunements we learn to understand and navigate our immediate interpersonal world (through embodied patterns of implicit relational knowing) even before mastering linguistic expression. Although such intersomatic memories are first developed with respect to one's parents (in most cases, especially to one's mother) and other significant others, they become generalized yet also modified by later experience; and they are unreflectively woven into a complex embodied structure of habits – of affective, cognitive, social, postural, and motor dispositions that are intimately intertwined and that essentially constitute one's personality.

Such implicit affective intersomatic memories, I have argued, can help explain why ethnic and racial prejudices prove extremely resistant to rational arguments of tolerance. Because such prejudices are grounded in implicit visceral feelings and muscle memory of discomfort of which we are not fully conscious, we may not even be aware of them and of the prejudice they generate, though others will note it in our behavior. Parents can unwittingly instill such feelings in their children without saying a word and without any dramatic display of prejudice, but simply by subtle postural and facial expressions of discomfort that the sensitive child absorbs and responds to [13].

4. Our interpersonal relations take place within a larger social setting. But if interpersonal implicit memory in some way already implies the social, we can also distinguish a more distinctively social form of implicit memory, in terms of inhabiting, recalling or replaying distinctive social roles. These roles very often involve a distinctive form of embodiment. One example I remember from military service in Israel is that of the drill sergeant major at our unit's headquarters. Though typical Israeli military posture is rather relaxed reflecting a general somatic (and more general military) ideology that advocates the supple, fluid, and flexible, our drill sergeant major had instead learned to incorporate the rigidly erect posture and very stiff, mechanical movements that define the more traditional conventions of military drill and thus of his special social role. Even when he was not performing his official duties, we could always easily recognize him on the base by his stiff posture and gait, even if we could only view him from the back and at a great distance.

Other roles have their characteristic embodiment. A policeman, a judge, a doctor all possess different forms of authority in their roles, and they display distinctively different forms of embodying those forms of authority. Success in their roles requires incorporating the right bodily attitudes and comportment, whose mastery involves implicit muscle memory in spontaneously performing them.[5] Moreover, we deploy implicit memory in transitioning from one role to another.

[5] In these roles, distinctive uniforms that are worn on one's body serve as bodily cues or tools to help individuals incorporate the proper somatic dispositions and comportment.

When the female police officer comes home to assume the role of a tenderly loving mother to her infant son, she does not need to explicitly remind herself to generate the different somatic dispositions and feelings appropriate to her maternal role. Muscle memory instructs her how to transition without her needing to remind herself explicitly what it means to be a mother. Just thinking of her baby while she is driving home may initiate the proper somatic changes, even before she actually sees him and removes her uniform so her badge won't scratch him.

5. Putting on and taking off clothes are typical examples of the most obvious type of muscle memory: performative or procedural memory. Normally we do not have to think about how to dress or undress ourselves. We typically do not notice which sock or shoe we put on first, which arm or leg is first inserted into a sleeve or trouser, which button is first buttoned, and whether in buttoning we use the index or pointer finger with the thumb. On many occasions, one decides to get ready for bed, and suddenly finds oneself in pajamas without remembering the various stages of undressing and then dressing for bed. Other skills of experienced mastery in performing sequential tasks range from the most common functions of walking, running, tying one's shoes, or eating with utensils to more complicated skills like swimming, dancing the tango, riding a bicycle, touch typing, driving a car, shooting a turn-around jump shot, or playing a piano sonata. These tasks include distinctively cognitive ones such as speaking, reading, and writing. We perform such skills with such effortless unthinking spontaneity that we can understand why philosophers like Merleau-Ponty describe such somatic performance in terms of "marvels," "miracles" and "magic" [see 14 and 15; for more discussion of this point, see 13].

This sort of muscle memory is certainly most efficient by allowing us to direct our always limited resources of explicit consciousness to other places that need it. We can thus concentrate our attention on the ideas we are writing rather than thinking of the location of the letters on the keyboard which we want to type. I can look down the basketball court to see if a teammate is open near the basket, rather than having to think about how I handle the ball to dribble and then pass it to him. By freeing our consciousness to engage other things, muscle memory extends our range of attention and perception, and thus enhances our freedom of action. With many complex motor skills, moreover, it is often claimed (by philosophers, psychologists, and movement experts) that if we tried to perform them explicitly recalling and deliberating at each step, we would awkwardly stumble. As the great choreographer George Balanchine would tell his dancers, "don't think, dear; just do."[6]

6. The last kind of implicit muscle memory I note here is an unhappy one of unfreedom – traumatic memory. Pain is implicitly remembered in the body and projected through it into future attitudes, as proverbs like "once bitten, twice shy" suggest. Many forms of education involve painful disciplines of training, an approach that may have helped prompt Nietzsche's overstatement that "only what does not cease to cause pain remains in memory."[7] In productive forms of disciplinary education, if pain is deployed it is carefully controlled and framed in relationship to positive meaning and value. Traumatic memory, in contrast, is characterized by its inability to connect positively to meaning and value. Because of trauma's intense shock and pain, the victim cannot properly integrate it into a clear, conscious, meaningful memory, since the experience overwhelms one's normal sense of self, rupturing the narrative continuity that gives meaning and stability to experience, including remembered experience. Instead, as the explicit narrative memory of trauma is significantly blurred or even lost in many of its details, so the traumatic memory thrives in implicit behavioral form – in terms of somatic complaints such as flashbacks (that repeatedly relive the trauma); physical symptoms such as sweating or a racing heartbeat; frightening dreams; behavioral reactions of avoiding things that might recall the traumatic experience; being easily startled, tense, or edgy; or contrastingly emotionally numb. Such traumatic memory forms the crux of what is diagnosed as posttraumatic stress disorder (PTSD). Because traumatic memory withdraws from explicit consciousness while implicitly working through the body to preserve, reinforce, and spread its painful effects, it is very difficult to treat and overcome its devastations. Therapy thus often involves making the implicit me-

[6] This frequently quoted saying of his can be found even in mass-media dance articles, such as this review from the San Francisco Chronicle [16]; and this interview from New York's *Timeout* [17]. Some renowned masters of dance, notably the most influential theorist and composer of Nō theater and dance, do not share this view, for reasons I explain in [18], where I also explain more generally the limits of arguments that claim explicit attention to one's action is always detrimental to effective performance after the actions of performance have been learned and habituated into muscle memory.

[7] "Man brennt Etwas ein, damit es im Gedächtniss bleibt: nur was nicht aufhört, weh zu thun, bleibt im Gedächtniss" [19].

mory more explicit in some way so that it can be more clearly identified and treated [for more on this topic, see 20].

If traumatic memory is one form of implicit somatic memory whose implicitness is not entirely advantageous, I shall now consider how the other forms of implicit or muscle memory also can prove problematic, albeit in a generally milder way. When I first spoke of such problems (in a paper in French) I called them *petites pathologies* [see 21] but here I wish to explore them under the category of somaesthetic pathologies of everyday life, alluding to Freud's book on the *Psychopathologies of Everyday Life* which also deals with problems far less severe than trauma, such as slips of the tongue or other minor lapses.

Somaesthetic pathologies of muscle memory and their treatment

There is not space here to treat all the different ways that insufficient somaesthetic awareness (i.e. inadequate perception of our somatic comportment and feelings) leads to minor everyday problems of dysfunction, error, discomfort, pain, or decline from proper efficiency. They include unnecessary self-induced accidents like biting one's tongue when eating; tripping over one's own feet; choking by swallowing food or drink down the wrong "pipe"; hurting one's back or knee by lifting or turning in the wrong position; straining one's lower back by not noticing the discomfort experienced in having sat too long at one's workstation. Then there are everyday somaesthetic pathologies involving a variety of malfunctions in sports-related skills – like failing to hit a ball properly (in tennis, golf, or baseball) because one is unaware that one's eyes, hands, and other body parts are not in the right position for making proper contact. We also find similar motor malfunctions in work-related activities, such as mistakenly clicking on the mouse when not really ready to send one's message or others errors arising from not being sufficiently aware of one's handling of the computer keyboard or one's cell phone touch screen. Other common somaesthetic problems include not being able to sleep because one is not aware that one's breathing is too short and one's body too tensely held to induce a condition of repose that can induce sleep.

The various somaesthetic pathologies of everyday life could be grouped in different ways, but rather than proposing a general taxonomy here, I will discuss a few examples drawn from the five positive forms of implicit memory noted earlier, while suggesting how they may be remedied through heightened somaesthetic awareness. Organizing this discussion in terms of these different modes of muscle memory should give greater clarity and unity to this paper, though I can imagine better ways of classifying the wide variety of everyday somaesthetic pathologies or even the few we shall presently consider.

1. In affirming an implicit abiding memory of self that provides our sense of personal identity and continuity of consciousness, James insists that it is essentially somatic, a muscle memory of feeling oneself as the same person. Even in our moments of pure thinking, "we feel the whole cubic mass of our body all the while, [and] it gives us an unceasing sense of personal existence" [8]. If James describes "the past and present selves" as unified by "a uniform feeling of 'warmth,' of bodily existence… that pervades them all… and gives them a generic unity, he insists that "this generic unity co-exists with generic differences just as real as the unity" [8].

James's language here is not entirely clear, but I think he is not (and should not be) asserting that there is one single, isolatable, constant and unchanging somatic "me" feeling that accompanies all my other bodily feelings and that defines my sense of unity. Rather, one's sense of being the same person is an emergent, holistic feeling of sameness based on a whole network of feelings of "warmth and intimacy" [8] between the generic pattern of one's present somatic feelings and that of one's remembered counterparts. One's actual body feelings will always change with changing conditions though the generic pattern can remain stable while also expressing significant differences. Not all somatic feelings, according to James, have the same weight in determining one's sense of self. In *The Principles of Psychology*, he identifies the crucial somatic feelings of the core self (the innermost self of active consciousness which he calls "nuclear self" "the Self of selves") with various "muscular adjustments" – "for the most part taking place within the head" or "between the head and throat" [by which he means to include adjustments of the cephalic sense organs associated with thinking such as pressure and orientation of the eyeballs, as well as muscular contractions of the brow, jaw, and glottis [8]. It is understandable to highlight feelings in the head and neck area, which not only houses the brain, the organs of vision, hearing and taste, and the vestibular system of the inner ear (that provides stability of posture and gaze) but also the first two cervical vertebra (the atlas and axis) whose articulations and attached ligaments and muscles are what enable us to raise, lower, and rotate the head, thus affording greater scope for the head's sensory organs.

James later particularly emphasizes the bodily feelings of breathing as what gives felt unity to one's "stream of thinking," locating those feelings of breath too narrowly in the nose and throat.[8] Without insisting that feelings in the head and neck area are what defines our inner self-feeling, we can recognize that those feelings could be very important to one's sense of self, so that even when we do not explicitly notice these feelings they form a familiar perceptible background to our more explicit objects of consciousness and foci of attention. Such feelings can become so habitual and pervasively familiar that they form part of one's implicit sense of self. This can happen even if these particular feelings in the head and neck are neither necessary (i.e. alternative feelings are equally possible) nor beneficial.

Many individuals suffer from a somaesthetic pathology that exemplifies this situation. They have a condition of chronic excessive tension in the neck, caused by habitual reactions of muscular contraction to repeated situations of stress. Because this condition of excessive tension is habitual, it also becomes familiar as a background feeling. The affected individuals typically do not even know that they have this problem because the excessive tension feels familiar (and in that sense normal) to them; indeed it forms part of their core feeling of who they are, even if such tension results eventually in the noticeable discomfort of headaches, neck aches, and backaches. We can recognize such people by the way they always have their shoulders quite tensed and elevated closer to the upper neck and ears than one's shoulders should normally be in a proper, adequately relaxed posture. The pressure of the raised shoulders involves muscular tensions that in turn put excessive pressure on the muscles of the neck and the cervical vertebrae; we thus could describe this pathology as the chronically pinched neck. Besides the pain and damage to the cervical spine that this chronic contraction can eventually cause, such posture hinders the efficiency of our action, since its tensed posture inhibits movement in the neck, shoulders and ribcage. Nonetheless through its habituated incorporation into a familiar bodily feeling, the pinched-neck posture feels normal to those who suffer from this somaesthetic pathology, which is thus a pathology of perception (aesthesis) as well as of posture.

Clinical experience has taught me that when such a person is asked to relax his shoulders to ease his neck, he will happily assent to the request but essentially fail to comply, though he thinks he is complying (very often by making a sort of shrug that just raises the shoulders further before letting them subside to their habitual raised position). Not only does he not realize that his elevated shoulders and neck are excessively tensed (because they feel normal to him), but he also does not know how to lower or relax them because he no longer knows what that relaxed posture feels like. When, after some hands-on work with him, I induce a relaxation in his neck and shoulders, he reports that it feels a bit strange to him, that he feels somehow lazy or soft and not quite himself. He confuses the release from chronic hypertension with a loss of the familiar sense of his forceful dynamic self that has become habitually linked to his chronic feelings of excessive muscular contractions. This change of posture may thus not be psychologically comfortable for him, even though it is physiologically more comfortable and can be behaviorally more advantageous.

A patient's identity may be so intimately linked to her handicap or problem that even when she complains about the problem, she may at a deeper level resist efforts to rid herself of it. [I knew a talented, beautiful, and wealthy Parisian academic who, for many years, complained to me about being miserable because of the man she lived with. But whenever I suggested she leave him, she replied that this problematic relationship had become a cornerstone of her identity and her psychological coping structure, supplying her with an excuse for being unhappy and for not writing all the books she thought she should write. Without this problem, she argued, she would have no adequate excuse for her failures and would thus be even more miserable and full of self-loathing.] With respect to the somaesthetic pathology of the pinched neck, if the chronic feeling of tension is felt as an important part of the person's sense of self, then he must take the trouble of revising his familiar sense of self so that a more relaxed muscular tonus is not confused with torpor and can instead be associated with his resilient dynamism. For many individuals, to take the time and effort to make this transition may not seem worth the sacrifice, especially since

8 My consciousness or "stream of thinking," James argues, relying on his own introspection, "is only a careless name for what, when scrutinized, reveals itself to consist chiefly of the stream of my breathing. The 'I think' which Kant said must be able to accompany all my objects, is the 'I breathe' which actually does accompany them." James concludes that "breath, which was ever the original of 'spirit,' breath moving outwards, between the glottis and the nostrils, is, I am persuaded, the essence out of which philosophers have constructed the entity known to them as consciousness" [9]. James surprisingly ignores both the feelings of inhalation and the fact that one very often feels one's breathing not only in the head and neck but also down into one's thoracic area, where the movement of the lungs interacts with movements in the chest or ribcage; and that same thoracic area provides the familiar background feelings of one's beating heart.

the advantages of the new posture and sense of self are neither very clear nor guaranteed in advance, while the problems they currently suffer from their pinched-neck pathology seem manageably minor and familiar. That is one reason why this somaesthetic pathology remains so prevalent.

2. Muscle memory guides us in spatial orientation but it can also misguide us. One space-related somaesthetic pathology of everyday life is orientational bias. Did you ever notice that whenever you go to a movie or lecture without assigned seats you tend to sit on one side (left or right) of the room rather than the other; did you ever notice that when you are standing or sitting your range of vision is greater on one side than the other? The reason is that one's body frequently has an orientational bias; many people feel more comfortable turning toward one side rather than another, and this bias is also reflected in posture, as a tendency (when standing or sitting) to have one's body or head not perfectly straight but slightly turned toward one direction. Perhaps you sit on the right side of the movie theatre because your left eye is stronger and thus sitting on the right puts the left eye more toward the center especially when tilting your gaze leftwards (which sitting on the right enables you more comfortably to do). Or perhaps your right-side seating habit is because you implicitly feel (for a variety of possible reasons relating to your somatic history) more comfortable with your body slightly turned or shifted toward your left.

There is nothing wrong with this sort of postural bias in itself, but if we fail to recognize it and compensate for its effects, it can lead to problems. For instance, a teacher or lecturer who has a left orientational bias will often unintentionally turn his side or even back to those people in the audience who are seated to his right, without even knowing that he is excluding them from eye contact. If he is aware of this bias, he can correct for it by readjusting his posture so that he is facing more of his audience (either by centering his orientation or by stepping further back to minimize the effects of the bias). A much more dangerous result of such orientational bias is reduced ability to notice oncoming traffic from the side somewhat blinded by the bias; experience indeed shows that many individuals tend to suffer accidents significantly more on one side than another. If orientational bias seems a likely cause for such accidents, then improved awareness of such bias through heightened somaesthetic perception is a likely remedy.

As orientational bias concerns issues of how we *situate* ourselves in space, so there are everyday somaesthetic pathologies of navigating our trajectories through space. Too many times my muscle memory directs my walking and driving through habitual paths toward familiar locations that are, however, not the ones I meant to choose; so I am forced to backtrack and consciously remind myself of the right destination and path. Muscle memory likewise induces everyday somaesthetic pathologies of inhabiting place, one of which was already introduced in discussing my implicit "chairman's office" memory. It was pathological to be suddenly thrust into a state of breathless tension (and without even explicitly recognizing it) just by entering that place, even if I had nothing more urgent to do there that day than chat with an old friend who found it the most convenient place to meet. After somatic training improved my somaesthetic awareness, I was able to identify my pathological reaction, but also treat it by explicitly applying various strategies of breathing and muscle relaxation.

3. In my discussion of implicit interpersonal muscle memory I argued that racial and ethnic prejudice – an all too common everyday pathology – has roots in visceral feeling and that its incorporation in implicit memory makes it very difficult for the person with the prejudice to properly recognize it, let alone extinguish it by a mere conscious judgment that such prejudice is unreasonable. Sharpening a person's awareness of her bodily feelings so that she can recognize the mild discomfort that certain races or ethnicities or other groups provoke in her can help her to identify the prejudice and its roots, so that she may try to contain it or even overcome it, if she wishes to, perhaps by trying to reeducate her somatic feelings. As we know from acquired tastes, visceral reactions or dispositions can be to some extent refined or transformed through sensory reeducation. Of course, if the person with prejudice has no such meliorative desire for reform, then heightening the awareness of visceral discomfort and its relation to the prejudice may not result in efforts to control or eliminate the prejudice. Indeed heightened awareness might even strengthen the feelings of discomfort, and in that way reinforce the prejudice in rendering it more conscious. Knowledge, including self-knowledge, is not always beneficial; it depends on how it is used. One could argue that knowing one is prejudiced is a cognitive improvement on not knowing it, even if positive ethical results of such knowledge are not forthcoming.

Muscle memory can generate another minor pathology of interpersonal interaction. Some persons have characteristic postures that others find disturbing, even if the disturbing feelings remain rather mild and implicit. For example, some individuals have a way of engaging their interlocutors in conversation by coming very close to them and then tilting or leaning toward them with a rather tensely contracted soma. The motivation for this posture is typically friendly but it often conveys a disturbingly aggressive stance to the interlocutor, who feels somehow threatened by this intrusion in her personal space, especially if the overly proximate body leaning toward her is considerably larger than her own. Her implicit reaction is to withdraw both posturally and psychologically from the friendly speaker with the aggressive stance, which tends to evoke in him a further implicit adjustment of looming still closer, perhaps with the feeling that his interlocutor is not a friendly person, even though she may indeed harbor friendly inclinations to him, at least initially, before this unfortunate dance of approach and withdrawal that results from his somaesthetic insensitivity to posture.

Such interpersonal problems are magnified when culturally different senses of appropriate distance come into play. Recall the joke about the international conference cocktail party where one can identify the Finns by the fact that they're the ones gradually withdrawing toward the walls of the room, retreating while conversing with the Brazilians who are recognized by their constant forward-pressing, hands-on approach in the same conversations. Consulting intercultural guidebooks about the appropriate posture to adopt in various cultures will not solve the problem, if one remains insufficiently aware of the posture one is actually assuming, as well as the postural reaction of the soma with whom one is interacting. Somaesthetic awareness is necessary for both; and while many individuals spontaneously display such awareness, many others require an effort of conscious attention to cultivate and deploy this awareness.

4. Muscle memory's incorporation of social roles can create its own somaesthetic pathologies of everyday life. Take the drill sergeant from my days as an officer in Israeli military intelligence. So fully had he absorbed his professional persona – with his body always held rigidly erect in hyperextension and his habitual stiff, jerky gait and sharp, mechanical hand movements – that he seemed incapable of shedding this attitude. We laughingly imagined how he returned home to make love to his wife in the same barking cadence, mechanical gestures, and jerky rhythms that defined his somatic behavior, without his even realizing that he was behaving like a drill sergeant rather than a lover and thus missing out on love's more tender and fluid communicative pleasures. Although we never followed him home to see (or ask his wife) whether he indeed suffered from this somaesthetic pathology, I did indeed witness during my years in Israel a different form of incorporated role fixation that was implicit, unintentional, and unnoticed by the role player.

My then father-in-law, a Tel Aviv judge who dearly loved his family did not realize that he daily brought his courtroom *habitus* back to the dinner table, augustly bellowing orders to family members as if they were bailiffs or accused criminals. He did not realize that his tone and body language were inappropriate, until his daughter and wife called them to his attention, and he apologized with genuine embarrassment. Fortunately, after his postprandial siesta, he awoke largely freed from his courtroom soma that had earlier been primed by a stressful morning in court. Because it often takes time, distraction, and relaxing substances to free oneself from a deeply embodied and labor-intensified social role and prepare a differently embodied persona, I understand why bars are so important on evening commuter trains and on the pedestrian's and motorist's way home from work.

5. Implicit performative or procedural memory is indispensable for getting us efficiently through countless everyday activities. By enabling us to perform so many familiar tasks with no explicit attention, it allows us to direct our limited resources of attentive consciousness to more difficult problems. As noted earlier, a writer can focus on how to express his philosophical ideas instead of how to position his hands and flex and move his fingers to perform the necessary actions for pressing the right keys to generate the letters of the words he wishes. A violinist can likewise concentrate on the expressive qualities she wants to produce rather than on the way she is gripping her instrument and positioning or moving her shoulders, torso, and arms when performing. In the same way, a DJ can concentrate on the songs or tracks he is sampling rather than on the posture of his ribcage and hips when he is spinning those records. In these and similar cases, their muscle memory performs the necessary sequential acts of muscular contraction, positioning, and movement without explicit consciousness. Unfortunately, however, as I learned from clinical practice, the habits of muscle memory formed to perform such spontaneous body adjustments often do so in ways that are not somatically advantageous and lead to unnecessary fatigue, pain, or injury. The writer develops carpal tunnel syndrome from holding his wrists too rigidly; the violinist suffers pain in the back, neck, and arms because she holds her shoulders and ribcage too tight, thus forcing her bow strokes to be more effortful. The DJ (who happened to be a graduate student at the New School for Social Research) fell victim to a very sore elbow, because his habit of freezing his hips and ribcage in mental concentration (a habit quite common in academic readers who

daily spend many hours in focused seated study) put extra pressure on the elbow joint it its effort of spinning the records. But when he learned how to relax the hips and torso so they could rotate with the record-spinning arm, his elbow problem disappeared.

Let me conclude by noting some pathologies relating to a much more basic activity typically governed by performative muscle memory: eating. For all its natural or instinctive aspects, eating is a sequential activity that we learn how to perform, both through implicit and explicit forms of learning. We learn the sequence of cutting and chewing a large slice of meat before we swallow it; or the sequence of first lifting and then tilting the cup to one's mouth to drink our water rather than lowering the mouth and extending the tongue to lap it up. We develop distinctive habits in the way we eat, and these go beyond the obvious examples of formal table manners and the handling of various eating utensils (knives, forks, spoons, chopsticks, cups, glasses, bowls, pitchers, salt shakers, etc.). There are different habits of how one deploys one's lips and tongue, what part of the mouth one uses in chewing; how fast, how long, and how vigorously one chews; how fast, how often, and how hard one swallows; how often one pauses during eating in order to drink, to speak to one's dining companion, or to reflect on the food's taste, aroma, or texture or on one's diverse feelings in eating including the feeling of becoming satiated. The performative muscle memory of eating is very deeply entrenched because it is a procedural skill we use daily. The result is that we typically eat without thinking explicitly about it.

This is surely convenient because attention instead can be wholly absorbed on something more interesting or useful, such as reviewing the lecture notes for an ensuing lecture. But such muscle-memory automatism of eating can prove problematic if one's dining habits are faulty; and they can be flawed in a variety of everyday ways. For example, there are people with habits of ugly, sloppy, or excessively noisy ways of eating that pose somaesthetic problems for dining companions who have to witness them. Besides the visual or auditory displeasure they experience, observing such unaesthetic eating styles may rob them of their own appetite and enjoyment of food. Other somaesthetic pathologies resulting from habits of muscle memory can affect the problematic eater himself. One touted feature of habit is that its muscle memory increases speed of performance because no time is taken (or needed) to deliberate in action. So relying purely on muscle memory without attentive deliberation about how we eat enables us to eat more quickly, but those who habitually eat too quickly often suffer from poor digestion and a variety of related somatic discomforts (whose portrayal and medicinal remedies fill countless hours of television advertising). Many who suffer in this way know that part of their problem is eating too fast, but one reason they continue to eat too fast is that they do not notice how fast they are eating because muscle memory sets the rhythm and style of their eating. They thus pay no attention to how they perform this sequential, temporal activity; and without such attention they cannot monitor it so as to slow it down. Recent studies show, moreover, that eating fast also promotes obesity; and once again, if we are unaware of our speed of eating, we cannot know how to slow it down to avoid its negative consequences.[9]

Another somaesthetic pathology of inattentive habit contributes to overeating. When food or drink is consumed rapidly and inattentively, we are less able to appreciate its taste. As our eating enjoyment is diminished by this inability to properly savor our food, so we tend to compensate by eating more. Unsatisfied by the flavors and textures of what we've already eaten (because they have gone largely unnoticed through our habitual hurried or inattentive eating), our quest for the satisfaction which we know s*hould* come from food drives us to continue eating in the hope that such satisfaction *will* eventually come. This unfulfilled hope often keeps us eating even after we've already had our fill. Such frustrations of satisfaction through inattentive eating habits that rely entirely on the swift efficiency of muscle memory may be one cause for the common pathology of overeating in America and other fast-food, rapid consumption societies. In any case, its failure of gustatory and hedonic appreciation constitutes in itself a regrettable somaesthetic pathology of everyday life.

These are not the only somaesthetic pathologies that contribute to the overeating and consequent obesity from which so many suffer in contemporary consumerist culture. Driven to consume through persistent and ever increasing stimulation that continuously strains and blunts our discriminatory sensitivities (in ways de-

[9] There are studies that link fast eating with obese adults and adolescents, but also experimental studies that show that "increase in the speed of eating in normal weight volunteers caused overeating…, replicating the pattern of eating in a group of obese patients." One study showed that the use of Mandometer (a machine that tells eaters while they are eating that they are consuming food more rapidly than their eating therapist designates) led to loss of weight [see 22–24, and 25]. In [25] the authors note that earlier efforts to reduce obesity through therapy lifestyle interventions were more effective in younger children than in adolescents; there may be many reasons for this, but one reason might be that the eating habits of adolescents are more deeply entrenched, hence more resistant to change.

scribed by the Weber-Fechner law), many people are unable to perceive that they have eaten enough until they have considerably overeaten [for more discussion of the relation of the Weber-Fechner law to issues in somaesthetics, see 13]. They have lost the somaesthetic discrimination of the proprioceptive feelings of having their hunger satiated or being comfortably full. They can only discriminate the stronger, discomforting over-stimulation of feeling "stuffed," so they identify that unpleasant feeling with having reached satiety or eating satisfaction, and they thus continue to eat until they feel such discomfort. We thus have a vicious cycle of eating more but enjoying it less, because one is not properly aware of when to stop eating; and such awareness is a matter of somaesthetic discrimination.

These arguments regarding eating and obesity have a particular relevance to the ramified project of somaesthetics, an interdisciplinary field of theory and practice broadly defined as the critical study and meliorative cultivation of the soma as a site both of sensory appreciation (aesthesis) and creative self-fashioning. As creative self-fashioning suggests the aesthetic stylizing of the soma as an external object of attractive representations, so the focus on aesthesis concerns the soma's perceptual acuity and inner experience, where cultivation of improved aesthesis means "feeling better" both in the sense of enjoying better feelings but also in the sense of perceiving what we experience more accurately and clearly.[10] It is sometimes useful to emphasize the distinction between the perceptual or inner dimension of somaesthetics and the dimension of external body representations that so dominate our culture's concerns with embodiment. But if deficient somaesthetic perception of our eating can be casually linked to problems in maintaining one's external somaesthetic form, then there exists an important connection between somaesthetics' perceptual and representational dimensions. It is common to say that how we feel affects how we look; happiness can give us a winning smile, while depression, pains of illness or fatigue can make us look unattractively dull and diminished. Our brief, closing arguments for deploying somaesthetic perception to overcome obesity from eating habits of inattentive muscle memory provides, however, a new meaning to this familiar saying.

[10] Because of our culture's fascination with advertised ideals of bodily beauty and pleasures (along with our unavoidable failures to achieve them), several philosophers presumed that somaesthetics' focus must be the quest to have perfectly looking bodies and to enjoy those of others. They narrowly viewed somaesthetics' concern with body consciousness as consciousness of the body as an attractive object; and thus they criticized the project as a servile reflection of society's superficial body values, while I was equally (if not more) interested in emphasizing the body as soma (or body-mind), i.e. as a perceiving, intentional, locus or subject of consciousness, whose powers of sensory perception (aesthesis) can be heightened through cultivation and reflection. Through such enhanced perceptual powers, we can improve our self-use (including the stylizing of our external somatic form) by overcoming problematic habits of muscle memory.

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A PARADIGM FOR IDENTIFYING ABILITY COMPETITION (PROVIDING EXAMPLES OF SPORT GAME AND FIGHT)

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ABSTRACT
Effective competition for access to social resources is dependent on skills defined also as competences for action, cooperation and counteraction. Therefore, the objective of the study was to formulate a consistent set of criteria by means of which it would be possible to ensure objective identification of an individual's skills to take action in competitive conditions, with particular attention to sport game and fight. It was assumed as the basis of the paradigm that the skill of sport game and fight is the conscious or intuitive application of solutions surprising the competitor by their uniqueness, choices or speed of action. The following criteria were distinguished among the criteria proposed for identifying competitive skills: surprise by creativity of action shown by precision, flexibility and uniqueness of performance, surprise by choice indicated by the dynamics of the repertoire of actions, and surprise by speed of action resulting from increasing velocity or making use of the variability of rhythm, speed and direction of action. The concept presented appears to be a consistent paradigm of objectivized identification of competitive skills. On the basis of this identification, it is possible to formulate practical directives which allow for the improvement of processes: educating, coaching, or managing the development of competences with respect to effective competition for access to social resources, including sports resources.

Key words: competences, competition, surprise, flexibility, variety, speed

Introduction

The effective resolution of social situations of various degrees of difficulty is determined by the skills of action, cooperation and counteraction. Among the skills essential for effective living, a particular role is played by the skills of cooperation and competition for access to resources. Sport skills, because of their transparency and the dynamics of conflict situations occurring in sport competition, constitute an excellent basis for the examination of both cooperative and competitive skills with regard to the case of sport games, as well as solely competitive skills in the case of individual sport competitions and martial arts.

Issues regarding identification of human action skills in the social context are considered within the scope of cooperative actions. The studies concern skills defined as soft and hard [1–3]. Soft dynamic skills adapted to the situation include personal and relational skills. The former are determined by cognitive skills, that is, knowledge and emotional intelligence, linguistic skills defined as fluency in speaking and writing, and physical skills which are determined by the anatomic structure of the body, sensomotor features, the structure of sense organs and health. On the other hand, relational skills include communication and organizational skills.

Another group of social cooperation skills includes hard competences identified with stable professional qualifications reinforced during a long-term process of education and self-education.

The sport game and fight are considered social phenomena apart from cooperative skills demanded from the participants to show competing skills. The skill of action and counteraction appearing in individual martial sports as well as in team games as actions of players relatively dependent on partners undoubtedly result from individual competences, and these competences are considered in the context of competition. On the other hand, the skills of cooperation and co-counteraction appearing in the team game indicate relational competences destructive in nature [4, 5]

When systematization of sport skills is developed, we can distinguish the skills of the sport fight and the sport game. Even though the conditions defining the sport game or fight are similar – in both cases we are concerned with antagonistic parties, with conflict of interest, with hidden motivations, with camouflage and surprise, as well as the limited possibility of counteraction of the opposite party – the means applied, and especially the skill of performing tasks, show fundamental differences between sport game and fight [6, 7].

A game is a regulator of sport conflict and the parties participating in it aim at resolution of the competition to their benefit. A game is carried out according to accepted rules, with a limited right of physical influence on the opponent. Resolutions of sport games are binding on the parties within a specified time resulting from the tournament cycle. Participants in a sport game aim at the effective achievement of contradictory goals by skilful relocation of the equipment (ball, shuttlecock, disc) or by counteracting its relocation within the game field by applying blows, throws, grasps and blocks.

On the other hand, a fight is a regulator of sport conflict differing from a game in the possibility of applying physical influence on the opponent. The parties participating in a sport fight aim at the effective achievement of contradictory goals by skilfully limiting the psychophysical activity of the opponent and counteracting limitation of their own activity by applying blocks and grasps, throws and blows to the opponent. In the case of sport fights, resolutions are binding for the parties within a specified time determined by the dates of competition, e.g. world or European championships.

Taking into account the above criteria, we can classify sport disciplines as sport fights or sport games. The combat sports will undoubtedly include, among others, boxing, wrestling and judo. However, in sport disciplines traditionally regarded as sport games such as rugby, American football or ice hockey, we observe the balanced contribution of actions included in both fights and games. Football and basketball are disciplines in which the dominant regulator is a sport game, while in competition the means of sport fight are used more and more often, even though the rules of the disciplines considerably limit the possibility of their application. Volleyball and individual games, for instance, lawn or table tennis as well as fencing, are disciplines in which the sport game is the only regulator of the activity course.

Sport skills are determined by the availability and situation-related opportunity for the completion of a given action. A significant number of studies regarding external factors such as conditions having an influence on sport skills are compliant with the Cartesian paradigm. The studies provided in particular the possibility of presenting effort-related motor abilities and psychosocial factors. Effort-related abilities have been the subject matter of many studies, among others on the biochemical [8] and physiological [9, 10] levels. In addition, motor abilities have been extensively identified [11 – 13], with special focus on the research of condition-related [14] and coordination [15 – 17] abilities. Studies regarding psychosocial factors [18 – 20] have also been conducted. In relation to these factors, the role of external conditions, that is, the situation in which the sportsman takes action, comes down mainly to treating them only as factors disturbing the skills of action rather than any essential factors.

The importance of availability- and situation-related capabilities for action in the sport game as factors determining operating skill has been emphasized by many sport game researchers, however assigning different weights to these factors (Gracz [19], Naglak [21, 22], Panfil [4–7], Superlak and Wołyniec [3], Superlak [23, 24]. Although Naglak [21], whilst defining game skills, recognizes the influence of external conditions on these skills, this author emphasizes the basic importance of disposition-related feasibility by asserting that "[...] proficiency in the game is dependent on many dispositions, such as the ability to think, speed and rationality of decisions, unconventional motor skills, and most of all the ability to cooperate with partners". In another publication [22, p. 38], he consistently emphasizes the role of availability-related conditions of action, however extending their dimension. Naglak states that championship is achieved by the player who "[...] in the condition of strong motivation for achievement and appropriate emotional stimulation quickly makes correct decisions and fulfils them effectively" [21, p. 68]. Among dispositions for the game, this author lists personality traits, fitness and coordination abilities, special perceptual and motor skills, bodily flexibility and morphological features.

On the other hand, the publications of Superlak and Wołyniec [3] indicate the need to take into account the influence of the circumstances in which the player operates on game skill. Based on the assumption that in the sport game players aiming at the creation of a situation favourable to them in this way put the opponent in an unfavourable situation. The authors mentioned state that the favourable situation is determined by completeness of information, certainty of decisions and the freedom of actions resulting from them. The characteristic features of unfavourable situations are incompleteness of information, uncertainty of decisions and as a consequence limited freedom of manoeuvre. This indicates that the level of risk and entropy determine the situational freedom of players' activities.

On the other hand, Panfil [7], carrying out an analysis of situation in the game, distinguished so called independent and fixed, as well as dependant, operationally modifiable actions. He stated that fixed and independent situational factors determining game skills include the game time elapsed, place of the game, current score, game of the opponents, regulations and rules, for example 'fair play'. Situational dependent factors, subject to operational modification, cover game strategy, tasks of players, behaviours of the coach and partners, the incentive system and climate within the sport team.

The game or fight skill is undoubtedly a relative value defined each time, a disposition-related and situational possibility of taking an action. It means that a specified system of individual abilities is transformed into disposition for actions, if the situation allows it (it is not too difficult). It can be concluded from the above that the sport game or fight determines the level of disposition, and we evaluate this level in relation to external circumstances. That is, a sportsman with formed dispositions can act skilfully only when the conditions allow him to reveal these dispositions. It means that in many cases reduction in skill shown in sport competition after promotion of the player to a higher level of qualified competition is not the result of coaching failures but of objective individual limitations. The situation after the promotion is too difficult and the individual dispositions presented are no longer sufficient to compete skilfully. Therefore, the term a 'wasted sport talent' for a sportsman promoted to a higher level of classified competition is often used in an inappropriate way.

Therefore, the disposition-related possibility of action which is illustrated in Fig. 1 is determined by the optimal level of individual abilities identifiable in a systematic way. Among basic dispositions, mainly the need to take action and ability to take risk are distinguished. The need to take actions ensures the dynamics of incentive, emotional and motor processes, while the ability to take risk determines the efficiency of thinking processes, i.e. the ability to acquire knowledge about the action which allows the individual to focus attention on any facts essential to the action. The ability to take risks defines also the scope of association of facts (intelligence) and this facilitates the forecasting of situations. The individual dispositions listed above determine the selection of actions and their anticipated completion which further on makes it possible to surprise the sport competitor. Along with the process of acquiring the skill of taking action and the growing dynamics of the situations in which the action is taken, the role of the awareness of action is limited for the benefit of unconscious control of it. Thus the action becomes intuitive.

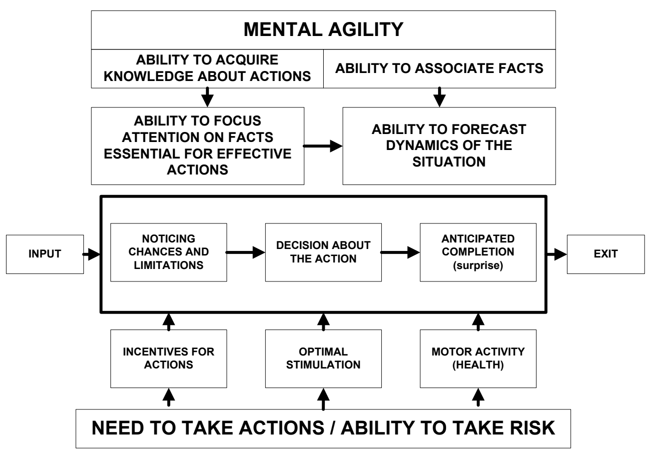

Figure 1. Disposition-related possibilities for the sportsman to take action

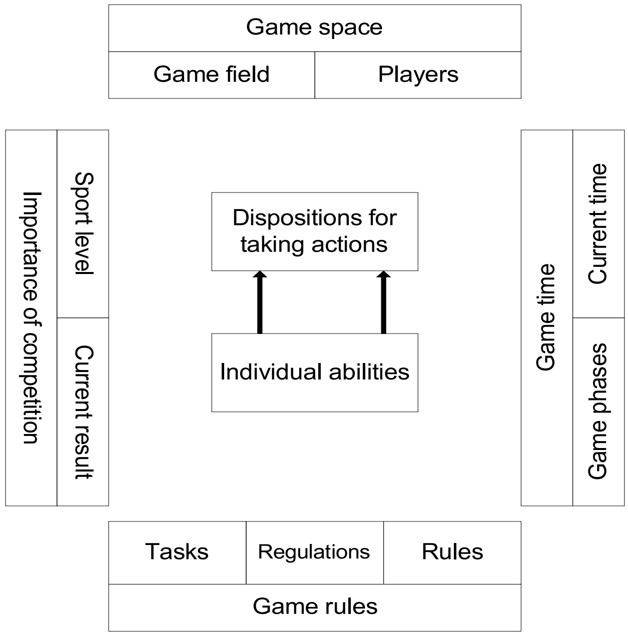

Figure 2. Situational possibilities of the sportsman's actions

On the other hand, the situational possibility of taking action, that is, the possibility of transforming individual abilities into dispositions for action in sport results mainly from independent factors such as the importance of competition, space or time of game and those dependent on participants of the sports competition, i.e. tasks, motivators or principles (Fig. 2).

The following are examples of identification of the skills of taking action considering the disposition-related and situational possibilities:

1. football:
   - taking the ball away from the competitor (action objective) by shoulder charging (disposition-related possibilities) in the midfield zone of the game field along the side line with the score 0:1 in the 88th minute of the game (situational possibility),
   - scoring a goal (action objective) by kicking the ball with one's foot (disposition-related possibility) without any contact with the opponent at a distance of 10 m from the goal (situational possibility),
2. volleyball:
   - scoring a point (action objective) by a single block (disposition-related possibility) when

the ball is hit by the competitor from zone III with the score 13:13 in the fifth set in the European championship game (situational possibility),

3. lawn tennis:
   – maintaining the ball in the game (objective) by hitting the ball by volley (disposition-related possibility) over the competitor near the net, from the game field corner with the score 40:15 in the first set in the presence of an audience including 5000 people (situational possibility),
4. wrestling:
   – scoring a point (action objective) by throwing over the hip (disposition-related possibility) in the final phase of the fight, with a competitor recorded higher in the ranking, in the fight for the bronze Olympic medal (situational possibility).

Differentiation of the importance of individual dispositions represented by individual sportsmen and allowing the skilful resolution of situations within a game or fight create the need for an individual perception of the sport skill profile and the consideration of equifinalism in action. These dispositions include mental, motor, constitutional, psychological and pro-team.

The problem presented in this way allowed us to formulate the objectives of the publication:

Cognitive objective:
– on the basis of many years of research on the game, a consistent set of definitions and terms defining the individual's skill of taking action in competitive conditions was formulated.

Practical objectives:
– on the basis of the criteria defined, the skills of cooperation and competition in the game and in the sport fight were identified, and illustrated using examples.

The skill of playing a game or competing in a fight is the conscious or intuitive application of a solution which surprises the competitor with creativity, selection/variation or speed of action. Surprising by an action means causing a situation which the competitor did not expect or did not take into account when the decision about taking an action in an attack or defence was made. In each action, we take into consideration any circumstances which may have an effect on its result. Any unexpected events cause confusion and reduction in action effectiveness, for instance, reducing acting speed, increasing the probability of making a mistake. If the surprised sportsman does not have a ready scheme of reaction (counteraction) which would allow him to overcome the confusion and disorganisation, he experiences the tendency to apply primitive actions and the reaction of increased emotional stimulation, sometimes also a reduction in the motivation for action. In the situation of surprise, the important action is to conceal one's own intentions to make sure that they are not completely known to the opponent. In order to hide intentions, information about one's own indispositions is disseminated, the composition of the team is concealed, unexpected methods are used in the game or fight, the game is avoided or seemingly irrational action is taken. Withdrawal from rational action is called a paradox by surprise which often unintentionally happens to an inexperienced sportsman. The experienced sportsman in a conscious way surprises the competitor as follows:

– by performing the actions in a perfect way (according to a rational model),
– flexibly adjusting the action to varying situations,
– applying various actions,
– using a change of velocity, direction or speed of action,
– cooperating with the use of anticipation,
– introducing new variants and combinations into the game or fight.

We achieve surprise with an action by using various tricks which consist in the intentional creation of an unexpected situation for the competitor, by confusing them and causing their temporary helplessness.

We carry out identification of individual methods of surprising the competitor in the sport game and fight on the basis of specified criteria, i.e. surprise by creativity, speed or choice.

Surprise by creativity

The determinants of creativity of solutions used in the sport game and fight are precision, flexibility and new quality. The criteria mentioned are interdependent in such a way that actions performed precisely are transformed into flexible ones, and any corrections and modifications increasing the flexibility of action lead to the creation of new solutions.

Surprise by precision of action

Precision of action is the result of developing an individual pattern of performing actions. Precision of action is ensured by the effective use of the coordination of movements and mental agility in relation to an objective of the sport game or fight. The action is regarded as precise if in the evaluation of experts, e.g. coaches, it is carried out according to a rational model 'smoothly', surely and naturally. One important determinant of the precision of actions in the sport game or fight is also the stability of precision, that is, the skill of maintaining it in spite of growing fatigue. The action should be treated as precise if the motor activity used in the action is a mastered reflex. Such an action will be conducted subconsciously, and with an intentionally chosen objective and a consideration of situational context.

Examples of precision actions are:
- in judo, winning the fight by throwing the competitor on his back over your hip,
- in fencing, scoring a point by cutting the competitor,
- in lawn tennis, scoring a point by hitting the ball with a volley,
- in football, winning the ball by so called sliding tackle.

Examples of cooperation in double or triple combinations or variants:
- in volleyball, scoring a point by a double block in defence or a single short ball in attack,
- in football, winning the ball by so called doubled coverage in defence or winning the game field by passing the ball to a partner running around the defender in attack.

This indicates that when precision of action is evaluated contrary to the evaluation of precision of a motor activity, we take into account the evaluation of the player's decision about the game's or fight's objective, and particularly its adequacy and speed.

In the situation in which the player while performing a given action concentrates on the fight's or game's objectives and performs motor activities intuitively, higher flexibility of action becomes the indication of increasing the scope of possibilities for surprising the competitor.

Surprise by flexibility of action

Flexibility of action is the ability to apply a specific action in changing situations in the game or fight with varying degrees of difficulty. The scope of flexibility of action is determined by the number of situations in which the player applies a specific action. Therefore, ensuring that actions are performed precisely comes down to correcting or modifying these actions in order to extend the scope of their applicability. External (situational) factors determining flexibility, in narrower understanding, are:
- the structure of the competitor' body, i.e. height, body weight, limb length,
- the competitor's activity, i.e. active or reactive,
- strong and weak points of the competitor in attack or defence, as well as
- the volume of the operating space.

In broader understanding, the flexibility of an action is indicated by its precise execution regardless of the current score, phase of sport competition, sport level of the competitor, etc.

In the case of cooperation in double and triple combinations and variants, in attack and defence, in sport team games, indications of flexibility of cooperation include:
- the possibility of exchanging functions within the combination or variant,
- the number of players who take part in the combination or variant,
- the volume of space in which the variant or combination is played,
- the number of zones in which the variant or combination is played.

The greater the possibility of exchanging functions, the higher the number of players who can participate in the given combination or variant in various zones of the game field, the smaller the space required to complete the combination, and the more flexible the cooperation.

Surprise by a new action

Ensuring flexibility of action in a systematic way by making situational corrections and modifications leads to transformation of the given action into a new one, giving it the dimension of a new quality.

The creation of new qualities in the sport game or fight is the most important factor in extending the scope of actions used in the sport game or fight because it ensures the greatest possibility of surprising the competitor with an original solution not used earlier.

Examples of transforming flexibility of actions into new qualities, thus new actions, are:
- in volleyball, winning a score by achieving higher flexibility, the so called single short ball, led to the development of so called single moved ball or "pipe",
- in lawn tennis, higher flexibility of the volley led to development of the drive volley,
- in football and basketball, so called shortening of protection for actions of the partner taking the ball away from the competitor led to transformation of protection into double coverage of the competitor.

Surprise by velocity

Another factor in surprising the competitor identified in this paper is the velocity of action in the sport fight and cooperation in the sport team game, with surprise by velocity covering both increase and change in velocity.

Surprise by increase in the speed of action

The speed of action in the sport game and individual games, as well as performing mutually dependent actions in sport team games, is determined sometimes by execution of an action, i.e. the time of making decision and performing it.

For instance:

– decision – to win the field and perform – dribbling
– decision – to score a point and perform – throw into the basket.

The shorter the time for action, the greater the chance of surprising the competitor. The speed of offensive action is determined mainly by motor dispositions (coordination of movement, dynamic strength and motion velocity). In the case of defensive action, speed depends equally on prediction of the competitor's actions, anticipation of them and motor execution.

On the other hand, speed of cooperation is determined by synchronization and coordination of action taken by players participating in the double or triple combination or variant. The speed of action results from timing, that is, from the anticipation of performance. By predicting the actions of the partners, it is possible to take action in advance and in this way surprise the competitor. In practice, synchronized and coordinated actions are taken simultaneously or slightly in advance. Examples of quick cooperation are in volleyball scoring a point by a short or moved ball, in football passing the ball without taking control of it to a so called third partner running to the position, in basketball passing the ball to the partner who is jumping to the basket. The idea of quick cooperation in attack is passing the ball without taking control of it to partners moving (running, jumping) in the narrowed space of the game. Factors determining the speed of cooperation are mainly intellectual dispositions, including in particular:

a) features of attention:
   – focusing attention on the combination executed,
   – moving attention to cooperating partners, and
   – sharing attention between partners and the ball.
b) knowledge of the rules for executing the combination,
c) predicting actions of partners and taking action in advance.

In the case of cooperation, motor features are secondary because relocation of the ball by passing it and movement of cooperating players are easy as far as motor aspect is concerned.

Surprise by change in the speed of action

Surprise by the speed of action includes also surprise by change in rhythm, rate and direction of selected movements. The variety of combinations in the change of rhythm, rate and direction determines the possibility of surprising the competitors. Moving the ball at a changing rate means fluctuating between slower and faster relocation with the ball. The changing rhythm involves fluctuating between frequent contacts with the ball, for example short passing of the ball in football or low bouncing in basketball, and less frequent contacts such as so called longer passing of the ball in football or high bouncing in basketball. Any changes in the direction of ball movement also lead to surprising the competitor.

In the case of a defensive game, any change of rate and rhythm concerns changes of intensity (force) of pressure on the competitor. Change of direction means varying the sides of counteraction (from the left side of the competitor or from his right side, lower or higher).

In the case of cooperation in sport team games, the changes concern rate and direction, i.e.:

– changing the speed of running to the position (using acceleration) and
– changing the direction of passing the ball (to the player or in front of the player).

In the case of double or triple counteraction, any change of speed of cooperation against the ball includes changing the rate and rhythm, i.e.:

– counteraction at the first or second rate,
– counteraction in a constant or varying rhythm.

Another indication of the rate of action is the time to combine a sequence of actions. The shorter the interval before beginning a subsequent action, the faster the action and the greater the chance of surprising the competitor. Thus, the factor increasing the chance of surprising the competitor with the speed of action is the 'smooth' combination of actions following each other in attack or defence in the sport game or fight, as well as smooth movement from attack to defence and the other way round. Combining actions in sport competition is identified with the game or fight the progress of which forces the player to continuously execute various actions one after another, often using anticipation. Therefore, habitual quick movement from one action to the next increases the chances of surprising the sport competitor.

Surprise by choice of action

The third factor identified among the skills of surprising the competitor is surprise by choice of action. The choice of actions depends on variability, that is, the scope of actions that the player may apply to resolve a given situation. Contrary to flexibility, variability of action is the skill of resolving the given situation by means of various actions. For example:

- in football, choosing the way of winning the game field by an action relatively dependent on the partner, that is, dribbling or moving the ball or bypassing the competitor using a feint, or winning a running competition. Also, choosing the way of winning the game field by means of an action absolutely dependent on the partner, i.e. playing the ball by running around the player with the ball or running from behind the back of the player with the ball or making a change of position (transverse, perpendicular, parallel), etc.,
- in boxing, choosing the way of scoring points by simple blows or hooks or 'on the body', and also choosing the method of protection from a blow by shielding, blocking or clenching.

Variability of action in the sport game and fight can be identified in the static dimension with a set of actions or in the dynamic dimension with variability of an action sequence.

Surprise by range of actions

In the first case we define a set of actions performed by the player precisely and flexibly and which are used to resolve a given situation in attack or defence. The higher the number of actions mastered by the player, the greater the possibility of potentially surprising the competitor by choice of action. There is also the possibility of evaluating the variability of occurrence in the situation in which the player uses at least two different actions to resolve a given situation in the sport game or fight. Using only one solution precludes the possibility of surprising the competitor by choice.

The higher level of action variety in the static dimension is indicated also by uniform distribution of the number of performances for individual actions used to resolve a specific situation, e.g. winning the game field by means of individual actions in sport games or scoring points using offensive actions in martial sports. The more uniform the distribution of actions, the higher the chance of surprising the competitor by variety. For instance, if the player uses four actions in attack to win the game field, he will show the highest variety if individual actions are performed at 25%. We identify similarly the variety of performing double and triple combinations and variants in sport team game.

Surprise by dynamics of action sequences

Another indication of the level of surprising the competitor by choice of action is so called dynamic variety identified on the basis of a variety of sequences of actions (two or three) taken one after another in the following systems:

- individual actions in attack performed consecutively, e.g. in football, winning the game field by bypassing the competitor using a feint/ dummy, then dribbling and scoring a goal by kicking the ball into the goal,
- individual actions in defence taken in sequence one after another, e.g. in football, winning the ball by using the shoulder charge**,** then leaving the opponent behind and sliding in,
- cooperation in attack by means of performing a sequence of actions one after another, including, in volleyball, creating situations for playing the ball by passing it to the playmaker and scoring a point by making a single short ball,
- cooperation in defence by means of performing a sequence of actions one after another, including defence in the field and double blocking.

A very important component of dynamic variety is to perform a sequence of actions combining defence with attack, that is, the ability to move from defence to attack and vice-versa:

- in football, after accepting the ball by sliding in, winning the field by passing to a partner,
- in basketball, after winning the ball by taking it from the board in defence, winning the field by passing to a counterattacking partner,
- in team handball, after defending a throw by the goalkeeper, passing to a counterattacking partner,
- in fencing, striking after repelling.

The higher the variability of the systems of actions in offensive, defensive, offensive-defensive and defensive-offensive sequences, the greater the dynamic variability and the chance of surprising the competitor with variety.

Conclusion

Formulating a consistent system-based paradigm for identifying the sportsman's action skills in the sport game and fight makes it possible to evaluate sporting skills and as a consequence define rationalized practical directives improving the processes of teaching sport game and fight, as well as coaching of sportsmen and sport teams and management of sport skills.

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"YOU THINK YOU ARE TOO OLD TO PLAY?" PLAYING GAMES AND AGING

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ABSTRACT
Health deteriorates with age due to hormonal changes and reduced physical, mental and social activity. In turn, this deterioration can lead to a wide range of problems including a fear of undertaking any forms of physical movements. Reports from exercise-based studies indicate there might be considerable improvement with appropriately programmed exercise workloads. However, the lasting effect of such programmes seem to be doubtful as a lot of the elderly drop out along the way, sensing it to be too "organized" and too stressful. Therefore, we claim that some traditional games, as a form of physical activity, can serve its role in engaging elderly adults. They do not require high level of specialization and technical perfection and may also be useful as a form of physiotherapy, particularly with elderly individuals who suffer age- and health-related problems.
Play as a form of physical, playful activity is essential for healthy development of any individual as it seems to facilitate the linkages of language, emotion, movement, socialization and cognition. As a movement activity, it is a rather free-spirit activity that makes a positive difference in brain development and human functioning. Although rooted in biological aspects of life, play needs to be associated with cultural aspects of human development. Especially with the elderly population, this social and also cognitive stimulation is sometimes more important than physical. So in our paper we ask: what potentially positive effects can a traditional play/game have on the elderly people?
Since there has been no research on the health-related effectiveness of such games, in this article we will highlight this problem from a number of different angles as a proposal for various community-based exercise programmes. This will allow us to design and adapt those games, specially to the health needs and social interests of this particular section of the population. It is also meant to serve as a proposal for potential future research.

Key words: aging, traditional games, health benefits, play

Introduction

The percentage of the population over the age of 65 is growing rapidly in Europe. In 2007, it was 16% and by 2050 it is projected to be 28% [1]. The number of *oldest-old* (aged 80 and over), is projected to increase even more rapidly, almost tripling from 22 million in 2008 to 61 million in 2050. While many people in this older age group are healthy, independent and active in various roles contributing significantly to their families and society, it is well known that functional disability increases with age. The increase in concurrent medical conditions causes excess morbidity and mortality as well as disability and decline in functional performance [2].

The physical, psychological, cognitive, and social changes that occur as part of the normal aging process can impact and limit functional performance in the elderly. The extent of the impact on functional performance in the elderly depends on numerous factors, including cognitive status, physical disability, and medical illness, social aspects, and quality of life. When considering a prescription for healthy, successful aging, the vital role of physical activity is immediately apparent in order to remain independent, prevent the development of various diseases and chronic illnesses, reduce the risk of fall-related injuries, and increase overall mood and satisfaction with life [3].

O'Brien Cousins [4] estimates that half of all physical declines associated with aging are preventable if adequate levels of physical activity are maintained. However, only 13% of adults aged 65 to 74, 6% aged 75 to 84 and less than 3% aged 85 and older are adequately active (engaging in vigorous physical activity for at least 20 min three times a week) [5 Physical activity is associated with reduced health care costs of about 7% over 2 years [6]. These expenditures are projected to

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increase by 25% by 2030 (National Centre for Chronic Disease Prevention & Health Promotions).

There is ample scientific evidence on the positive effects that traditional exercise-training programmes (e.g. gymnastics, balance training, tai chi) have on improving physical fitness, but traditional exercise programmes are generally less effective in improving performance of the overall physical, motor, cognitive and social performance. It might be possible to improve performance in older adults to an even greater extent through a more open training programme using recreational games. The purpose of this article is to show the potential benefits of traditional recreational games on the overall performance and quality of life of older adults.

Physical activity and physiological benefits

Numerous studies have previously described the decline in the function of most body systems (for a detailed overview see [3]) muscle loss at a rate of 5% per decade starting in the fourth decade; in people aged 80 and older, muscle mass has on average declined by 50% when compared to young controls; body mass adjusted decline in VO_2max between 15 to 18% for men and 7 to 30% for women per decade after the age of 60; increase in body fat; decrease in postural control, slowing of reaction speed and movement time, and the deterioration of sensory systems (vision, smell, hearing).

Epidemiological studies have demonstrated a dose-response pattern for physical activity that is associated with a lower risk of physical limitations. In particular, resistance training has a moderate to large effect on muscle strength with similar findings on endurance due to aerobic exercise. These effects do seem to transfer to functional activities such as sit-to-stand, stair climbing and walking tasks [7–9].

Physical activity and cognitive benefits

Research on cognitive development across the lifespan has demonstrated that performance in different domains of cognitive functioning follow different trajectories across age [10, 11]. The two dimensions of the human mind – fluid and crystallized intelligence – provide a framework for analysing the mental functions that appear to improve with age and those that appear to decline [12, 13]. Fluid intelligence (e.g., fluid reasoning, working memory, vision perceptual abilities, processing speed) refers to the ability to reason and to solve new problems independently of previously acquired knowledge, whereas the term crystallized intelligence (e.g., verbal knowledge) refers to accumulated knowledge gathered over a lifetime of experiences. Crystallized abilities have been considered generally stable with increasing age, while fluid abilities decline with increasing age, some are thought to begin declining as early as in one's 20s [14–16]. Furthermore, results from longitudinal studies show that there are large inter-individual differences in the intra-individual rates of change of cognitive abilities [17]. More specifically, with age, higher order cognitive functions that rely on the integrity of the prefrontal cortex and the medial-temporal lobes – including executive functions, working memory, and episodic memory – show pronounced decline. Furthermore, the speed at which we perform mental operations decreases and long-term memory functions less effectively. In addition, there is evidence that with age, it is more difficult to ignore irrelevant information or thoughts, and to inhibit dominant responses [18–20].

Cognitive training provides an effective means of improving cognitive function in the target ability, but any improvement from training is relatively short lived, and not all subjects are able to benefit from training [21]. Therefore, other factors by which cognition may be enhanced in older adults receive more attention. One such approach is to examine lifestyle variables. Certain lifestyle factors such as nutrition, physical activity and fitness have been found to moderate age-related changes in selective aspects of aging [22]. The issue of potential interactive effects of different training forms has been assessed in two randomised controlled studies which studied cognitive training, physical training, and their combination in comparison to a control condition. Fabre et al. [23] found that the average difference between pre-training and post-training memory scores was significantly higher in the combined group than in either the aerobic or mental training alone. Potential mechanisms underlying the effect of exercise on cognition are based on physical, mental and social processes [24].

Physical activity and social benefits

Numerous studies focused on the role of social relationships in the lives of older adults indicate an important, predictive association between social support and physical and psychological health outcomes [25]. Older adults experience a myriad of social losses and disruptions to their social support networks, which might lead to feelings of loneliness in old age [26]. Social support networks may change when people retire with the problem of less social contact through work. The decreased ability to drive or even to walk unaided further limits opportunities for socialization. Disruptions to social networks also often continue due to the death of a spouse or close life-long friends.

Epidemiological studies have noted that social support and social networks have significant potential to positively affect older adults' cognitive and functional status, their coping with the stresses of aging and depressive symptoms. Studies have also shown the effectiveness of social support in improving the resistance to diseases which affect the cardiovascular, endocrine, and immune systems [27–29].

The World Health Organization [30] has reported on both immediate and long-term social benefits of remaining physically active. Physical activity empowers older adults and encourages a more socially active part in society. For example, participation in group physical activity can lead to the formation of new friendships and widen existing social networks. It also offers one of the few opportunities for older adults to acquire positive new roles. When Stathi et al. [31] studied the well-being perceived by older adults who participated in physical activity, their findings supported the WHO's recommendations. Respondents frequently indicated that physical activity allowed them to stay fit, which helped to reduce isolation that often results from decreased physical functioning. In addition, all participants stated that physical activity provided an opportunity for them to meet people with similar interests and to broaden their social lives.

Skill acquisition – Motor learning

With increasing age, individuals perform complex tasks more slowly and, in some cases, less accurately than they used to do. Additionally, they also begin to execute motor tasks in qualitatively different ways [32, 33]. Skill acquisition is the process of acquiring a skill that is linked to goal-directed action. Voelker-Rehage shows that performance gains in fine motor tasks are diminished in older adults, whereas the results for the acquisition of gross motor skills are inconsistent. Furthermore, it was shown that age-related learning differences are statistically more robust in complex tasks, whereas in low-complexity tasks, the learning of younger and older adults is very similar. As cognitive resources decline across the lifespan, skill learning performance declines as well. Kennedy et al. [34] confirmed in their study that age-related differences in perceptual motor skill acquisition are partially mediated by declining cognitive resources.

Can traditional activities be a solution for getting the elderly adults engaged?

Recreational games help to develop strength, postural control, eye–hand coordination, agility and reflexes and can contribute to general fitness at any age. Due to their relatively low entry barrier, it can also serve as ice-breaker for social interactions. In fact, research has shown that many of the benefits of leisure activities are the result of its capability of fostering companionships and friendships. These social benefits can increase participants' well-being and mental health. Recreational games or even the simplest forms of traditional plays can provide a focus for social activity. They can be helpful in facilitating social introductions, provide an opportunity to develop social networks, reduce social isolation and, hence, have potential to support the development of social capital. These activities can facilitate bonds between individuals, resulting in social loyalty and team-spirit. Rowe and Kahn [35] point to three factors which, if handled correctly, could have a positive anti-aging effect and enhance successful aging: 1) disease and disability, 2) maintained physical activity and mental function, 3) engagement in any form of social activity. Therefore, our hypothesis is that engagement in low-competitive but playful pastime activities such as a game of Italian *bocce*, English *lawn bowls*, Spanish *skittles* or Polish *sztekiel*, in a socially valuable setting, can make a real difference to the emotional and cognitive engagement of older adults and thus can potentially enhance the quality of life. This thesis is based on the assumption that play is essential for healthy development as it seems to facilitate the linkage of language, emotion, movement, socialization and cognition. As Frost [36, p. 8] has previously said: "It is playful activity, not direct instruction, seclusion, deprivation or abuse that makes a positive difference in brain development and human functioning."

Each of the games mentioned in the paper (Tab. 1) can have a strong socializing influence and this can also help to motivate older people to take part in a game of *sztekiel* in an open air environment or have several brisk walks during the game of *lawn bowls*, which would extend their health and build up their self-esteem as well as the positive socializing effects. It should also be noted that each of these activities bring clear health gains such as muscle endurance, reduction in the strain put on knee joints (while walking or keeping balance during throwing), increase in heart rate. Such activities also certainly improve cognitive processing and slow down the onset of functional incapacity.

Table 1. Classification of traditional games according to potential health benefits

Health factor	Definition	Traditional game	Chances of potential improvements	Requirements (in terms of skills)
Information processing speed	Ability to process input quickly for better response time and an enhanced ability to adapt to changing environment	Bierki Bocce Darts Lawn bowls Pierścieniówka Ringo Sztekiel	low moderate high moderate high high high	reflex
Attention	Ability to both focus on information of relevance to the organism and inhibit or ignore information which is task-irrelevant	Bierki Bocce Croquet Curling Darts Lawn bowls Pierścieniówka Horseshoe pitching	high high high high high high moderate high	eye–hand coordination
Mental set shifting	Ability to shift back and forth between multiple tasks, operations or mental sets	Bierki Bocce Darts Pierścieniówka Ringo	moderate low moderate high high	reflex and eye–hand coordination
Working memory	Limited capacity store for retaining information over the short term (maintenance) and for performing mental operations on the contents of this store (manipulation)	Bierki Darts Pierścieniówka Ringo	moderate moderate high high	reflex
Inhibition	Ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary	Bierki Darts Pierścieniówka Ringo	high high high high	eye–hand coordination
Solving planning problem	Delineation, organization, and integration of behaviours needed to operationalize an intent or achieve a goal	Bierki Bocce Curling Pierścieniówka Ringo	high moderate high high high	eye–hand coordination reflex
Moderate strength of postural muscles	Ability to execute smoothly movements requiring bending and lifting objects of moderate weight and size both in the horizontal and vertical planes while standing	Barrel rolling Bierki Bocce Curling Lawn bowls Piercieniówka Ringo Horseshoe pitching	moderate low high high moderate high moderate moderate	strength, postural control, agility
Kinetic (walking) abilities	Ability to walk steadily, at different velocities involving various muscles of both legs and arms	Barrel rolling Bocce Croquet Curling Darts Pierścienówka Ringo	high high high high moderate high high	strength, general fitness, postural control
Keeping postural control and balance	Ability to maintain balance by activating appropriate muscles at a necessary level of tonus, with flexibility of the nervous and motor system to control the body position while leaning forward/backward (i.e. throwing or rolling a ball situations)	Barrel rolling Bocce Croquet Curling Darts Lawn bowls Ringo Horseshoe pitching	high high moderate high low high high moderate	general fitness, agility, postural control

Below are descriptions of selected examples of games and potential advantages, which can be provided by those traditional, non-competitive games. It has not been possible to describe all of the games listed in Table 1, but most of them are well-known in their many traditional forms. More detailed descriptions can be found in the World Sport Encyclopedia [37] or other national sport guidebooks.

1. *Bocce* (sometimes *boccia*, in French known as *boules* or *petanque*) – a ball game played one-on-one or by teams. In the one-on-one variety each competitor has 4 balls (team game of *boccia* is played by 2 teams of 2–4 players, each having 2 balls). The aim of the game is to throw one's balls as close as possible to the smaller target ball called *pallino* or *boccino*. The participant whose ball is the closest to the *pallino* wins the round. The game is played up to 9 rounds. The major health gains may be found in the characteristics of the movements involved. Picking up objects (the bocce ball) each weighing approximately 650–800 g. There is also swinging arms and losing the balance involved while throwing the ball at a distance, walking to the place where the balls have landed and bending the body (spine and knees operating) to measure the distance between *bocce* and *pallino* and eventually to lift up the balls up for the next round. All these actions need muscle control and mental readiness to cope with some basic competition, not to mention socialization. The opportunity to spend spare time actively with a group of people of the same age, having similar hobby and often the same health problems allows older people to feel much better not only physically, but also psychically. All of these factors make the participants happier and healthier.

2. Similar health gains may be expected from participating in a game of English *lawn bowls*. *Lawn bowls* (similar to s*kittles* or *bowling*) involves rolling or bowling a heavy bowl with accuracy towards a predetermined spot some distance away. This requires application of an appropriate level of force of the upper limb in a bending position where the centre of gravity is usually lowered to counterbalance the person's unstable balance. Each player has a number of trials and then all players walk 30–40 meters to the place where all the balls have been settled to estimate the distance between the bowls and the central spot. The player with the bowls closest to that central spot is the winner. And to avoid carrying heavy bowls the players change direction and start another game from there, but some carry those heavy balls back to the starting point again. In some countries (i.e. Spanish *bolos*) the balls are thrown at the skittles in order to knock them down and although the use of a range of movements may vary a little bit, the idea of the game remains the same.

3. *Sztekiel* (in English known as *tip-cat*, in French *pilouette*, in Pakistanian *gulli dunda*, in Spain *estornella,* in German *klippe* and in Scandinavia known as *klippa*) – the object of the game is to knock a short stick sharpened at both ends by the use of a longer bat as far away as possible. The game starts from the circle marked on the ground where the short stick (*sztekiel*) rests. First, a player tries to strike the sharpened end of the *sztekiel* with the longer stick (bat) to flip it up and then the player tries to hit the *sztekiel* once again with the longer stick on the volley and knock it as far away as possible. Then, he or she follows this with another hit continuing from where the *sztekiel* has landed and another, altogether giving three hits. After three hits the entire distance is measured (using footsteps or a measuring tape). Measuring begins from the starting circle to the place where the *sztekiel* has landed after the third hit. The winner is the person with the longest overall distance. Thanks to traditional games like *sztekiel,* group of attracted participants have always a reason to meet in a friendly open-air environment. Especially it is good for the 'war generation', who missed their childhood play time due to the war. This kind of games can, in a small way, compensate for what they missed whilst growing up. There are also positive health impacts: using arm strength to strike and hit the stick, walking and bending to pick it up. More significantly, the play is about the accuracy of eye-to-hand coordination. The movements in this game often involve a loss of balance during taking a hit and good level of back muscles' strength. Additionally, participants usually forget their health problems and are not bothered by the pain or other inconveniencies. They are happy to have a go and the presence of other participants gives rise to extra motivation.

Discussion

Despite the fact that a majority of people (in all age categories) agree that physical activity is “potentially health benefiting”, the number of people who actually follow this belief is decreasing. One of the possible explanations for this contradiction may lie in the way physical activity is perceived – as a form of organized exercises (resulting from their earlier school experience where the emphasis was on the body improvement). This is something the elderly are unaccustomed to and which is especially discouraging for those feeling physically vulnerable, particularly elderly women. Some reports [38] have highlighted the strong belief of such women about the assumed risks that deterred them from participating in anything more than gentle recreation.

Attitudinal aspects like self-mobility, self-confidence, expectations and sense of humanity that all add to the quality of independent living are often neglected in research as they are difficult to quantify. Grant [39, p. 782] states even that “given that physical activity means different things to different people and many of the benefits are subjective, intangible and impossible to quantify, adopting an alternative theoretical position would be desirable. Accepting such a notion would require incorporating a range of visions and voices into the research agenda in order to capture a more informed meaning about this aspect of an older person’s life”. Moreover, according to his report on the findings of his research, for the positive health gains to occur in the elderly population, two levels need to be considered: personal and societal, both including changing perception of physical activity and its influence on the culture of successful aging. Also, findings emerging from brain research indicate how nurturing is important to the learning process. These findings provide practitioners with new information on the appropriate timing for different types of learning. By conditioning our minds and bodies correctly, it is possible to take advantage of the brain’s potential for plasticity and to facilitate learning processes. Recently [40], it has been shown that the potential benefits of aerobic exercise extend beyond the cardiovascular health marker but also improve brain health in children and older adults. Despite this though, the problem seems to be how to engage those groups in behaviours and in activities that would enable them to meet the recommended criteria?

Some programmes which are specially designed to meet the needs of elderly people (in. *aquarobic for elderly,* evening *gymnastic classes* or even *Masters Games* for sport veterans and elderly population) prove to be too demanding and too competitive for the vast majority of this sector of population. National surveys in Canada, Australia, New Zealand, the United Kingdom and the USA [39, 41] indicate that only a minority of this age category regularly engage in physical activity at the level requiring high functional capacity. Furthermore, it is often the case that risk factors often occur in combination of unhealthy behaviours with physical inactivity being only one among such patterns of behaviour as tobacco use, excessive alcohol consumption and an unhealthy diet [42]. An awareness of those most typical combinations of sociological attributes and factors may certainly enable prevention to be planned so that multiple behaviours can be modified simultaneously, but this should not discourage physical activity specialists from developing programmes centred around movement only. The report [43] on the effects of the North Carolina Senior Games programme, which was focused on year-round involvement through traditional game activities in local communities, proved positive. Older adults who were most active perceived the most benefits from senior games but did not necessarily have the fewest constraints.

Therefore our recommendation of including traditional games and even simple movement plays originating in folk habitual activities in organized programmes for the elderly populations may be a vital concept that would add some new and much-needed vitality into the health-care system of this sector of the population.

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GROWTH, MATURITY AND FUNCTIONAL CHARACTERISTICS OF FEMALE ATHLETES 11–15 YEARS OF AGE

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ABSTRACT
Objective. To evaluate the growth, maturity and functional characteristics of female sport school participants 11–15 years of age. **Material and methods.** The sample included 200 girls aged from 10.55 to 15.42 years. The majority (173) trained in track and field. Height, weight, three skinfolds and % Fat (NIR) were measured. Grip strength, standing long jump, 2 kg medicine ball throw and 20 m sprint were tested. Athletes were compared by menarcheal status and track and field discipline with MANCOVA. Multiple linear regression analysis was used to estimate the relative contributions of age, height, weight and adiposity to the four functional indicators in two age groups, 11–13 years and 14–15 years. **Results.** Median age at menarche was 12.99 ± 1.11 years. None of the functional tests differed between pre- and post-menarcheal athletes 13 years, while only grip strength differed between late and early maturing athletes 14–15 years. Height, weight and % Fat, but no performance items differed among track and field athletes by discipline. Team and individual sport athletes were heavier, fatter and stronger than track and field athletes but the latter performed better in the sprint and jump. Height, weight and adiposity accounted for significant portions of variation in the four functional indicators in each age group. **Conclusions.** Trends in body size of female athletes attending sport schools were generally consistent with observations for female athletes in several sports. Percentages of variance explained in functional indicators were greater in athletes 11–13 than 14–15 years of age.

Key words: menarche, power, strength, speed, youth sports

Introduction

The heights and weights of young female athletes in a variety of sports or disciplines within a sport are reasonably well documented [1–3]. Athletes in the majority of sports have mean statures that equal or exceed reference medians for the general population of females. Artistic gymnastics is the only sport that consistently presents a profile of short stature. Figure skaters also present shorter statures, on average, though data are less extensive. Body weight presents a generally similar pattern. Female athletes in most sports also tend to have body weights that, on average, equal or exceed reference medians. Artistic gymnasts, figure skaters and distance runners tend to have lighter weights. Gymnasts and figure skaters, however, have appropriate weights for their statures. Female distance runners, though average in height, tend to have low weight-for-stature. In contrast to height and weight, data dealing with maturity status (except for age at menarche), body composition and functional capacities of young female athletes in different sports are less extensive [1–3].

Sport programs for youth vary in structure and operation throughout the world [4, 5]. In many countries, sport federations have national governing bodies with a top-down approach from the elite or national teams to the local level. Major sport clubs also have programs that span the local through professional levels and many have academy or developmental programs for the major sports. Sport schools also offer instruction and competition in specific sports, but schools vary by level of emphasis. Some focus on the elite while others offer opportunities for the general population of youth. In between the extremes, there is a mid-level which focuses on youth who are in the mid-range of athletic abilities and/or who are not necessarily interested in pursuing elite status. The characteristics of young athletes in sport schools of different levels may thus be of interest.

This paper considers the growth, maturity and functional characteristics of female sport school participants

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11 – 15 years of age. It has four purposes: (1) to evaluate the growth, maturity and functional status of sport school participants, (2) to compare the growth and functional status of track and field athletes by discipline, (3) to compare the growth and functional status of athletes in track and field with athletes in other sports, and (4) to estimate the contributions of age, body size and adiposity to variation in functional capacities.

Materials and methods

Subjects

The sample included 200 girls 10.55 to 15.42 years of age from sport schools in the Lower Silesia region (Wrocław, Jelenia Góra, Wałbrzych, Bogatynia, Zgorzelec) in 2004. Most were involved in track and field (*n* = 173) while the remainder (*n* = 27) were distributed among four team (*n* = 22, basketball 9, volleyball 6, softball 5, handball 1, football 1) and two individual (*n* = 5, swimming 3, karate 2) sports. Track and field disciplines included general athletics (*n* = 58), sprinters (*n* = 35), middle distance runners (*n* = 34), distance runners (*n* = 23), jumpers (*n* = 22) and throwers (*n* = 1).

The youth had been training for one to two years prior to the study for about 1.5 hours per session, two times per week. The younger athletes (< 13 years) can be viewed as beginners in their respective sport specializations, while the older athletes (14 – 15 years) are further along in sport training. The project was approved by the local Ethics Committee. Parents of the youth provided informed consent while each athlete provided assent. All athletes were notified that the project was voluntary and that they could withdraw at any time. Identities of individual athletes were anonymous for the analyses.

Variables considered

Each athlete was interviewed about menarcheal status (pre- or post-menarche); if post-menarcheal, the athlete was asked to recall the age at which menarche occurred. Duration of involvement in sport (years) and hours of training per week were reported by each athlete. Anthropometric dimensions included height, weight and triceps, subscapular and abdominal skinfolds measured following the protocol of Martin and Saller [6]. Subjects wore shorts and a T-shirt. Measurements were taken at the same time each day and in a standardized sequence. Height was measured to 0.1 cm with an anthropometer. Weight was measured to 0.1 kg with a medical scale. Skinfolds were measured to 0.1 mm with a Harpenden caliper (pressure of 10 g × mm^{-2}). The BMI was calculated and the three skinfolds were summed to provide an indicator of subcutaneous adiposity.

Relative fatness (% Fat) was estimated with the near-infrared interactance (NIR) method using a Futrex analyzer apparatus calibrated for youth (model 5000A/ZL). The instrument measures optical density at the biceps; age, sex, weight and height are included in the algorithm with optical density to predict percentage fat [7]. The device provides a non-invasive method for assessing body composition

Four indicators of functional capacity were measured. Two trials were administered for each indicator and the better of the two was retained for analysis.

Right and left grip strength was measured with a Jamar hydraulic dynamometer (Sammons Preston, Inc.) to the nearest 1 kg. Subjects were standing and were encouraged to give a maximal effort. Right and left grips were summed to provide an indicator of static muscular strength.

The standing long jump was the indicator of muscular power of the lower extremities. The subject stood behind the take-off line with the feet slightly apart and was encouraged to jump as far as possible. The distance from the take-off line to the point of contact of the heels at landing was measured to the nearest 1 cm.

The two kilogram medicine ball throw was the indicator of muscular power of the upper extremities. The subject stood behind a line with the feet slightly apart and facing the direction to which the ball was to be thrown. The ball was grasped with both hands and the subject was instructed to throw the ball as far as possible in an overhead manner (similar in motion to the football [soccer] throw-in). The distance from the throw line to the point of landing was measured to the nearest 10 cm.

A 20 meter sprint with a running start (5 m) was used as an indicator of speed. The subject was instructed to run as fast as possible. After a preliminary warm-up, two sprints were performed with a rest interval of 2 – 3 minutes between attempts. The sprint was measured to the 0.01 second.

Analysis

Descriptive statistics (means, standard deviations) were calculated by age group for the total sample. Age-specific means for height, weight, BMI, better grip and standing long jump were compared to corresponding means from the 1999 national survey of growth and physical fitness of Polish youth [8]. The national survey used the Eurofit test battery; grip strength of the preferred hand was used [9]. For comparison, it was assumed that the better grip strength between right and left hands was that of the preferred hand.

Median ages at menarche and 95% confidence intervals for the total sample and for the sample of track and field participants were estimated with probit analysis. Menarcheal status and recalled ages at menarche of athletes 13 – 15 years were used to evaluate differences in growth and function by maturity status. Among girls 13 years of age, characteristics of pre- (n = 17) and post-menarcheal (n = 27) athletes were compared. A different approach to classification was used for athletes 14 – 15 years. All but 11 of the 101 athletes 14 – 15 years had attained menarche. Using the median age at menarche of 12.8 years in the national physical fitness survey [8] and a standard deviation of one year, the athletes 14–15 years were classified into three maturity groups: average (age at menarche between 11.8 and 13.8 years, n = 70), early (age at menarche < 11.8 years, n = 8), and late (age at menarche > 13.8 years, n = 12), The 11 pre-menarcheal athletes ranged in age from 13.8 to 15.3 years; attaining menarche at these ages would classify them as late maturing. Two maturity groups thus were formed: (a) pre-menarcheal and late maturing girls (n = 23) and (b) on time and early maturing girls (n = 78).

Multiple analysis of covariance (MANCOVA) with age and age squared as covariates, i.e., to hold age effects constant, was used to compare maturity groups in body size, adiposity and functional capacity. The same statistic was used to compare track and field athletes by discipline and also to compare track and field athletes as a group with the combined sample of team and individual sport athletes.

Multiple linear regression analysis was used to estimate the relative contributions of age, height, weight, the interaction of height and weight, and adiposity to functional test in athletes in two age groups, 11 – 13 years and 14 – 15 years. The younger group approximates the interval of rapid growth associated with the adolescent spurt in girls. Menarche occurs, on average, about one year after peak height velocity [3] and 69 of 99 athletes 11–13 years were pre-menarcheal. The older group approximates late adolescence in girls as most have likely experienced peak height velocity (PHV) and were post-menarcheal (only 11 of 101 had not attained menarche). Mean ages at PHV among Polish girls regularly active in sport were 12.3 ± 0.8 years in 13 girls from the Wrocław Growth Study and Wrocław Longitudinal Twin Study [10] and 12.0 ± 0.8 years in 23 girls from Warsaw sport schools [11].

Separate regressions were done with either the sum of three skinfolds or % Fat included among independent variables. Though related (partial correlation controlling for age, r = 0.74), the two estimates of adiposity are not identical. The former indicates subcutaneous adiposity, while % Fat is a global estimate of adipose tissue as a percentage of body weight. The height × weight interaction term was derived from centered scores [(height – mean height) × (weight – mean weight)]. The regression analysis permitted all variables to enter into the equation, and then the variables that met the criterion for elimination (backward elimination) were sequentially removed. In this protocol, the variable with the smallest partial correlation with the dependent variable was considered first for removal; if it met the criterion for removal (p > 0.10), it was removed. The procedure was repeated for the other variables until those that did not meet the removal criterion remained

Table 1. Characteristics (means and standard deviations) of female athletes by age group

Variable	Age groups, years									
	11 (n = 24)		12 (n = 30 – 31)		13 (n = 41 – 44)		14 (n = 55)		15 (n = 46)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age, yrs	11.1	0.3	12.0	0.3	13.0	0.3	14.0	0.3	15.0	0.3
Training, yrs	1.2	0.6	1.9	1.2	2.0	0.9	2.3	1.4	2.5	1.6
Training, hrs/wk	1.7	0.3	1.8	0.3	1.7	0.4	1.8	0.6	1.8	0.6
Height, cm	149.4	6.8	154.7	7.5	161.1	6.1	163.8	5.9	164.4	5.2
Weight, kg	37.7	6.0	42.9	6.5	48.4	7.8	50.5	5.6	52.0	7.5
BMI, kg/m^2	16.8	1.8	17.8	1.7	18.6	2.2	18.8	1.7	19.2	2.2
Sum skinfolds, mm	23.4	5.5	25.9	7.0	30.4	11.3	29.8	8.0	29.1	8.9
Fat, %[1]	15.9	2.7	17.6	3.4	25.2	5.9	23.7	4.2	23.5	4.9
Sum R+L grip, kg	39.0	10.7	44.6	9.3	53.6	12.7	59.3	9.7	63.9	9.0
Standing long jump, cm	151.7	12.1	164.0	17.2	167.3	17.7	175.2	17.2	175.3	18.5
2 kg ball throw, m	4.2	0.8	5.1	0.9	5.4	1.2	6.3	1.1	6.7	1.1
20 m sprint, sec	3.43	0.17	3.28	0.21	3.29	0.22	3.26	0.43	3.19	0.39

[1] n = 25 at 12 yrs and n = 37 at 13 yrs

in the equation. The standardized regression coefficients (β) allow comparison of the estimated contributions of each independent variable to the explained variance. Coefficients are not related to the scale of the raw data and are interpreted without scale. Positive and negative coefficients indicate, respectively, an increase and decrease in function associated with change in the specific independent variables.

The Statistical Package for the Social Sciences (SPSS) version 14.0 was used for all analyses.

Results

Descriptive statistics for each age group between 11 and 15 years are summarized in Table 1. Years of training increase with age, while training time per week is rather constant across age groups. Body size increases and three of the functional indicators improve, on average, from 11 through 15 years of age. The sum of skinfolds and % Fat increase from 11 to 13 years and then are rather constant. Performance in the 20 meter dash improves (lower time) between 11 and 12 years, is stable between 12 and 14 years, and then declines at 15 years.

Compared to the national sample of Polish youth in the 1999 fitness survey, the athletes, on average, are taller age for age (Fig. 1), have identical weights (Fig. 2), and thus a lower BMI (Fig. 3). The athletes are also stronger in grip strength (Fig. 4) and more powerful in the standing long jump (Fig. 5).

Median age at menarche for the total sample is 12.99 ± 1.11 years (95% CI 11.51–13.85 years) and slightly later, though not significantly, for track and field athletes, 13.08 ± 1.14 years (95% CI 12.00 – 13.84 years).

Characteristics of athletes by maturity status are summarized in Tables 2 and 3. Post-menarcheal 13-year-old athletes are, on average, taller and heavier with a larger BMI, sum of skinfolds and % Fat. Only the difference for the sum of skinfolds is significant ($p < 0.05$), while those for body weight and % Fat are of borderline significance. None of the four functional tests differ between pre- and post-menarcheal 13-year-old athletes. Grip strength is, on average, greater in post-menarcheal

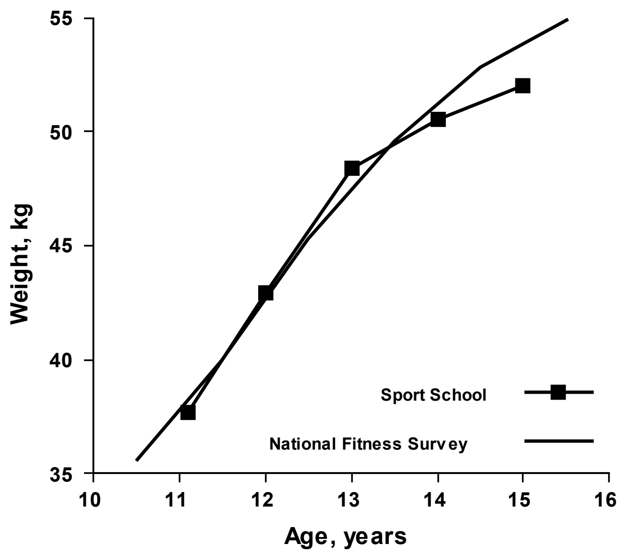

Figure 2. Mean weight of female athletes plotted relative to mean weight of girls in the 1999 national survey of growth and physical fitness of Polish youth [8]

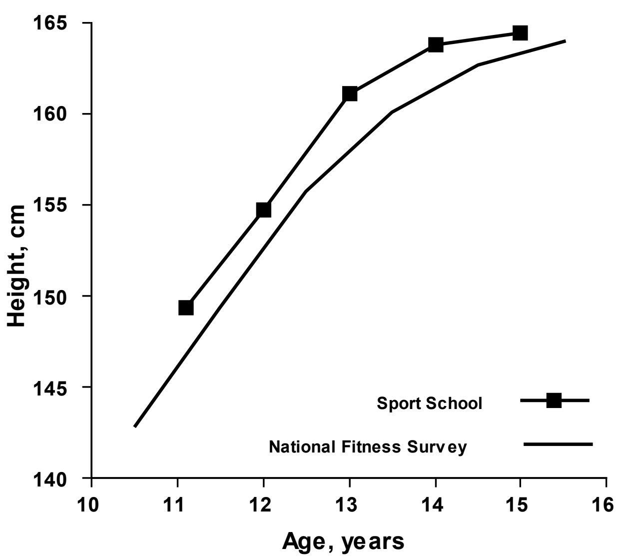

Figure 1. Mean height of female athletes plotted relative to mean height of girls in the 1999 national survey of growth and physical fitness of Polish youth [8]

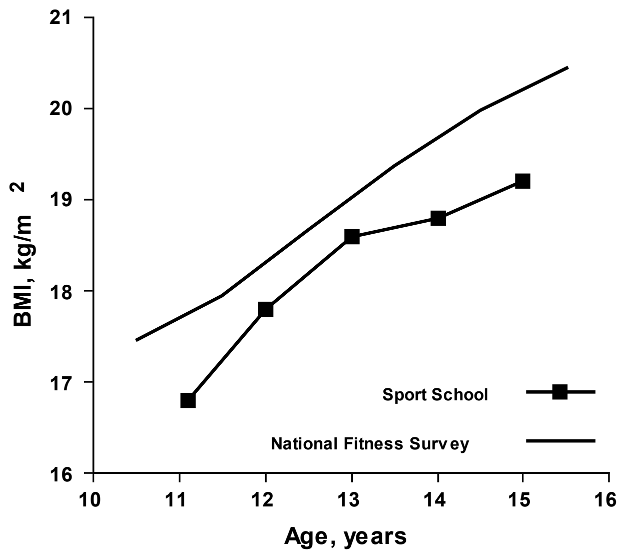

Figure 3. Mean BMI of female athletes plotted relative to mean BMI of girls in the 1999 national survey of growth and physical fitness of Polish youth [8]

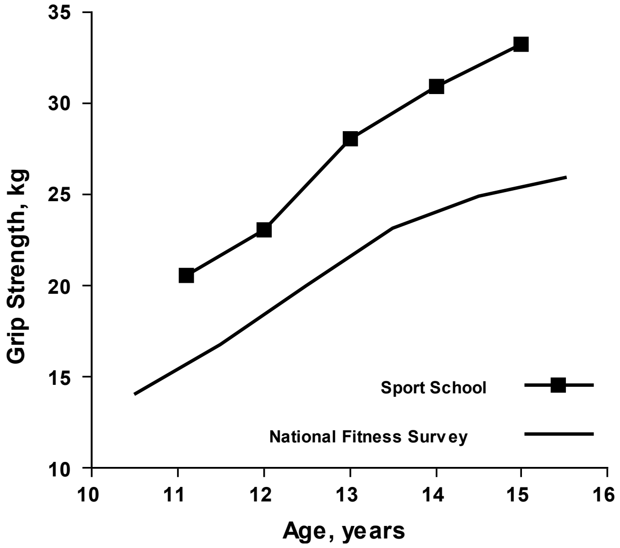

Figure 4. Mean grip strength of the dominant hand of female athletes plotted relative to mean grip strength of the dominant hand of girls in the 1999 national survey of growth and physical fitness of Polish youth [8]

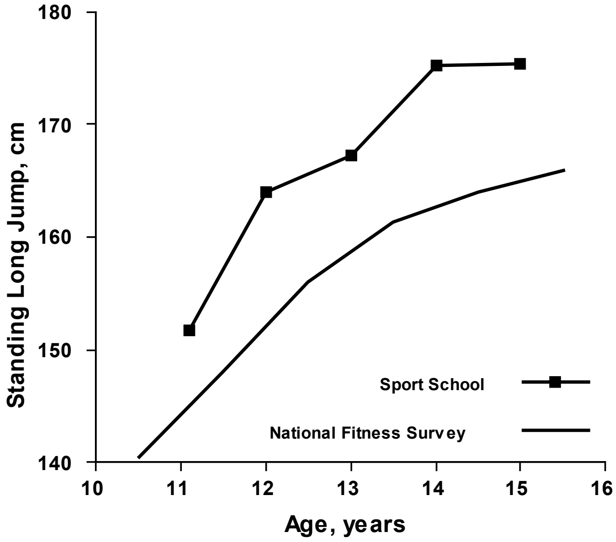

Figure 5. Mean standing long jump of female athletes plotted relative to mean standing long jump of girls in the 1999 national survey of growth and physical fitness of Polish youth [8]

Table 2. Characteristics (means and standard deviations) of pre- and post-menarcheal 13 year old athletes, results of MANCOVA controlling for age, and age-adjusted means and standard errors

	Menarcheal status						Menarcheal status: age-adjusted			
	Pre (n = 16–17)		Post (n = 26–27)		F	p	Pre-		Post-	
	Mean	SD	Mean	SD			Mean	SE	Mean	SE
Age, yrs[1]	12.9	0.3	13.1	0.3						
Height, cm	158.9	5.0	162.5	6.4	2.49	ns*	159.2	1.5	162.3	1.2
Weight, kg	44.8	6.6	50.7	7.8	3.67	= 0.06	45.6	1.9	50.2	1.5
BMI, kg/m²	17.7	1.8	19.1	2.3	2.39	ns	17.9	0.5	19.0	0.4
Sum of skinfolds, mm	28.0	9.2	34.2	11.8	6.73	< 0.05	24.8	2.7	33.9	2.1
Fat, %	24.4	7.5	27.2	4.2	3.05	= 0.08	22.5	1.4	26.9	1.1
Sum R+L grip, kg	50.3	11.1	55.6	13.3	0.31	ns	52.2	3.0	54.4	2.3
Standing long jump, cm	170.6	17.3	165.2	17.9	1.57	ns	172.0	4.7	164.4	3.6
2 kg ball throw, kg	5.3	1.2	5.5	1.2	0.09	ns	5.5	0.3	5.4	0.2
20 m sprint, sec	3.26	0.22	3.30	0.22	0.52	ns	3.25	0.06	3.31	0.04

[1] ANOVA, F = 4.26, p < 0.05, * ns = not significant

Table 3. Characteristics (means and standard deviations) of 14 and 15 year old athletes classified by maturity status, results of MANCOVA controlling for age, and age-adjusted means and standard errors

	Maturity groups						Maturity groups: age-adjusted			
	Late (n = 23)		Average + Early (n = 78)		F	p	Late		Average + Early	
	Mean	SD	Mean	SD			Mean	SE	Mean	SE
Age, yrs[1]	14.6	0.5	14.4	0.6						
Height, cm	162.8	6.7	164.4	5.2	1.91	ns*	162.6	1.2	164.5	0.6
Weight, kg	49.1	7.9	51.8	6.0	4.47	< 0.05	48.6	1.3	51.9	0.7
BMI, kg/m²	18.4	2.2	19.1	1.9	3.23	0.08	18.3	0.4	19.2	0.2
Sum of skinfolds, mm	28.0	9.2	29.9	8.1	1.07	ns	27.9	1.8	30.0	1.0
Fat, %	22.3	5.0	24.0	4.3	3.05	0.08	22.2	1.0	24.1	0.5
Sum R+L grip, kg	58.2	8.5	62.3	9.8	5.15	< 0.05	57.5	1.9	62.6	1.0
Standing long jump, cm	180.1	16.6	173.8	17.9	2.07	ns	180.0	3.8	173.8	2.0
2 kg ball throw, kg	6.2	1.0	6.5	1.1	2.23	ns	6.2	0.2	6.6	0.1
20 m sprint, sec	3.13	0.39	3.26	0.42	1.53	ns	3.13	0.09	3.26	0.05

[1] ANOVA, F = 2.91, p = 0.09, * ns = not significant

athletes while the standing long jump is, on average, greater in pre-menarcheal athletes. Standard deviations in the two tests are quite large. Mean performances for the 2 kg ball throw and 20 m sprint are similar in the two maturity groups.

Results are generally similar in comparisons of size and function in contrasting maturity groups of 14- to15-year-old athletes. Athletes who are average and early in maturation are, on average, taller and heavier with a larger BMI, sum of skinfolds, % Fat and grip strength compared to athletes who are late maturing. Only the differences for weight and grip strength are significant ($p < 0.05$), while the differences for the BMI and % Fat are of borderline significance ($p = 0.08$). The standing long jump is, on average, greater in late maturing girls, but the standard deviations are large and the difference is not significant. As in younger athletes, mean performances for the ball throw and sprint are quite similar in the two contrasting maturity groups.

Age-adjusted means and standard errors for track and field athletes by discipline are summarized in Table 4. Height, weight and % Fat differ significantly ($p < 0.05$) by discipline. Although height differs significantly, none of the post hoc pairwise comparisons is significant. Girls in general athletics are taller than middle distance and distance runners, but the differences are of borderline significance ($p < 0.11$). Girls in general athletics, on the other hand, are significantly heavier and fatter than distance runners ($p < 0.05$). All other pairwise comparisons for height, weight and % Fat are not significant. In contrast to body size, none of the functional capacity measures differs significantly among track and field athletes by discipline.

Age-adjusted means and standard errors for track and field athletes and the combined sample of athletes in team and individual sports are summarized in Table 5. Height and the 2 kg ball throw do not differ. Athletes in team and individual sports are heavier and have a larger BMI, more subcutaneous adiposity and a greater % Fat ($p < 0.001$). The team and individual sport athletes are also stronger in grip strength ($p < 0.05$) whereas track and field athletes are faster in the 20 m sprint ($p < 0.05$). Track and field athletes also perform better in the standing long jump but the difference is of borderline significance ($p = 0.07$). Given the small sample size for athletes in team and individual sports, the risk of type II error is increased.

Results of the regression analyses are given in Tables 6 and 7. Among athletes 11–13 years of age, more variance is explained by the predictors for grip strength (56% and 64%) and 2 kg ball throw (51% and 55%), while explained variance is less for the standing long jump (21% and 20%) and 20 m sprint (11% and 4%). The explained variance is greater for grip strength and throw and lesser for the sprint when % Fat is among the independent variables (Tab. 6). The sum of skinfolds is a significant predictor only for the sprint and % Fat is a significant predictor only for grip strength.

With the sum of skinfolds among predictors, primary explanatory variables are as follows: grip strength – age and weight (both positive), standing long jump – age (positive) and height × weight interaction (negative), 2 kg ball throw – weight (positive), and 20 m sprint – age (positive) and skinfolds (negative). With % Fat among predictors, significant explanatory variables are as follows: grip strength – height, weight and % Fat (all

Table 4. Characteristics of female track and field athletes by discipline. Means and standard deviations for age and training history and age-adjusted means and standard errors based on MANCOVA with age at the covariate

	Sprints ($n = 35$)		Middle distance ($n = 33–34$)		Distance ($n = 21–23$)		Athletics ($n = 57–58$)		Jumps[1] ($n = 23$)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Age, yrs	13.5	1.4	13.9	1.3	13.6	1.4	13.0	1.1	12.9	1.5		
Training, yrs	2.0	1.4	2.2	1.3	2.4	1.4	1.9	1.4	2.2	1.3		
Training, hrs/week	1.8	0.7	1.7	0.4	1.9	0.3	1.8	0.5	1.6	0.3		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*F*	*p*
Height, cm	160.1	1.0	158.5	1.0	158.1	1.2	161.9	0.8	160.5	1.2	2.45	< 0.05
Weight, kg	47.3	1.0	45.9	1.1	44.2	1.3	48.8	0.8	46.7	1.3	2.60	< 0.05
BMI, kg/m²	18.3	0.3	18.2	0.3	17.6	0.4	18.5	0.3	18.0	0.4	0.96	ns**
Sum skinfolds, mm	28.5	1.2	26.2	1.3	25.0	1.5	27.9	1.0	26.7	1.6	1.03	ns
Fat, %*	21.7	0.7	21.2	0.7	19.2	0.9	22.6	0.6	21.7	0.9	2.52	< 0.05
Sum R+L grip, kg	54.7	1.6	53.9	1.7	50.0	2.1	55.1	1.3	53.2	2.0	1.17	ns
Standing long jump, cm	166.7	2.9	169.2	3.1	165.6	3.7	170.7	2.4	175.0	3.6	0.97	ns
2 kg ball throw, m	5.7	0.2	5.4	0.2	5.6	0.2	5.9	0.1	5.8	0.2	1.14	ns
20 m sprint, sec	3.21	0.05	3.33	0.06	3.23	0.07	3.27	0.05	3.19	0.07	0.87	ns

[1] The sample includes one thrower; remainder were jumpers, * $n = 45$ for the sample in athletics, ** ns = not significant

Table 5. Characteristics of female athletes in track and field and in other sports. Means and standard deviations for age and training history and age-adjusted means and standard errors based on MANCOVA with age at the covariate

	Track & field (n = 169–173)		Other sports[1] (n = 27)		F	p
	Mean	SD	Mean	SD		
Age, yrs	13.4	1.3	13.3	1.1	0.03	ns**
Training, yrs	2.1	1.4	2.2	1.1	0.84	ns
Training, hrs/week	1.8	0.5	1.7	0.3	0.92	ns
	Mean	SE	Mean	SE		
Height, cm	160.3	0.5	159.8	1.2	0.16	ns
Weight, kg	47.1	0.5	51.6	1.2	11.34	< 0.001
BMI, kg/m^2	18.2	0.1	20.0	0.4	21.44	< 0.001
Sum skinfolds, mm	27.2	0.6	36.4	1.6	29.65	< 0.001
Fat, %*	21.5	0.4	26.0	0.9	23.05	< 0.001
Sum R+L grip, kg	53.8	0.8	58.0	1.9	3.85	< 0.05
Standing long jump, cm	169.8	1.3	163.3	3.3	3.37	= 0.07
2 kg ball throw, m	5.7	0.1	6.1	0.2	2.71	ns
20 m sprint, sec	3.25	0.03	3.41	0.06	5.66	< 0.05

[1] The sample includes sport school participants in basketball (9), volleyball (6), softball (5), handball (1), football (1), swimming (3), karate (2).
* n = 160 for the sample in track and field, ** ns = not significant

Table 6. Significant predictors of functional capacities and estimated R^2 in 11–13 year old athletes based on multiple regression analyses including either sum of skinfolds (n = 95–97, left) or percentage fat (n = 82–84, right) among the predictors as an indicator of adiposity

Variable	Predictors	β	p	R^2	Adj R^2	p	Predictors	β	p	R^2	Adj R^2	p
Grip strength	age weight	0.170 0.646	< 0.05 < 0.001	0.57	0.56	< 0.001	height weight % Fat	0.213 0.315 0.322	= 0.09 = 0.07 < 0.05	0.62	0.61	< 0.001
Standing long jump	age Ht × Wt	0.204 –0.346	< 0.05 = 0.001	0.22	0.21	< 0.001	age Ht × Wt	0.288 –0.267	= 0.01 < 0.05	0.22	0.20	< 0.001
2 kg ball throw	weight	0.716	< 0.001	0.51	0.51	< 0.001	age weight	0.156 0.644	< 0.01 < 0.001	0.56	0.55	< 0.001
20 m sprint*	age skinfolds	0.339 –0.240	< 0.01 < 0.05	0.12	0.10	< 0.01	age	0.225	< 0.01	0.05	0.04	< 0.01

* Signs of the coefficients were reversed because a lower time was a better performance.

Table 7. Significant predictors of functional capacities and estimated R^2 in 14–15 year old athletes based on multiple regression analyses including either sum of skinfolds (n = 101, left) or percentage fat (n = 101, right) among the predictors as an indicator of adiposity

Variable	Predictors	β	p	R^2	Adj R^2	p	Predictors	β	p	R^2	Adj R^2	p
Grip strength	height weight skinfolds	–0.238 1.007 –0.486	< 0.05 < 0.001 < 0.001	0.45	0.44	< 0.001	age weight	0.141 0.552	= 0.09 < 0.001	0.35	0.34	< 0.001
Standing long jump	weight	0.211	< 0.05	0.04	0.03	< 0.05	weight	0.211	< 0.05	0.04	0.03	< 0.05
2 kg ball throw	weight skinfolds	0.642 –0.220	< 0.001 < 0.05	0.29	0.28	< 0.001	height weight % Fat	–0.252 0.920 –0.372	< 0.01 < 0.001 < 0.05	0.29	0.27	< 0.001
20 m sprint*	height weight skinfolds	0.263 –0.564 0.575	< 0.05 = 0.001 < 0.001	0.17	0.15	< 0.01	no significant predictors					

* Signs of the coefficients were reversed because a lower time was a better performance.

positive), standing long jump – age (positive) and height × weight interaction (negative), ball throw – age and weight (both positive), and sprint – age (positive).

Among athletes 14 – 15 years of age, greater percentages of variance are explained in grip strength and sprint with the sum of skinfolds among predictors, whereas the explained variance in the standing long jump and throw do not differ when skinfolds or % Fat are included among the predictors (Tab. 7). The sum of skinfolds is a significant negative predictor for grip strength and ball throw, but a positive indicator for the 20 m sprint, while % Fat is a significant negative predictor for the throw. Body weight is the only predictor of the standing long jump but the explained variance, though significant, is very low. Results for the 20 m sprint are different. With the sum of skinfolds among predictors, 15% of the variance is explained. Height and weight have, respectively, a positive and negative influence, while the sum of skinfolds has a positive influence on the sprint. In contrast, there are no significant predictors of the 20 m sprint when % Fat is included among predictors.

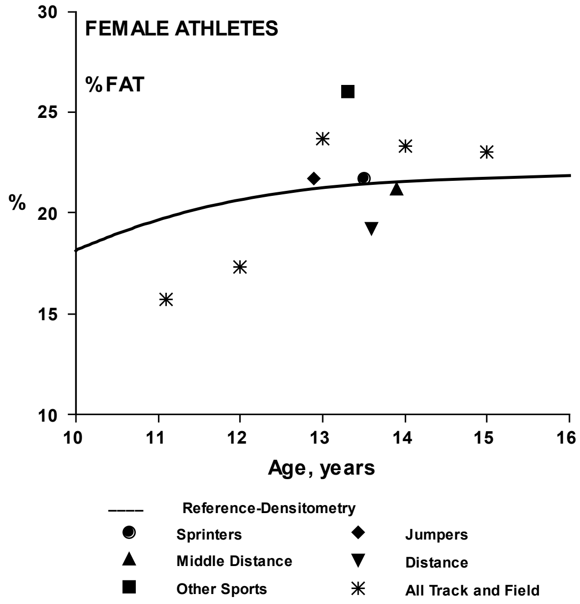

Figure 6. Estimated mean % Fat based on NIR for female track and field athletes by age group and age-adjusted estimated mean % Fat for track and field athletes by discipline and the combined sample of athletes in other sports plotted relative to estimated % Fat based on densitometry in non-athletic youth. Derivation of the non-athlete reference and source studies are reported in Malina et al. [14] and Malina [15]

Discussion

Trends in body size of female athletes attending sport schools were generally consistent with observations for female athletes in several sports [1–3]. Mean heights varied between the age-specific medians and 75th percentiles of reference data for American youth, while mean weights tended to approximate reference medians [12]. As a result, mean BMIs were slightly, but consistently, below the age-specific reference medians. The data were consistent with the notion that young female athletes tend to be taller than average and to have body weights that approximate the average; hence, they have less weight-for-height. Female artistic gymnasts and figure skaters are an exception.

Corresponding reference data for body composition are lacking. FFM has a growth pattern similar to height and weight so that variation in FFM in young athletes varies with body size. It is perhaps for this reason that most studies of body composition of young athletes focus on % Fat, although more recently attention has shifted to bone mineral due in large part to advances in DEXA technology [13]. Densitometric estimates of % Fat in non-athletic samples of girls from the early 1960s through the mid-1980s provide a reasonable reference for the general population prior to the obesity epidemic which surfaced in the late 1980s [14, 15]. Estimated % Fat in the female athletes based on NIR is shown in Figure 6. Mean values for track and field athletes 11 and 12 years were below the reference while estimates for athletes 13–15 years were above the reference. Age-adjusted means for % Fat in sprinters, middle distance runners and jumpers approximated the reference while age-adjusted means for distance runners and general athletics were, respectively, below and above the reference based on densitometry. NIR estimates of % Fat for athletes in specific track and field disciplines were consistently higher than estimates for other samples of athletes of the same age range and in the same disciplines based on densitometry, total body water, DEXA or BIA [16, 17].

The validity of NIR estimates of % Fat compared to densitometric estimates has been questioned, specifically larger standard errors of estimate. Part of the problem relates to use of equations for estimating % Fat provided by the manufacturer [7]. Sample-specific equations have been developed from measured optical density values. The approach resulted in a relatively small error (1.8%) in the prediction of % Fat with NIR in college age female athletes in several sports [18]. Corresponding studies with young athletes gave mixed results in male wrestlers [19, 20], male participants in several sports [21] and female gymnasts [22].

Estimated ages at menarche for the total sample (13.0 ± 1.1 years) and for track and field athletes (13.1

Table 8. Estimated ages at menarche based on the status quo method in samples of adolescent athletes[1]

Country, sport	Median	SD
This study, total sample	13.0	1.1
This study, track and field, disciplines combined	13.1	1.1
Hungary, track and field, events combined[2]	12.6	–
Hungary, track and field, general athletics	13.1	1.1
Hungary, team sports[2]	12.7	–
United States, football (soccer)	12.9	1.1
United States, swimming	13.1	1.1
United States, swimming	12.7	1.1
United States, diving	13.5	1.3
United States/Canada, figure skaters	14.2	0.5
Hungary, artistic gymnasts	15.0	0.6
International, artistic gymnasts[3]	15.6	2.1

[1] Comparative data are from Malina [2, 16] and Malina et al. [3] which contain references to specific studies.
[2] Standard deviations were not reported for these samples.
[3] This sample from the 1987 world championships in Rotterdam did not include gymnasts < 13 years of age so that the estimate may be biased towards an older age at menarche.

± 1.1 years) were only slightly later, on average, than the estimate for the national physical fitness survey of 1999, 12.8 years [8]. Variance statistics were not reported for the national sample. The median ages for athletes were similar to corresponding status quo estimates (probit analysis) for samples of young athletes in the same or similar sports (Tab. 8).

A common theme in discussions of maturation in athletes is later ages of menarche, which are attributed by some to early training. As evident in Table 8 and elsewhere [2, 3, 16], menarche data for adolescent athletes, either status quo or prospective, are quite limited. Status quo surveys of adolescent athletes give estimated ages at menarche that are generally close to the average of the population; exceptions are artistic gymnasts, figure skaters and divers. On the other hand, most data for athletes are based on the retrospective (recall) method in late adolescent and adult athletes. Within the same sport, estimated ages at menarche of athletes based on retrospective studies are, on average, later than estimates with the status quo method. The difference relates to sampling. Status quo estimates are generally based on youth 9–17 years; such samples include athletes with a wide range of abilities. Late adolescent and adult athletes are more specialized in the respective sports and have persisted in or were selected for the sport. Related factors are selective drop-out of less talented and earlier maturing girls, and perhaps selective success of later maturing girls in some sports [2, 3, 23].

Comparisons of contrasting maturity groups of athletes 13–15 years of age (Tab. 2 and 3) were generally consistent with observations for adolescent females [3]. The small sample sizes of late maturing athletes in the two age groups probably affected the significance of the differences in some variables. Comparisons of groups of small sample size are prone to Type II errors.

The percentage of variance explained in each of the functional indicators was greater in athletes aged 11 – 13 years (Tab. 6) compared to athletes aged 14–15 years (Tab. 7). Age was a significant predictor among athletes 11 – 13 years of age but not among athletes 14 – 15 years of age, emphasizing the role of age *per se* in the development of the functional indicators. This was generally consistent with literature on adolescent girls, though data are limited for female athletes [3]. The variance explained in grip strength, 2 kg ball throw and standing long jump was generally similar with the inclusion of either the sum of skinfolds or the NIR estimate of % Fat among predictors in both age groups. The directions of the standardized regression coefficients were straightforward for the grip, throw and jump; coefficients for age and weight were positive and those for skinfolds were negative. By inference, older and heavier girls with thinner skinfolds tended to perform better. A standardized coefficient for the height × weight interaction appeared among predictors only for the standing long jump in athletes aged 11 – 13 years; it was negative suggesting that among girls of the same height, those with lower body weight, i.e., less weight-for-height performed better in the jump. Height appeared among predictors of only grip strength in athletes 11 – 13 years of age; the standardized coefficient was positive. In contrast, height was a significant predictor of strength and the ball throw in athletes 14 – 15 years of age, but the coefficients were negative, suggesting that girls who were shorter but heavier had better performances.

Results for the 20 m sprint were more complex for interpretation. Age was a predictor in athletes 11 – 13 years and skinfolds (but not % Fat) had a negative influence (Tab. 6). Among athletes 14 – 15 years, there were no significant predictors of the sprint when % Fat was included among independent variables. With the sum of skinfolds among independent variables, the coefficients for height and skinfolds were positive and that for weight was negative. By inference, 14- to 15-year-old athletes who were taller and lighter and who had a thicker sum of skinfolds performed better in the 20 m sprint. The results may reflect the limited range of variation in sprint times among athletes aged 14 – 15 years (2.58 to 4.14 sec) in contrast to the wide range of variation in the sum of skinfolds (17.4 to 50.6 mm). The coefficients of variation for the 20 m sprint and skinfolds were 12.7% and 28.4%, respectively.

Although height, weight and adiposity accounted for significant portions of variation in the four functional indicators, a considerable amount of variation was not explained by size and fatness in this sample of female athletes. Strength and performance are affected by motivation, quality of instruction and practice and other factors. Although experience in the sport school programs increased with age in this sample of female athletes, the amount of time spent in training per week was similar across age groups. This would seem to imply a need for more refined indicators of the duration and intensity of training in the sport schools to estimate potential influences on functional capacity.

The study was limited to four indicators of functional capacity. There is a need to expand observations to other indicators, e.g., aerobic endurance, anaerobic capacity, agility, etc., and also to sport-specific skills in team (basketball, soccer, etc.) and individual sports (tennis) and to more technical skills in track and field and swimming. It would also be interesting to expand the number of sports considered.

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EVALUATION OF ACCURACY OF THE BODY COMPOSITION MEASUREMENTS BY THE BIA METHOD

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ABSTRACT
Purpose. The main purpose of this study is to verify the accuracy of body composition measurements by the BIA method, using TANITA 418 MA unit. **Basic procedures.** For purposes of our study we decided to use the type-A uncertainty evaluation method (statistical processing of measured data). To formulate diagnostic error for the BIA method we used typical (standard) error of measurement from differences between pairs of repeated measurements – which is in principle a mean error of the test. The research was carried out on a group of 10 students whose field of study is physical education and sport. These students were chosen from the total number of 74 students in such a way that they represent as wide range of fat fraction as possible. Representation of their fat fraction oscillated between 9.0 to 31.2% of body fat. Input value of body fat, which was the basic criterion for selection of students to the measurement etalon, was determined by the DEXA method. **Main findings.** We described the uncertainty (type A) in selected file of etalons by an average value and by a standard deviation in percentage of fat: 0.13 ± 0.05. A diagnostic error of the method expressed by means of typical (standard) error of measurement was 0.38% of body fat. **Conclusion.** Considering the detected values of uncertainty (type A) and of typical error of measurement, we can conclude that measurement of body composition by the BIA method using TANITA 418 MA unit is sufficiently accurate for requirements of practical use. The necessary condition for the above mentioned measurement accuracy is a strict observance of standard measurement conditions.

Key words: measurement uncertainty, method reliability, body composition

Introduction

Diagnostics of body composition is at present profusely used not only in the area of physical education process and sport training, but also in medicine. In sport training we can say that the most often monitored parameter is the value of body fat representation [1 – 4], because it is widely known that its exceedingly high values lead to a decrease in sport performance in a lot of sport disciplines. In medicine, data on body composition is used mainly in diabetology, obesitology and in osteoporosis treatment [5 – 8].

When detecting body composition, we always make estimations. And for these estimations we use a large scope of methods. These methods can be divided into laboratory methods and practical methods. Some selected laboratory methods serve simultaneously as reference methods (e.g. DEXA) [9, 10]. They are too demanding for practical use – not only in reference to technical equipment and demands for skilled operators, but also owing to high financial demands. Therefore, practical methods are mainly used in standard practice. Here we can include anthropometry and, in the first place, the method of bioelectric impedance (BIA) which is currently very widely used. This method operates on the base of different spreading of low-intensity electric current in various biological structures. It is based on the principle of differing electric characteristics of tissues, fat and especially body water. The current flows through water and electrolyte components in fatless matter and the output resistance is therefore proportional to its content [10, 11].

No measurement can determine the real value of measured quantity. In present technical measurement practice it is usual to use a concept of uncertainty, which is a parameter corresponding to the measurement result. This parameter characterizes the range of values, which can be rationally assigned to the measured value. Resultant uncertainty is expressed through the sum of squares of two basic types of uncertainties. Considering the fact that the methodology of determination of uncertainty – type B (type B = based on other than statistical processing of measured data) is quite complicated, it was not possible to detect it in our research due to the

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lack of necessary sources [12–14]. Our research is significantly limited by this situation, because one of the purposes of this study is to initiate discussion on the problem of technical measurements in kinanthropometry.

Classical theory of tests uses the reliability coefficient $r_{XX'}$ to express this method's diagnostic error. Hopkins [15] criticizes the practice where only correlation coefficient obtained by a stability method (test–retest) is used for reliability evaluation. He suggests using typical (standard) error of measurement for diagnostic error estimation.

The purpose of this study is to compare the accuracy of body composition measurement by the BIA method using TANITA 418 MA unit from the viewpoint of measurement uncertainty concept and from the viewpoint of classical theory of tests. The results obtained can help us in evaluation of body composition changes caused by external interventions (e.g. training programme, change in nutrition habits, etc.).

Material and methods

When expressing measurement deviations in the form of measurement uncertainty we use so-called etalon, which should be composed of at least 10 items [12]. The selected file of etalons for this study consisted of 10 students (5 men and 5 women) whose field of study is physical education and sport. They are people who regularly practice motor activities related to their field of study (physical education and sport) and to their sport activities. Considering this fact, it is possible to use obtained data for other diagnostics of people engaged in sports in various sport disciplines (and we also make this diagnostics). The average age of selected group was 20.85 years. These students were chosen from the total number of 74 students (45 men and 29 women) in such a way that they represent as wide range of fat fraction as possible. Representation of their fat fraction oscillated between 9.0 to 31.2% of body fat.

Input value of body fat was determined by a DEXA method (Densitometer Holgic QDR, 3rd generation) in all 74 students. We used tetrapolar bioimpedance weighing machine TANITA 418 MA for the BIA method in selected 10 students.

We tried to eliminate gross errors by a strict observance of standard measurement conditions. Reading errors were not taken into account owing to very easy manipulation of the equipment and to the long working experience of the measurement operator.

Equipment error was expressed by a standard uncertainty (type A) in absolute and relative values [12, 13]. The absolute value is expressed by standard deviation (SD) value and the relative value is expressed by a variation coefficient (V, calculated as SD/mean). Standard deviation values SD, mean M and variation coefficient V were calculated for each person from 10 subsequent measures. Diagnostic error of the method was expressed by means of typical (standard) error of measurement, which Hopkins [15] recommends especially for this type of measurements. Hopkins [15] presents this method of expressing reliability of measurements of 7 skinfolds for estimation of body composition. The extent of this error is expressed in percentage of body fat. The calculation was also done based on 10 subsequent repeated measurements. Statistical processing was performed by means of statistical program SPSS 17.0.

The study protocol was approved by the Ethics and Research Committee of the University of Ostrava. All participants signed an informed consent form.

Results

Table 1 presents basic somatic characteristics of probands assigned to the research

Basic descriptive statistical characteristics and uncertainty values (type A) for single etalons are presented in Table 2.

Uncertainty (type A) of our technical measurements in absolute values of percentage of fat oscillated in the range of 0.02 to 0.19. Characteristics of selected file of etalons are described by the average value and by the standard deviation of single uncertainties: 0.13 ± 0.05.

Table 3 presents a diagnostic error of the method expressed by typical (standard) error of measurement for single pairs of repeated measurements. Resulting value of typical error is calculated from the root of scalar product of square power of typical errors (TE^2) of experiment pairs and degrees of freedom divided by a total sum of degrees of freedom [16].

Resulting typical error of measurement =

$$\frac{\sqrt{\sum_i TE_i^2 \cdot Df_i}}{\sum_i Df_i} .$$

Typical error value oscillated in the range of 0.23% to 0.46% of body fat. Resulting value of typical error was 0.38% of body fat.

Discussion

Uncertainty of type A, which is presently used in technical measurement practice for expressing the quan-

Table 1. Input somatic characteristics of probands

	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10
BH (cm)	190.0	170.0	160.0	171.0	174.0	159.0	159.0	168.0	197.0	190.0
BW (kg)	78.3	66.1	58.0	60.0	78.1	51.6	60.3	59.7	88.7	83.5
BF (%)	9.0	26.8	11.2	27.4	14.6	22.8	23.4	31.2	18.3	16.4

P – person (no.), BH – body height, BW – body weight, BF – body fat measured by DEXA device

Table 2. Values of 10 measurements of body fat for each person measured by the BIA method and values of uncertainty (type A)

Trial	P 1 (%)	P 2 (%)	P 3 (%)	P 4 (%)	P 5 (%)	P 6 (%)	P 7 (%)	P 8 (%)	P 9 (%)	P 10 (%)
1.	11.0	27.3	17.0	20.6	23.1	26.7	18.7	13.9	8.1	11.3
2.	11.2	28.6	16.6	21.0	23.1	26.6	18.9	13.7	8.2	11.3
3.	10.9	27.4	16.3	19.4	22.5	26.5	18.7	13.5	8.8	11.2
4.	11.8	28.2	15.7	20.2	22.3	26.9	18.9	13.6	9.3	11.3
5.	11.6	27.8	15.4	21.4	22.5	26.8	19.0	14.0	8.7	11.1
6.	11.5	27.8	15.8	20.9	22.4	27.0	18.7	14.0	9.1	11.3
7.	11.8	27.8	15.5	20.2	22.5	27.2	19.6	15.7	9.4	11.3
8.	11.3	27.8	15.6	20.9	22.3	27.3	18.6	14.3	8.8	11.2
9.	11.5	27.9	15.3	19.9	22.3	27.6	18.9	14.3	9.1	11.3
10.	12.0	27.8	15.0	20.8	23.7	27.4	19.2	13.6	9.6	11.2
M	11.46	27.86	15.82	20.53	22.67	27.00	18.92	14.06	8.91	11.25
SD	0.34	0.34	0.59	0.56	0.44	0.34	0.28	0.60	0.46	0.06
Type A	0.11	0.11	0.19	0.18	0.14	0.11	0.09	0.19	0.15	0.02
V	0.029	0.012	0.037	0.027	0.019	0.012	0.014	0.043	0.052	0.005

P – person no., M – mean, SD – standard deviation, Type A – uncertainty (type A), V – variation coefficient

Table 3. Differences between experiments in tested persons given in percentage of fat and descriptive characteristics

Person	Trial								
	2–1	3–2	4–3	5–4	6–5	7–6	8–7	9–8	10–9
1	0.2	–0.3	0.9	–0.2	–0.1	0.3	–0.5	0.2	0.5
2	1.3	–0.6	–0.6	0.8	–0.4	0.0	0.0	0.1	–0.1
3	–0.4	–0.3	–0.6	–0.3	0.4	–0.3	0.1	–0.3	–0.3
4	0.4	–1.6	0.8	1.2	–0.5	–0.7	0.7	–1.0	0.9
5	0.0	–0.6	–0.2	0.2	–0.1	0.1	–0.2	0.0	1.4
6	–0.1	–0.1	0.4	–0.1	0.2	0.2	0.1	0.3	–0.2
7	0.2	–0.2	0.2	0.1	–0.3	0.9	–1.0	0.3	0.3
8	–0.2	–0.2	0.1	0.4	0.0	1.7	–1.4	0.0	–0.7
9	0.1	0.6	0.5	–0.6	0.4	0.3	–0.6	0.3	0.5
10	0.0	–0.1	0.1	–0.2	0.2	0.0	–0.1	0.1	–0.1
M	0.2	–0.3	0.2	0.1	0.0	0.3	–0.3	0.0	0.2
SD	0.46	0.55	0.51	0.54	0.31	0.65	0.60	0.39	0.62
TE	0.33	0.39	0.37	0.38	0.23	0.46	0.43	0.28	0.44

M – mean, SD – standard deviation, TE – typical (standard) error

titative indicator of measurement quality, is in monitored etalons relatively low. For more extensive discussion on the observed values we did not find any relevant data in the technical literature available. Observed values approach zero – this fact indicates high quality of the measurement performed using the above mentioned equipment. However, there is still the problem of impossibility to express uncertainty (type B), which naturally increases the detected uncertainty. The reason was the impossibility of obtaining the necessary data from the manufacturer (e.g. technical specifications of the equipment, equations used for calculation of single parameters, etc.). Therefore, we could not calculate the resulting – combined uncertainty, which would yet more precisely characterize the range of values that is possible to assign to the measured quantity. On the other hand, we assessed the uncertainty of measurement for various etalons covering a wide range of fat distribution in body composition of probands. At first sight it seems that portion of body fat distribution does not influence the value of uncertainty (type A). This opinion is only preliminary and it is necessary to perform more detailed research to verify it. Comparison of our results to results of other authors would be possible only in the area of technical measurements in other fields of study, e.g. in physics [16–20].

The obtained typical error of measurement corresponds to the results of other authors who present an interval of measurement accuracy at level $\alpha = 0.05$ in the range 1–3% of the resulting value (our result was 0.76%) [21–25, 10]. When making comparisons it is necessary to take into account the fact that authors used other equipment working on the base of BIA method and they also selected other procedures to obtain results. Resulting value of typical error in % of body fat was 0.38%. It is the value calculated from 10 repeated measurements in 10 persons. When we decreased the number of repeated measurements, this error decreased even more. The breaking point in the number of repetitions was 7 repetitions (from 7 to 4 repetitions the error was only 0.37% of body fat).

We are aware of the fact that our results can be influenced both by the range of our selected file and by diagnosed persons. When we generalize our results we have to proceed carefully. We realize that obtained results are valid especially for the given equipment on which we took our measurements.

Conclusion

Regarding the extent of the equipment error (for TANITA 418 MA) expressed by the uncertainty (type A) and the low diagnostic error expressed by typical error of measurement, we can conclude that body composition measurement (in this study represented by portion of body fat) is sufficiently accurate for the sphere of physical education and sport training. We are able to assess the extent of influence of external interventions to the changes in the sphere of body composition (represented by body fat) in monitored persons even at relatively low changes. The necessary requirement for the above mentioned measurement accuracy is a strict observance of standard measurement conditions. When using the BIA method it is especially important to observe the fundamentals regarding the hydratation, nutrition and motor activities of human body.

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SOMATIC BUILD OF ROWERS IN THE PERIOD FROM 1995 TO 2005

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ABSTRACT
Purpose. The aim of the paper is an attempt to show the sizes of morphological features of rowers, in order to establish the type of body build proper for present requirements of this sports discipline through the determination of morphological features of the greatest importance in rowing including the type of a racing boat. **Basic procedures.** Analysed material includes competitors practising rowing, who were members of the Polish junior national team in this sports discipline in the period from 1995 to 2005. A group of 31 anthropometric measurements have been analysed; body composition has been measured by the BIA method, including rowing boat categories. Musculature rate for each participant was calculated on the basis of chosen somatic indicators. Collected material has been elaborated with basic statistical methods. **Main findings.** Rowers are characterized by the significant height of the body, large body mass and a considerably slender figure at the same time. Characteristic features are: trunk with its large length and large circumferences, long upper and lower limbs, shoulders of medium broadness, narrow pelvis, flat chest. Big musculature of upper and lower limbs which classify competitors to the group of thigh-set limbed and the considerable stoutness of the body, expressed with the thickness of skin-adipose folds, with the proportional fat content, are also characteristic features. Analysed teams show the differentiation depending on types of racing boats, with achieving larger mean features by the crew of oars, at the greater proportional participation of the fat in the general body mass. **Conclusion.** Competitors doing rowing at the high level of sports advancement must accomplish the criteria of morphological build, and the level of these requirements is adapted to the specificity of this sports discipline and types of racing boats.

Key words: rowers, body build, body composition, anthropometry

Introduction

The top performance level in rowing depends on the various factors such as efficiency, capability, endurance and strength preparation, very high efficiency parameters, somatic build of contestants, joint movability, level of technical, tactical and physical preparation, nutrition, technological progress in constructing rowing boats and paddles, weather conditions or training process optimisation. At the same time, the difference in the body build of sportsmen is more and more dependent on the type of the boat (paddles, oars) and particularly in rowing disciplines.

The studies of Skład et al. [1], Forjasz, Kuchnio [2], Schranz et al. [3] show that rowers are distinguished from the individuals who do not do sport by high body mass and body height and also significant length of upper limbs, long length of lower limbs, especially shank, significant broadness of shoulders, width of distal epiphysis of upper and lower limbs, high muscle measurement of limbs, especially of the forearm and proper relationships between tissue components – minimal adiposity and developed thin body.

Elaborating a model of leading features for juniors who do rowing can be a way for periodic assessment of the adaptation of athletes for individual training load, evaluation of preparation and development of young rowers for which the junior age is only a stage on the way to championship [4].

The objective of this paper is to present the degree of morphological features of rowers aiming to define the body build which is proper to current demands of this sports discipline by setting the morphological factors most significant for rowing. The analysed body build model is the effect of selection to rowing, and then implementation of specific training load. The result of the research is a theoretical deliberation on the body build model of rowers and the research aim is to convey practical information to coaches which can serve as a criterion in the process of selection to rowing and setting programs for training load.

Material and methods

The material analysed in the paper includes 277 rowers who are members of the junior national team. The

Table 1. Number of teams of men under examination

	Number (n)			Age		Training seniority	
	total	paddles	oars	M	δ	M	δ
1995	26	9	17	17.35	0.68	2.08	1.02
1996	21	7	14	17.30	0.51	2.51	1.48
1997	43	17	26	16.98	0.47	1.92	1.15
1998	27	9	18	17.30	0.51	2.57	0.94
1999	32	9	23	17.37	0.61	2.82	1.32
2000	20	6	14	17.15	0.61	2.39	0.69
2001	22	9	13	17.26	0.49	2.64	1.46
2002	17	6	11	17.14	0.45	2.70	0.90
2003	21	11	10	17.30	0.52	3.64	1.34
2004	20	10	10	17.25	0.51	3.40	1.01
2005	28	10	18	17.08	0.51	3.13	1.41
Total	277	103	174				

anthropometric measurements were made during autumn consultations in the period from 1995 to 2005 in which the subjects called by Polish Association of Rowing Societies took part. The rowers examined belong to the category of juniors aged between 16 to 18 in their training seniority amounting from 0.5 year to 6 years (Tab. 1). During the research period, within the time structure of the training, the teams were in the preparation period, in the sub-period of comprehensive preparation.

The analysis included measurements of somatic features, taking into consideration features especially diagnostic in the rowers' build [2, 3]:

- length features: body height, trunk length, upper limb length, arm length, forearm length, hand length, lower limb length, thigh length, shank length, foot length,
- width features: broadness of shoulders, broadness of chest, depth of chest, width of pelvis, width of foot and hand,
- body measurements: chest circumference (at rest), circumference of waist, circumference of hips, circumference of arm (at rest, in the half of its length), circumference of forearm (maximum), circumference of thigh (maximum), circumference of shank (maximum),
- body mass,
- thickness of skin and adipose folds: below the lower angle of shoulder-blade, of arm (triceps), forearm, abdomen, thigh and shank,
- length between the fingertips of a man's outstretched arms (distance between anthropometric points dactylion$_{III}$ (da$_{III}$) of right and left hands at uncrossed upper limbs).

The measurements were taken according to the principles of anthropometry with the use of classical instrumentarium. Body mass measurement was made with electronic scales (accurate to 0.1 kg); length measurements were made with anthropometer (accurate to 0.1 cm), width measurements – with a small and big spreading caliper (accurate to 0.1 cm); circumferences were made with an anthropometric tape (accurate to 0.1 cm), thickness of skin and adipose folds were marked with skinfold caliper (accurate to 0.2 cm), and horizontal measurement of the stretched upper limbs – with an anthropometric tape (accurate to 0.1 cm).

Moreover, the composition of the body tissue was measured with the use of bioelectrical analysis of impedance, determining the amount of water, fat and thin body in the organism. In the research a bio analyser of body composition called "Spectrum Lightweight II" was used.

The questionnaire data gave information on the age and training seniority of the subjects (Tab. 2).

To perform all the examinations the consents of Bioethical Committee at Poznań University School of Medicine (No. 1758/03), Coach of Junior Team and participants were given.

Musculature rate for each participant was calculated on the basis of chosen measurements: arm, forearm, thigh, and shank (circumference × 100/length) and indicators: trunk (sst-sy × 100/B-V), shoulders (a-a × 100/ sst-sy), pelvis (ic-ic × 100/a-a), chest (xi-ths × 100/ thl-thl), Rohrer (body mass [g] × 100/(B-V)^3 [cm]).

Collected material was elaborated with basic statistical methods, counting arithmetic mean (M) and standard deviation (δ) of individual features for all examined teams depending on the type of rowing boats (paddles, oars). Significance of differences in feature means was estimated with the use of critical value of Student's t distribution on the basis of "t" test for independent samples.

Results

In the period included in the analysis (Tab. 2–9, Fig. 1–4), in the male crew, the changes of length measurements expressed by the body height, length of upper and lower limbs were not significant; among width measurements, the broadness of shoulders and the width of foot decreased while the chest width increased. Estimating the changes in body circumferences, there were no significant differences except for a decrease in hips and forearm circumferences as well as an increase in shank circumference. The body mass has not fluctuated significantly with a distinct decrease of fat layer thickness. The changes in muscularity of limbs consisted in the increase in arm and thigh circumfe-

Table 2. Numerical data on the examined features of rowers, taking into account the type of racing boats

	Body height			Length of upper limb			Length of arm			Length of forearm			Length of hand			Horizontal reach of upper limb		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	188.65	188.33	188.82	84.84	83.59	85.50	38.41	38.11	38.56	25.50	24.36	26.10*	20.93	21.12	20.84	–	–	–
	±5.25	±6.84	±4.16	±3.07	±3.98	±2.18	±1.82	±2.07	±1.65	±1.74	±1.89	±1.30	±1.49	±2.09	±1.03	–	–	–
1996	189.00	186.50	190.25	83.03	80.81	84.14*	34.52	33.91	34.82	25.62	23.30	26.79**	22.89	23.60	22.54	–	–	–
	±4.26	±3.30	±4.14	±3.20	±3.54	±2.33	±2.30	±2.60	±2.07	±2.36	±1.59	±1.73	±1.56	±1.20	±1.60	–	–	–
1997	187.58	185.86	188.71*	83.73	83.19	84.09	35.09	35.18	35.03	26.45	26.58	26.36	22.20	21.44	22.70**	–	–	–
	±4.24	±5.08	±3.11	±2.86	±3.32	±2.45	±2.33	±1.88	±2.58	±2.11	±2.71	±1.59	±1.39	±1.16	±1.31	–	–	–
1998	189.57	187.39	190.67*	82.46	81.67	82.85	35.60	34.67	36.07	26.52	26.39	26.58	20.33	20.61	20.19	–	–	–
	±3.67	±2.82	±3.56	±2.16	±1.70	±2.26	±1.93	±1.11	±2.08	±1.86	±1.85	±1.87	±1.23	±0.74	±1.40	–	–	–
1999	189.05	190.01	188.67	83.27	84.08	83.23	34.20	34.80	33.96	27.56	26.79	27.86	21.71	22.49	21.40	193.93	197.02	192.72
	±5.05	±4.53	±5.19	±4.02	±3.27	±4.41	±1.68	±1.39	±1.73	±3.37	±2.63	±3.57	±3.20	±2.44	±3.40	±7.37	±5.23	±7.72
2000	187.55	185.83	188.28	83.46	84.92	82.83	35.94	36.78	35.58	27.19	27.25	27.16	20.33	20.88	20.09	191.85	192.17	191.71
	±4.29	±5.51	±3.39	±2.67	±2.38	±2.54	±1.94	±1.79	±1.88	±1.51	±1.55	±1.49	±1.53	±1.62	±1.43	±4.40	±5.22	±4.00
2001	187.19	185.72	188.21	83.13	83.68	82.75	35.08	35.64	34.68	27.18	26.86	27.41	20.87	21.18	20.66	191.78	190.40	192.74
	±5.01	±4.87	±4.86	±2.52	±1.71	±2.89	±2.10	±1.31	±2.42	±1.49	±1.21	±1.62	±1.76	±1.26	±2.01	±4.63	±4.45	±4.50
2002	189.18	188.78	189.40	83.75	83.18	84.05	35.65	35.85	35.55	27.29	27.58	27.14	20.80	19.75	21.37	193.21	191.70	194.04
	±4.08	±3.21	±4.47	±3.52	±2.59	±3.90	±2.07	±2.15	±2.02	±1.42	±1.10	±1.55	±2.58	±2.87	±2.20	±5.67	±4.79	±5.93
2003	188.86	190.06	187.54	82.23	83.85	80.44	34.40	35.30	33.42	26.02	26.21	25.81	21.80	22.35	21.21	193.17	195.25	190.88
	±6.00	±5.59	±6.15	±4.82	±3.79	±5.18	±2.52	±1.86	±2.78	±1.54	±1.51	±1.55	±2.18	±1.33	±2.72	±7.93	±6.36	±8.80
2004	190.67	190.39	190.95	83.76	84.42	83.10	35.85	36.06	35.63	26.20	26.77	25.63	21.72	21.59	21.84	193.75	194.80	192.70
	±5.43	±5.60	±5.25	±3.22	±3.06	±3.24	±1.54	±1.69	±1.35	±1.63	±1.54	±1.51	±0.92	±0.84	±0.99	±5.94	±6.10	±5.59
2005	188.76	185.76	190.43*	83.16	81.42	84.13*	35.56$^{\#\#}$	34.18	36.33**	25.69	26.05	25.49	21.91$^{\#}$	21.19	22.31	194.92	191.81	196.64
	±5.40	±5.33	±4.66	±3.47	±2.33	±3.62	±2.08	±1.86	±1.78	±1.59	±1.85	±1.39	±1.49	±1.07	±1.53	±7.18	±5.97	±7.22

* $p \le 0.05$; ** $p \le 0.01$ for differences between paddles and oars; $^{\#}$ $p \le 0.05$; $^{\#\#}$ $p \le 0.01$ for differences between 1995–2005

Table 3. Numerical data on the examined features of rowers, taking into account the type of racing boats

	Length of trunk			Length of lower limb			Length of thigh			Length of shank			Length of foot		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	55.71	55.10	56.03	99.36	100.23	98.90	44.34	45.72	43.61	47.18	46.70	47.43	28.63	28.47	28.72
	±2.14	±2.43	±1.89	±4.02	±5.10	±3.21	±3.86	±3.65	±3.76	±3.03	±3.09	±2.96	±0.66	±0.78	±0.57
1996	51.61	50.64	52.09	102.89	101.21	103.73	49.39	50.67	48.74	43.52	40.70	44.93**	26.76	26.64	26.82
	±2.27	±1.94	±2.26	±3.41	±3.54	±3.02	±2.46	±2.76	±2.01	±3.05	±2.06	±2.42	±0.89	±0.90	±0.88
1997	54.13	54.64	53.80	98.84	96.65	100.28*	47.55	46.11	48.49	40.91	39.05	42.13**	28.17	28.17	28.18
	±2.76	±1.80	±3.20	±4.74	±4.51	±4.31	±4.48	±4.02	±4.52	±2.56	±2.22	±1.95	±1.02	±1.23	±0.85
1998	55.67	54.67	56.17	98.87	97.61	99.50	44.85	44.61	44.97	46.06	45.17	46.50	28.68	28.54	28.75
	±2.24	±1.67	±2.32	±2.62	±2.71	±2.34	±2.22	±2.11	±2.27	±1.90	±1.56	±1.89	±1.00	±1.10	±0.94
1999	56.16	55.74	56.32	98.80	99.41	98.56	43.43	43.28	43.49	47.40	48.21	47.09	28.84	29.13	28.72
	±2.10	±0.91	±2.40	±3.49	±3.35	±3.52	±2.44	±2.52	±2.40	±2.04	±1.65	±2.09	±1.10	±1.16	±1.05
2000	54.26	56.02	53.50*	99.81	96.70	101.14*	49.63	47.20	50.66*	42.27	41.42	42.64	28.10	28.08	28.10
	±2.55	±2.48	±2.19	±3.66	±2.49	±3.24	±3.16	±1.36	±3.14	±2.03	±2.44	±1.71	±1.22	±1.67	±0.97
2001	57.95	58.00	57.91	94.95	93.36	96.05*	40.76	39.74	41.47	46.24	45.32	46.87	28.06	27.96	28.13
	±3.58	±3.68	±3.51	±3.10	±1.76	±3.34	±2.66	±1.84	±2.90	±2.30	±2.62	±1.81	±1.39	±1.30	±1.44
2002	55.64	54.10	56.47*	98.32	98.73	98.10	45.71	45.98	45.55	42.61	42.58	42.63	27.49	27.60	27.44
	±2.33	±2.77	±1.50	±3.61	±1.62	±4.31	±2.57	±2.20	±2.74	±2.71	±2.61	±2.76	±1.14	±1.37	±0.99
2003	56.87	57.43	56.25	97.38	98.04	96.66	46.70	46.41	47.03	41.20	42.05	40.27	27.93	28.49	27.32
	±2.41	±2.04	±2.63	±3.97	±3.85	±3.98	±2.59	±2.97	±2.05	±3.38	±2.87	±3.65	±1.47	±1.38	±1.32
2004	53.03	52.49	53.57	102.90	103.28	102.51	48.96	49.94	47.97	44.51	44.19	44.83	28.54	28.85	28.23
	±2.19	±1.46	±2.62	±4.19	±4.58	±3.72	±2.78	±2.73	±2.45	±2.30	±2.29	±2.27	±0.99	±0.88	±1.00
2005	55.70	55.26	55.94	98.60	95.54	100.31**	47.22$^{\#\#}$	44.88	48.52**	42.82$^{\#\#}$	42.07	43.23	28.26	27.32	28.79**
	±2.01	±2.21	±1.84	±4.58	±4.02	±3.94	±3.30	±2.61	±2.90	±2.81	±2.64	±2.81	±1.34	±1.19	±1.11

* $p \le 0.05$; ** $p \le 0.01$ for differences between paddles and oars; $^{\#\#}$ $p \le 0.01$ for differences between 1995–2005

Table 4. Numerical data on the examined features of rowers, taking into account the type of racing boats

	Depth of chest			Width of chest			Width of shoulders			Width of pelvis			Width of foot			Width of hand		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	20.52	20.66	20.44	28.96	27.79	29.58**	42.50	42.26	42.63	29.60	28.88	29.98	10.75	10.78	10.73	8.87	8.64	8.99*
	±1.25	±1.01	±1.36	±1.65	±1.39	±1.42	±2.18	±2.52	±1.96	±1.60	±1.77	±1.35	±0.67	±0.62	±0.69	±0.35	±0.29	±0.32
1996	19.34	18.77	19.63	29.14	28.07	29.68*	42.26	41.69	42.55	29.66	29.50	29.74	8.85	8.19	9.19**	7.80	7.21	8.10
	±1.42	±1.40	±1.35	±1.59	±1.24	±1.46	±1.97	±1.41	±2.14	±1.55	±1.74	±1.44	±0.81	±0.55	±0.70	±1.00	±0.25	±1.10
1997	20.58	20.65	20.53	30.02	30.08	29.98	40.77	40.79	40.75	29.70	29.29	29.97	10.28	10.34	10.24	8.68	8.71	8.66
	±1.22	±1.07	±1.30	±1.56	±1.31	±1.69	±1.54	±1.72	±1.42	±1.15	±1.15	±1.07	±0.50	±0.44	±0.53	±0.37	±0.43	±0.33
1998	20.12	19.91	20.22	30.41	30.52	30.36	41.38	41.11	41.52	29.48	29.22	29.61	10.21	10.06	10.28	8.71	8.66	8.74
	±1.73	±1.48	±1.83	±1.55	±1.82	±1.40	±1.38	±1.31	±1.40	±1.24	±1.45	±1.10	±0.54	±0.48	±0.55	±0.32	±0.21	±0.36
1999	20.20	20.28	20.17	30.68	31.29	30.44	41.29	41.79	41.09	28.97	28.73	29.06	10.25	10.27	10.24	8.75	8.81	8.73
	±1.99	±2.29	±1.86	±1.83	±1.60	±1.86	±1.63	±1.48	±1.64	±2.25	±2.15	±2.28	±0.45	±0.30	±0.50	±0.32	±0.20	±0.36
2000	21.20	20.50	21.50	30.65	30.67	30.64	41.08	40.83	41.19	27.55	27.92	27.39	11.27	11.17	11.31	8.83	8.85	8.81
	±1.88	±1.15	±2.04	±1.28	±0.99	±1.38	±2.26	±2.34	±2.21	±1.94	±1.37	±2.12	±2.63	±2.27	±2.77	±0.35	±0.33	±0.36
2001	20.84	20.68	20.95	31.69	31.79	31.62	41.65	41.82	41.54	30.45	29.88	30.85	10.44	10.30	10.54	8.90	8.83	8.95
	±1.28	±1.25	±1.30	±2.01	±2.01	±2.00	±1.41	±1.03	±1.61	±2.26	±1.38	±2.64	±0.69	±0.75	±0.63	±0.42	±0.46	±0.37
2002	18.76	17.92	19.23	30.25	31.22	29.73	40.34	40.23	40.39	28.61	28.55	28.64	9.15	9.13	9.15	9.44	9.57	9.37
	±1.48	±0.70	±1.59	±1.85	±1.68	±1.72	±1.69	±2.38	±1.15	±1.28	±0.99	±1.41	±0.57	±0.52	±0.59	±0.67	±0.92	±0.48
2003	19.93	20.32	19.51	29.70	30.34	28.99	41.05	40.67	41.46	27.42	27.43	27.41	10.06	10.10	10.02	8.59	8.52	8.67
	±1.30	±1.12	±1.34	±1.63	±1.72	±1.17	±1.69	±2.01	±1.12	±1.49	±1.60	±1.36	±0.61	±0.66	±0.55	±0.64	±0.52	±0.75
2004	20.50	20.73	20.27	28.99	29.18	28.80	40.53	41.32	39.73	29.03	28.86	29.20	9.97	9.99	9.95	8.90	8.95	8.84
	±1.53	±1.56	±1.47	±1.22	±1.10	±1.30	±3.56	±3.52	±3.43	±1.48	±1.34	±1.58	±0.42	±0.39	±0.45	±0.47	±0.43	±0.50
2005	20.36	20.34	20.37	30.65$^{\#\#}$	30.45	30.77	40.69$^{\#\#}$	39.75	41.21	28.86	28.20	29.23	10.28$^{\#}$	9.96	10.46*	8.91	8.71	9.02*
	±1.10	±1.21	±1.03	±1.82	±1.11	±2.10	±2.45	±2.69	±2.14	±1.68	±1.83	±1.47	±0.60	±0.61	±0.51	±0.38	±0.40	±0.33

* $p \le 0.05$; ** $p \le 0.01$ for differences between paddles and oars; $^{\#}$ $p \le 0.05$; $^{\#\#}$ $p \le 0.01$ for differences between 1995–2005

Table 5. Numerical data on the examined features of rowers, taking into account the type of racing boats

	Circumference of chest			Circumference of waist			Circumference of hip			Circumference of arm			Circumference of forearm			Circumference of thigh			Circumference of shank		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	95.79	92.92	97.31*	80.60	81.77	79.98	103.12	100.11	104.71*	29.43	30.38	28.94	30.28	30.23	30.31	58.86	59.24	58.65	37.12	36.97	37.19
	±4.50	±3.44	±4.25	±2.38	±2.07	±2.29	±4.61	±3.67	±4.26	±2.00	±2.00	±1.80	±2.38	±2.54	±2.29	±2.14	±1.68	±2.33	±2.76	±2.64	±2.83
1996	100.17	97.50	101.50*	80.19	80.36	80.11	96.02	96.57	95.75	29.69	29.21	29.93	27.86	27.50	28.04	58.12	57.21	58.57	38.07	37.36	38.43
	±4.35	±4.65	±3.51	±3.21	±3.89	±2.80	±3.84	±3.99	±3.73	±1.30	±0.70	±1.46	±1.12	±0.76	±1.23	±2.83	±2.66	±2.81	±1.71	±1.51	±1.70
1997	98.03	98.25	97.88	79.58	78.82	80.07	99.63	97.80	100.83	29.76	29.32	30.04	28.77	28.66	28.83	58.80	57.27	59.80*	38.47	38.41	38.52
	±4.10	±4.11	±4.08	±3.23	±3.07	±3.24	±5.32	±2.75	±6.19	±1.75	±1.72	±1.70	±1.30	±1.47	±1.16	±3.48	±2.83	±3.51	±2.11	±1.89	±2.24
1998	98.24	97.54	98.59	80.12	81.17	79.60	96.77	95.62	97.35	29.88	29.63	30.00	27.74	27.52	27.85	57.71	57.88	57.62	38.03	38.33	37.88
	±3.94	±5.23	±3.03	±3.36	±4.20	±2.70	±4.13	±4.69	±3.69	±1.85	±1.55	±1.97	±1.22	±1.24	±1.20	±3.09	±3.68	±2.74	±2.27	±3.15	±1.65
1999	98.34	98.93	98.11	79.67	81.67	78.89*	97.12	98.44	96.60	30.17	30.76	29.94	28.13	28.14	28.12	58.57	59.52	58.20	37.92	38.23	37.80
	±3.95	±6.03	±2.70	±2.99	±3.67	±2.24	±4.73	±4.73	±4.63	±1.97	±1.65	±2.03	±1.14	±1.09	±1.16	±3.26	±3.77	±2.95	±2.33	±1.89	±2.47
2000	101.65	99.43	102.59	79.46	78.93	79.69	99.43	98.73	99.72	30.43	29.25	30.94**	28.08	27.58	28.29	58.13	56.35	58.89	38.09	37.67	38.27
	±4.56	±4.49	±4.25	±2.61	±2.47	±2.63	±2.70	±2.56	±2.70	±1.34	±1.27	±1.02	±1.02	±0.75	±1.04	±3.15	±2.06	±3.23	±1.88	±1.82	±1.88
2001	100.56	101.27	100.08	80.72	80.40	80.94	100.54	99.70	101.12	30.19	30.83	29.74	28.55	28.91	28.29	57.59	57.07	57.95	39.19	39.01	39.31
	±4.04	±3.73	±4.18	±3.31	±2.11	±3.92	±4.66	±3.73	±5.13	±1.83	±1.34	±1.98	±1.37	±1.53	±1.19	±2.87	±2.65	±2.95	±2.05	±2.58	±1.57
2002	95.99	96.40	95.77	79.20	78.72	79.46	97.58	97.35	97.70	30.29	31.27	29.75	28.09	29.05	27.56	55.90	57.68	54.93*	38.34	37.88	38.59
	±5.10	±4.98	±5.14	±4.28	±3.35	±4.69	±2.76	±2.96	±2.64	±2.26	±2.60	±1.84	±1.75	±1.63	±1.58	±2.70	±2.04	±2.51	±1.94	±1.82	±1.96
2003	95.12	96.36	93.75	79.29	79.68	78.85	97.05	97.27	96.80	29.00	29.23	28.75	27.71	27.77	27.65	57.55	57.36	57.75	38.12	37.59	38.70
	±3.73	±3.50	±3.47	±3.12	±3.61	±2.39	±3.77	±3.92	±3.58	±1.63	±1.86	±1.27	±1.08	±1.07	±1.07	±2.92	±2.61	±3.22	±2.12	±2.02	±2.08
2004	95.21	95.30	95.12	79.01	78.97	79.04	97.47	97.22	97.72	29.24	28.92	29.56	27.71	27.89	27.52	57.28	56.55	58.01	37.49	36.92	38.05
	±3.79	±3.06	±4.40	±3.36	±3.42	±3.29	±4.10	±4.11	±4.08	±1.63	±1.29	±1.85	±0.99	±0.76	±1.15	±2.47	±2.59	±2.11	±1.62	±1.95	±0.90
2005	98.19	98.16	98.20	80.15	81.32	79.49	99.50$^{\#\#}$	99.06	99.74	29.26	29.64	29.04	27.99$^{\#\#}$	27.42	28.31	58.00	58.08	57.96	38.50$^{\#}$	38.11	38.71
	±4.39	±4.51	±4.33	±4.27	±4.55	±3.95	±4.34	±5.68	±3.35	±1.67	±1.71	±1.61	±1.38	±1.24	±1.35	±3.57	±4.52	±2.90	±2.13	±2.07	±2.14

* $p \le 0.05$; ** $p \le 0.01$ for differences between paddles and oars; $^{\#}$ $p \le 0.05$; $^{\#\#}$ $p \le 0.01$ for differences between 1995–2005

Table 6. Numerical data on the examined features of rowers, taking into account the type of racing boats

	Body mass			Fold of shoulder blade			Fold in arm			Fold in forearm			Fold in stomach			Fold in thigh			Fold in shank		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	81.09	75.88	83.85**	13.58	11.78	14.53	12.23	12.67	12.00	8.58	8.11	8.82	11.31	9.22	12.41	18.49	19.09	18.18	14.24	14.84	13.92
	±7.03	±5.28	±6.22	±3.47	±1.93	±3.71	±3.12	±1.05	±3.76	±2.48	±2.18	±2.59	±4.40	±1.81	±4.94	±5.05	±4.38	±5.35	±4.53	±4.41	±4.57
1996	81.58	78.49	83.12	11.05	11.86	10.64	15.29	20.00	12.93**	6.67	10.00	5.00*	12.48	13.86	11.79	13.62	18.71	11.07**	16.10	18.57	14.86
	±6.47	±6.00	±6.14	±2.55	±3.09	±2.12	±4.97	±5.29	±2.52	±4.48	±6.00	±1.93	±3.69	±5.19	±2.34	±5.38	±5.06	±3.33	±5.69	±7.27	±4.19
1997	79.53	76.88	81.26*	10.28	10.18	10.35	9.16	9.47	8.96	3.53	4.06	3.19	10.00	9.82	10.12	10.56	10.94	10.31	10.40	11.18	9.88
	±6.65	±5.37	±6.83	±3.13	±2.57	±3.44	±2.93	±2.81	±2.99	±1.63	±1.51	±1.62	±4.16	±3.13	±4.71	±3.52	±3.84	±3.27	±3.24	±3.45	±2.99
1998	82.30	80.58	83.17	11.26	9.00	12.39**	11.19	10.00	11.78	7.96	6.56	8.67	13.78	11.78	14.78	13.44	12.11	14.11	12.44	12.33	12.50
	±6.79	±7.50	±6.23	±3.19	±1.76	±3.15	±3.28	±4.14	±2.55	±2.66	±1.89	±2.71	±4.84	±5.12	±4.37	±4.77	±5.47	±4.23	±3.10	±3.40	±2.93
1999	82.72	84.29	82.10	11.28	10.78	11.48	10.06	10.89	9.74	8.31	9.33	7.91	11.09	9.56	11.70	13.59	14.78	13.13	11.31	12.33	10.91
	±7.17	±6.65	±7.27	±2.67	±1.81	±2.92	±2.56	±3.45	±2.03	±3.46	±3.09	±3.51	±4.52	±2.59	±4.96	±4.67	±4.13	±4.78	±3.20	±3.53	±2.96
2000	80.80	78.53	81.76	10.85	10.00	11.21	9.18	11.33	8.26	5.16	5.33	5.09	10.55	10.00	10.79	15.10	16.67	14.43	17.20	20.83	15.64*
	±4.73	±4.72	±4.39	±2.37	±1.41	±2.60	±3.43	±4.82	±2.01	±0.83	±0.75	±0.85	±4.02	±1.00	±4.74	±3.13	±2.69	±3.06	±5.00	±4.41	±4.39
2001	81.78	80.83	82.43	11.17	10.44	11.68	8.14	7.36	8.68	5.00	4.67	5.23	9.86	8.04	11.12	16.03	14.27	17.25	12.97	12.07	13.60
	±6.47	±6.55	±6.34	±2.57	±1.31	±3.06	±2.56	±2.08	±2.72	±0.95	±0.69	±1.03	±3.87	±1.16	±4.53	±4.82	±4.32	±4.77	±3.74	±2.90	±4.11
2002	79.59	79.17	79.82	10.49	9.47	11.05	8.44	8.87	8.20	5.55	4.67	6.04	11.52	8.37	13.24	13.59	10.67	15.18	11.34	10.00	12.07
	±8.05	±6.20	±8.88	±2.40	±1.36	±2.64	±2.16	±2.46	±1.93	±2.17	±0.62	±2.53	±7.09	±2.48	±8.12	±5.28	±1.85	±5.83	±4.35	±3.84	±4.43
2003	80.00	80.72	79.22	10.34	10.07	10.64	8.11	7.33	8.98	5.22	5.04	5.42	9.50	8.45	10.64	8.45	8.09	8.84	6.80	6.62	7.00
	±6.65	±5.88	±7.33	±2.23	±1.79	±2.60	±2.23	±1.25	±2.70	±0.92	±0.87	±0.93	±3.29	±3.27	±2.92	±2.97	±1.96	±3.75	±1.86	±1.51	±2.18
2004	80.40	79.99	80.81	8.36	8.22	8.50	7.35	6.84	7.86	4.60	4.08	5.12*	8.21	7.42	9.00	10.44	9.02	11.86*	10.28	9.10	11.46*
	±6.32	±6.85	±5.72	±1.05	±0.90	±1.17	±1.45	±1.26	±1.45	±0.96	±0.54	±1.01	±2.74	±1.81	±3.24	±2.62	±1.85	±2.49	±2.24	±1.56	±2.19
2005	82.57	80.32	83.82	8.95$^{\#\#}$	9.16	8.83	7.37$^{\#\#}$	7.12	7.51	5.51$^{\#\#}$	5.02	5.78	11.25	12.16	10.74	13.04$^{\#\#}$	12.60	13.28	11.00$^{\#\#}$	10.32	11.38
	±8.08	±9.56	±6.82	±1.87	±2.15	±1.68	±1.43	±1.46	±1.39	±1.13	±0.94	±1.13	±4.30	±5.98	±2.85	±4.14	±4.27	±4.04	±3.24	±3.85	±2.77

* $p \leq 0.05$; ** $p \leq 0.01$ for differences between paddles and oars; $^{\#\#}$ $p \leq 0.01$ for differences between 1995–2005

Table 7. Numerical data on the analysed indicators of rowers

	Index														
	trunk			shoulders			pelvis			chest			Rohrer		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	29.54	29.28	29.68	76.34	76.71	76.15	69.74	68.42	70.44	71.15	74.57	69.34	1.21	1.14	1.25**
	±1.13	±1.35	±0.97	±3.87	±3.66	±3.97	±3.94	±3.43	±4.01	±6.99	±5.93	±6.82	±0.09	±0.05	±0.08
1996	27.31	27.17	27.38	82.05	82.45	81.85	70.35	70.75	70.15	66.46	66.89	66.24	1.21	1.21	1.21
	±1.04	±1.23	±0.92	±5.30	±4.43	±5.68	±5.24	±3.03	±6.05	±4.74	±4.46	±4.86	±0.08	±0.06	±0.09
1997	28.87	29.42	28.52	75.51	74.78	76.00	72.94	71.92	73.61	68.74	68.74	68.74	1.21	1.20	1.21
	±1.64	±1.15	±1.80	±5.05	±4.67	±5.23	±3.77	±4.12	±3.36	±5.33	±3.68	±6.18	±0.10	±0.11	±0.10
1998	29.36	29.18	29.45	74.45	75.28	74.03	71.31	71.19	71.37	66.28	65.33	66.76	1.21	1.22	1.20
	±0.93	±0.92	±0.92	±3.67	±3.36	±3.75	±3.83	±4.92	±3.15	±6.16	±4.53	±6.77	±0.09	±0.09	±0.09
1999	29.73	29.35	29.87	73.59	74.96	73.06	70.20	68.83	70.73	65.90	64.81	66.33	1.22	1.23	1.22
	±1.36	±0.87	±1.48	±3.34	±2.28	±3.53	±5.33	±5.47	±5.18	±5.73	±6.53	±5.32	±0.10	±0.09	±0.10
2000	28.93	30.14	28.42**	75.85	72.92	77.11	67.74	68.50	66.65	69.19	66.82	70.20	1.23	1.23	1.23
	±1.30	±0.71	±1.15	±5.17	±3.33	±5.30	±6.07	±3.70	±5.65	±5.64	±2.37	±6.29	±0.07	±0.09	±0.06
2001	30.94	31.21	30.76	72.12	72.37	71.95	73.08	71.42	74.24	66.02	65.36	66.48	1.25	1.26	1.24
	±1.45	±1.32	±1.50	±4.47	±4.47	±4.47	±4.41	±2.24	±5.12	±5.80	±6.26	±5.41	±0.08	±0.05	±0.10
2002	29.41	28.64	29.83*	72.63	74.61	71.54	71.02	71.23	70.90	62.29	57.57	64.86*	1.17	1.18	1.17
	±1.10	±1.05	±0.88	±4.34	±6.40	±1.84	±3.84	±5.21	±2.81	±6.50	±3.98	±6.16	±0.08	±0.08	±0.08
2003	30.11	30.22	29.99	72.26	70.81	73.85*	66.88	67.53	66.16	67.33	67.15	67.53	1.19	1.18	1.20
	±1.00	±0.96	±1.03	±3.22	±1.91	±3.59	±4.06	±4.18	±3.80	±5.72	±4.77	±6.61	±0.08	±0.11	±0.03
2004	27.82	27.59	28.05	76.44	78.71	74.17	72.19	70.40	73.98	70.92	71.21	70.63	1.16	1.16	1.16
	±1.03	±0.93	±1.07	±6.50	±6.46	±5.69	±7.15	±7.26	±6.58	±6.87	±6.70	±7.03	±0.07	±0.08	±0.04
2005	29.52	29.77	29.39	73.20$^{\#}$	72.08	73.82	71.08	71.04	71.10	66.62$^{\#\#}$	66.84	66.50	1.23	1.25	1.21
	±1.19	±1.30	±1.10	±5.97	±6.14	±5.77	±4.24	±3.52	±4.59	±4.97	±3.91	±5.47	±0.10	±0.11	±0.09

* $p \leq 0.05$; ** $p \leq 0.01$ for differences between paddles and oars; $^{\#}$ $p \leq 0.05$; $^{\#\#}$ $p \leq 0.01$ for differences between 1995–2005

Table 8. Numerical data on the analysed indicators of rowers

	Indicator muscle											
	arm			forearm			thigh			shank		
	total	paddles	oars	total	paddles	oars	total	paddles	oars	total	paddles	oars
1995	76.78	79.90	75.13	119.37	124.80	116.49	133.65	130.49	135.33	78.97	79.50	78.69
	±5.91	±6.16	±5.04	±12.48	±13.12	±11.1	±11.51	±12.14	±10.79	±7.50	±7.80	±7.33
1996	86.35	86.53	86.26	109.62	118.58	105.13**	118.07	113.16	120.53	87.78	91.90	85.72*
	±6.27	±5.23	±6.72	±10.69	±8.70	±8.56	±9.70	±6.67	±10.04	±5.42	±3.62	±4.97
1997	85.12	83.48	86.19	109.38	108.82	109.75	124.58	125.14	124.21	94.36	98.65	91.55**
	±6.79	±5.02	±7.55	±9.10	±10.78	±7.77	±12.08	±12.32	±11.92	±7.15	±6.78	±5.89
1998	84.12	85.51	83.43	105.25	105.03	105.36	128.85	129.75	128.41	82.79	85.01	81.67
	±6.41	±4.05	±7.21	±10.16	±11.21	±9.59	±7.43	±5.53	±8.19	±7.01	±8.26	±6.00
1999	88.40	88.50	88.35	103.72	105.96	102.84	135.27	137.92	134.24	80.17	79.40	80.47
	±6.76	±5.58	±7.17	±14.28	±9.67	±15.63	±10.35	±10.68	±10.03	±6.37	±4.85	±6.85
2000	84.93	79.66	87.19**	103.72	101.63	104.62	117.45	119.51	116.57	90.31	91.13	89.97
	±6.12	±4.56	±5.25	±8.47	±7.39	±8.73	±7.56	±6.23	±7.89	±6.20	±4.79	±6.68
2001	86.36	86.57	86.22	105.44	107.91	103.73	141.73	144.05	140.12	84.91	86.21	84.00
	±7.00	±3.97	±8.49	±8.97	±7.88	±9.28	±9.73	±11.58	±7.81	±5.32	±5.64	±4.88
2002	85.22	87.56	83.95	103.05	105.47	101.73	122.73	125.71	121.10	90.21	89.17	90.78
	±7.82	±9.13	±6.66	±6.54	±7.23	±5.72	±9.66	±7.34	±10.36	±5.54	±5.18	±5.65
2003	84.64	83.02	86.43	106.89	106.27	107.57	123.57	124.01	123.08	93.04	89.86	96.55
	±6.51	±6.85	±5.60	±7.57	±6.61	±8.46	±9.00	±8.42	±9.57	±8.14	±8.29	±6.34
2004	81.67	80.27	83.06	106.13	104.55	107.72	117.33	113.43	121.23*	84.44	83.79	85.08
	±4.95	±3.33	±5.83	±7.39	±6.98	±7.44	±7.65	±5.91	±7.20	±5.62	±6.45	±4.57
2005	82.57$^{\#\#}$	86.83	80.20*	109.35$^{\#\#}$	105.77	111.35	123.63$^{\#\#}$	130.13	120.02	90.14$^{\#\#}$	90.73	89.81
	±6.81	±4.78	±6.61	±8.41	±8.59	±7.61	±13.89	±15.73	±11.23	±5.65	±4.08	±6.33

* $p \le 0.05$; ** $p \le 0.01$ for differences between paddles and oars; $^{\#\#}$ $p \le 0.01$ for differences between 1995–2005

Table 9. Numerical data on the body composition of rowers

	% water			% fat			% lean mass		
	total	paddles	oars	total	paddles	oars	total	paddles	oars
1999	61.41	61.22	61.48	16.09	16.22	16.04	83.91	83.78	83.96
	±2.41	±2.53	±2.36	±3.21	±3.39	±3.14	±3.21	±3.39	±3.14
2000	63.45	64.00	63.21	13.30	12.50	13.64	86.70	87.50	86.36
	±3.09	±3.00	±3.10	±4.37	±4.07	±4.45	±4.37	±4.07	±4.45
2001	61.18	60.33	61.77	16.64	17.78	15.85	83.36	82.22	84.15
	±2.67	±2.16	±2.83	±3.64	±2.82	±3.92	±3.64	±2.82	±3.92
2002	61.88	62.83	61.36	15.71	14.33	16.45	84.29	85.67	83.55
	±2.56	±1.77	±2.77	±3.53	±2.43	±3.80	±3.53	±2.43	±3.80
2003	61.76	61.82	61.70	15.57	15.55	15.60	84.43	84.45	84.40
	±2.56	±1.80	±3.20	±3.50	±2.50	±4.34	±3.50	±2.50	±4.34
2004	62.10	62.10	62.10	15.15	15.10	15.20	84.85	84.90	84.80
	±2.39	±2.51	±2.26	±3.21	±3.14	±3.28	±3.21	±3.14	±3.28
2005	61.25	61.50	61.11	16.39	16.10	16.56	83.61	83.90	83.44
	±2.71	±2.66	±2.73	±3.74	±3.56	±3.83	±3.74	±3.56	±3.83

rences in relation to their lengths and the muscularity of forearm and thigh – circumference decreased in relation to their length.

Analysing the somatic build of rowers, taking into account the type of rowing boat, larger means of all analysed width features, body mass, thickness of skin and adipose folds and the length features in the crew of long paddles with the exception of the length of the forearm, were noted. During the last year of observations the team using oars was characterized by larger circumferences of chest, hips, forearm and shank and the rowers using paddles were characterized by larger circumferences of waist, arm and thigh. The average distance between the fingertips of a man's outstretched arms in the years 1999–2005 has changed from larger values among participants using paddles to larger ones

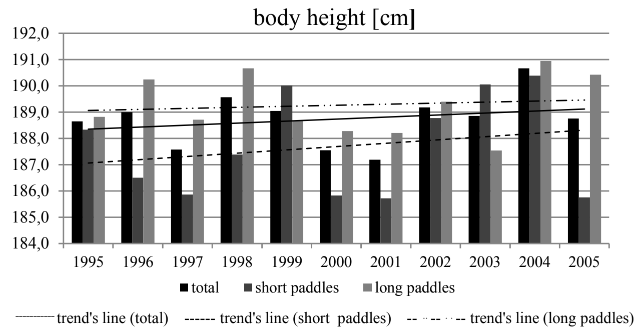

Figure 1. Body height of rowers in the period from 1995 to 2005

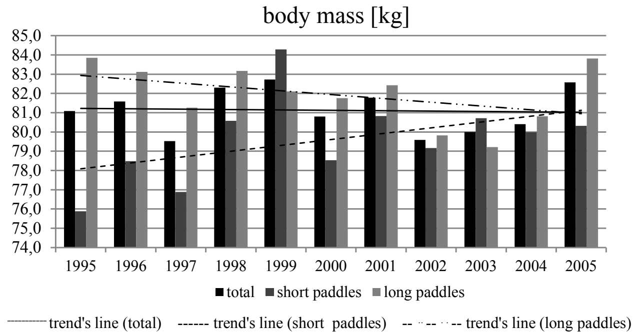

Figure 2. Body mass of rowers in the period from 1995 to 2005

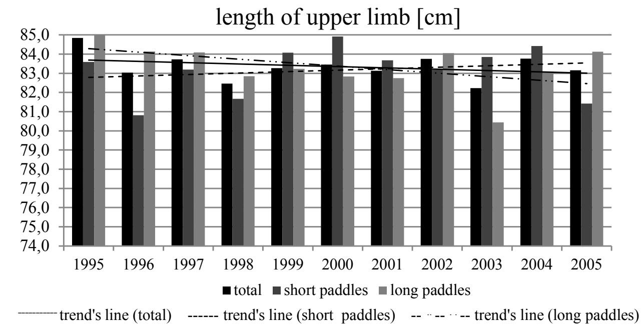

Figure 3. Length of upper limb of rowers in the period from 1995 to 2005

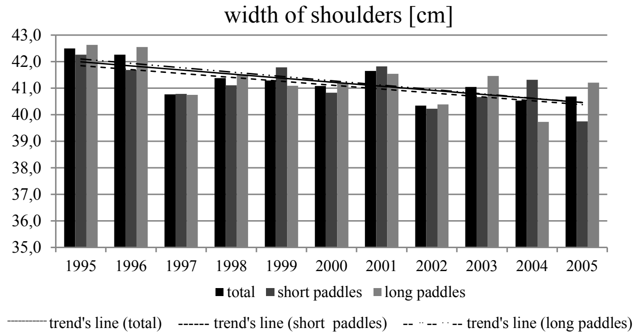

Figure 4. Width of shoulders of rowers in the period from 1995 to 2005

in the crew of oars. Analysing the quotient rates of body proportion in the crews of paddles and those of oars during the 10-year observations, no significant differences between the groups were noted. The participants of both categories of racing boats according to the accepted classification were characterized generally by narrow pelvis, medium broad shoulders and flat chest.

Discussion

In the last few years, professional sport has undergone transformations. There could be observed changes such as the increase in sports results level, the range of sports disciplines as well as the number of competitions in each sport. A systematic solution to problems connected with preparation of training process taking into account the level of special efficiency of participants, technical, tactic, psychical preparations and other special requirements and scientific basis of training has become very important. Several-years' observations of champions make it possible to bring forward a hypothesis that the sports performance in rowing, to a large degree, determined by somatic build of participants, is also connected with their age [1, 2, 5, 6]. Therefore, it was decided to describe the somatic build of this sports discipline athletes who belong to the junior national team and succeed in sports competitions of European and world ranks. In the years 1995–2005, in the Junior World Championships, Polish contestants won 16 medals in total (9 were won by men and 7 by women), including 3 gold, 5 silver and 8 bronze ones, and 34 teams took part in the final race (positions I–VI).

On the basis of cross-sectional study, it is very difficult to settle which elements of morphological build are the result of the body shaping training and which of them were subject to the process of selection. The feature which without doubt can be recognized as a selecting element is the body height, a feature marked by osseous measurements. Skeleton growth is genetically conditioned and is subject to the endocrine system but is also shaped within reaction standard under environmental conditions. The body height as well as other body measurements based on osseous measurement can reflect beneficial and non-beneficial influences which take place before the end of the growth period. In rowing, more suitable sportsmen are the ones with a high value of this feature, which very often exceeds the standard of population and, at the same time, the higher the sports level is, the higher the value of this feature [1, 7]. The subjects under examination who belong to the junior national team confirm the aforementioned direction of selection, giving way to the world leading sportsmen of this discipline [1, 7]. Nevertheless, taking into account the young age of junior rowers, it can be assumed that their skeleton growth has not ended yet. The length measurements of body – body height, length of trunk, length of upper and lower limbs in numerous technical disciplines, also in rowing, are important as a lever system, which means that their suitable measurements allow for work in the optimal angle range. Easiness of this work depends on movability of joints used in the biomechanical system of rowing cycle, mostly hip joint, shoulder joint, tarsal joint [4]. There are mutual relations between somatic conditions, boat positioning, paddles and other factors which determine individual technique of rowing and consequently influence the speed of boat. Technical perfection in rowing can be developed only by a vast use of motion and mechanical conditions of rowers. The crucial role is played by long upper limbs which allow rowing in the optimal range of angle work of a paddle and an oar as well as significant length of lower limbs, whose muscles are one of the main motive powers while performing rowing cycle [4].

Physical activity is known to influence bones mineralization which leads to their thickness and mass enlargement. Moreover, this process is enhanced by shaping function of muscles which makes the places of their attachment thicker. Hence, in individual sports disciplines the dominance of width features is clearly marked in these parts of the skeleton which are most engaged in the training process. This is justified by the fact that the width features are slightly less controlled genetically. In the team of men under examination, during the 10-year period of analysis, the decrease in shoulder broadness and increase in chest were noted. Interannual changes in the analysed features should be connected with the young age of participants, uncompleted skeleton growth and the annual changes in composition of subjects who belong to the national team. All of them influence the differences between means of features of succeeding years of examinations.

Undoubtedly, intense and systematic physical exercises, especially sports training at high level, make adaptive changes appear in the muscular system. According to Secher [8] and Steinacker [9] in the outstanding rowers' muscles which are most engaged in the sports discipline, there are from 70% to 85% slow contractile muscles being the factor predestinating to do resistance disciplines. In well-trained participants, the density of mitochondria is very high and increases with the increase of training level. Hypertrophy of the muscle groups with the major participation in rowing, is clear. The greatest influence on the development of the muscular system is exerted by weight training, whereas the resistance training leads to the development of more slender muscles of smaller circumferences.

In the years 1995–2005, in the team of examined men, the decrease of the hip circumference, slendering of the forearm and the enlargement of the shank circumference were found, which should be related to the specificity of this sport. The findings were confirmed by Pietraszewska [10] and Skład et al. [1], who among the features especially important in the body build of rowers mentioned large muscular circumferences of limbs, especially the forearm.

The body mass and thicknesses of the skin-adipose folds belong to the group of features recognised as very much ecosensitive. Physical effort and immediate influence of socioeconomic circumstances leave their own significant trace on these features. The analysis allowed us to notice the growth of the rowers' body mass, however these changes are statistically insignificant. This is related to the requirements imposed on sportsmen. Apart from much stamina which should characterise the rower, the skill of developing considerable muscular power is also essential, because along with the necessity of executing a number of repetitions of the rowing movement, it is essential to give as much force as possible into every pull. The best way of the growth of the working muscles strength would be enlargement of muscle mass, and consequently also the body mass. However, growth of the body mass would make it difficult to move the boat. Examined participants compared to the contestants of the Olympic Games who practise this sports discipline, are characterized by lower body mass [1, 7].

Within the analysed years one observes a decrease in skin-adipose folds thickness in the analysed crew. The subcutaneous fat includes about 50% of the entire fat of the organism; it reacts especially quickly to changes happening, among other things, under influence of physical exercises and sport training. The extension of the motive activity makes for the reduction of the adipose mass. The undoubtetly great importance should be attributed to socioeconomic events and to noutrition. Competitors practising rowing are forced by the requirements of this sport and the competition to maintain the right weight-growth proportions. Numerous consultations and sports camps dedicated to the correct nutrition have a beneficial influence on the level of the subcutaneous adiposity. The observed maintenance of the body mass at the similar level for the 10 analysed years at the same time keeping or diminishing the adipose layer is connected with the enlargement of the analysed circumferences of limbs and consequently with enlargement of the musculature. This is confirmed by the growth of average values of the musculature rate of the shoulder and shanks and the positioning of competitors in the year finishing the cycle of study in the thick-set limbed group with the exception of the average rate of shank muscularity.

Aiming to show predispositions of the subjects to achieve high sports results, an attempt has been undertaken in this paper to compare the average somatic features analysed with the findings of rowers taking part in the World Championships or the ones who are the members of the Olympic team, whose body build can be recognized as a model in this discipline. Comparisons of the average somatic features analysed in teams of juniors of the top sports level, both in the country and in the world [11] show that Polish athletes are characterized by a considerably greater thickness of fat layer, smaller broadness of shoulders and pelvis, greater musculature of bottom limbs; men – also with the lower mass of the body, and women – with smaller length of the upper limb. According to the somatic criteria accepted in rowing, it seems that the body build of rowers who take part in the World Championships predisposes them more to achievements at a champion level. Expected tendencies of morphological feature changes in Polish teams aim mostly toward a decrease of the adiposity.

In the present study one also accomplished analyses of the somatic features of rowers using short and long paddles. The technique of oars rowing does not differ from paddles rowing. The differences result from the use of only one and not two paddles and the unsymmetrical work of the whole rower's body. Analysing the results obtained, it was found that in the year closing the cycle of research, higher means of all the analysed features were reached in the crew of oars.

Models of the competitors' body build depending on rowing competition, generally known from the literature [1, 11, 12] are confirmed in the examination of young rowers. However, the literature lacks in detailed information concerning the body build of rowers, with division into types of racing boats (paddles, oars). Sportspersons of junior category, due to their young age, are not assigned to only one competition, whereas the type of the boat remains invariable (according to interview with the Coach of Junior Team). The tendencies of morphological feature changes shown were confirmed by the study of Krupecki [7], who indicated significant differences between rowers – participants in the Olympic Games in Barcelona and Atlanta – using paddles and oars. He showed that the athletes using paddles had smaller body height (by 2.6 cm) and lower body mass (by 2.8 kg) than rowers using oars. The observed differences between sportspersons, clearly appeared at the turn of the years 2000 and 2001, especially in body circumferences and thicknesses of skin-adipose folds. This situation, as one may suppose, could be caused by more severe criteria of selection, optimization of training process, better competence of coaches supported by scientific findings, especially on physiology and biochemistry [13–18] as well as anthropology. The body build is only one of the determinants in the crew selection, depending on the types of racing boats. Among other factors, one ought to mention: the ability of differentiating kinesthetic movement ("the feeling of the boat, feeling of the paddle"), fancies and psychical predispositions of the sportsperson (individual or team rivalry, the skill of cooperation in the group) or the reserve team of the rowing club.

Executing analyses of the rowers' body proportion comprising the years 1995–2005, insignificant changes in the mean of somatic indicators were found, except for a characteristic decrease of the shoulder broadness in relation to the trunk length and of the chest depth to its width, in the male team.

Estimating quotient indicators of the body proportion in the group of paddles and oars crew, within a 10-year observation period, no essential differences between the groups compared were noted. Rowers of both categories of racing boats, according to the accepted classification, were characterized by generally narrow pelvis, medium broadness of shoulders and flat chest. One established the shortening of the trunk length in relation to the body height of oarspersons together with slendering of the body build and lengthening of the trunk in relation to the body height and decreasing of the slendering degree in the group of paddles athletes. The phenomena of slendering and body measurements' decrease, especially in oars multi-rower crews, e.g. eights, was also noticed by Skład et al. [1], indicating the necessity of maintaining the above tendency so as not to influence negatively the speed of the boat and to level much resistance of the boat in the water environment, and perhaps less significant – air resistance. Therefore, the authors suggest selecting individuals of more slender and more delicate skeleton and musculature to multi-rower crews, though it can happen at the cost of the decrease in rowers' strength. This was confirmed by the observed crew slendering of eights participating in the Olympic Games in Barcelona.

In the present paper, changes of components of the rowers' body, within 1999–2005, were also comprised. They are characterized by highly eco-extensive features which change their own proportions under influence of the activity of different exogenous factors of the development, physical activity included. Sportspersons of the top sports performance are distinguished by a considerable fat reduction and a strong development of the active tissue. The teams examined showed the decrease in the water percentage in the body composition, the dry mass showed the decrease of the proportional content, reversely to changes of fat component. Taking into account categories of racing boats one noticed higher percentages of water and dry mass in the group of athletes using paddles, and a proportionally higher content of the fat component in the group of competitors using oars. Thus, one ought to suppose that the higher level of the adipose mass in rowers using oars is conditioned by predispositions of the somatotype to this category of racing boats. While comparing the body composition means obtained on the basis of author's own research with the research of rowers of similar age, participants in world championships [19] and competitors who belong to athletic clubs in Poznań [20], one found that rowers of top level performance were characterized by the lowest percentage of fat; competitors of the junior national team examined in 1999 were characterized by proportionally a little higher fat content. It can be supposed that an increase of the level of training causes a bigger reduction in fat percentage.

Various authors, based on examinations of professional rowers taking part in sports events of the highest rank, show a tendency to an increase in the adipose tissue content. Among the participants in the Olympic Games in Montreal, 7.8% of the fat mass in male rowers and 15.2% in female rowers were reported [21], and in the Polish rowers taking part in the Olympic Games in Barcelona the percentage of the adipose mass amounted to 9.3% [1, 6]. These findings would explain the increase in fat component in the examined junior rowers in the years 1999–2005. The data refer to athletes of the open weight category, because the body mass and the composition of lightweight competitors' body is a separate problem due to weight limit regulations. Male rowers and female rowers from the Polish Junior Team belong to the open weight category because of their young age. Participation in the lightweight category is connected with (most often) the necessity of lowering the body mass to the limits imposed by the regulations not always only at the cost of the adipose mass, but also the lean mass or dehydration of the organism, leading to decreases in strength and physical efficiency.

In the complex approach to the obtained findings one can state that rowers of the national junior team are characterized by a significant height of the body, high body mass and at the same time a considerably slender figure. Characteristic features are: trunk with its large length measurements and large circumferences, long upper and lower limbs, shoulders of medium broadness, narrow pelvis, flat chest. Big musculature of upper and lower limbs, which classifies rowers to the group of thigh-set limbed, and the considerable fatness of the body expressed by the thickness of skin-adipose folds with the proportional fat content are also characteristic features. Analysed teams show the differences based on types of racing boats, where the teams of long paddles obtain higher mean features having higher proportional fat share in the general body mass.

Using model characteristics of sportspersons who practise various sports disciplines and take part in competitions, observations and analyses of post-training effects, are essential. Sports results have reached such level that without the search for new ideas of analyzing a training process and without applying new technologies to elaborate the information available, there is no chance to compete with the best sportspersons in the world. The knowledge collected from a range of different scientific fields, anthropology included, will make it possible to throw light on mechanisms of shaping efficiency, to estimate the reason of observed stabilization of achievements, to ascertain its temporary or permanent character and also to express more precise principles of the development of the training level. Due to such analytical concept, one will be able to face the challenge of dynamically developing professional sport.

Conclusions

Summing up the considerations, the following findings and conclusions were drawn.

In the years 1995–2005 vital changes in the construction of morphological build of rowers occurred, appearing in the change of direction and dimensions of features. Transformations of the body build model are the result of changes being the participation of the human population, the reasonable selection of rowers, optimization of the training process and constructional requirements of rowing equipment.

The selection of competitors to rowing teams leaves the trace in the body build based on the type of racing boat.

Elite rowers must satisfy the criteria of morphological build, and the level of these requirements is adapted to the specificity of this sports discipline and types of racing boats.

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CHOOSING THE RIGHT BODY POSITION FOR ASSESSING TRUNK FLEXORS AND EXTENSORS TORQUE OUTPUT

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ABSTRACT
Purpose. The sitting position is generally adopted when measuring the torques produced by flexors and extensors of the trunk. Results of such measurements are influenced by the strength of both abdominal muscles and flexors of the hip joint. In order to assess the effect of exercises used to strengthen the abdominal muscles it was necessary to find such a measuring position which engaged mainly the abdominal muscles. The objective of the study was an assessment of EMG activity of abdominal and spinal muscles during the measurements of muscle torques in the sitting position, as well as in the lying position. **Basic procedures.** Thirteen female students of the University School of Physical Education in Wrocław participated in the study. The methods of measuring muscle torques and surface electromyography (sEMG) were used under static conditions. The torques were measured on a multifunctional chair in the lying and sitting positions. The surface EMG electrodes were placed on the right and left hand sides of m. rectus abdominis (RA) and m. erector spinae (ES). Signals from both muscles were sampled at 1000 Hz. **Main findings.** The maximal torques of trunk flexors in the sitting position and in the lying position were similar: 130.6 ± 31.7 Nm and 129.8 ± 37.9 Nm, respectively. By contrast, the torque of trunk extensors was significantly larger when the measurement was carried out in the sitting position (228.1 ± 76.4 Nm) as compared with the lying position (148.8 ± 25.3 Nm). The ratio of the maximal torques of flexors and extensors of the trunk in the women examined was 0.572 in the sitting position and 0.872 in the lying position. Both RA and ES showed higher EMG activity in the lying position than in the sitting position. **Conclusions.** The higher EMG activity of the RA muscle in the lying position at the same values of the trunk flexors torque in both positions may suggest that in the sitting position flexors of the hip joint are more engaged than abdominal muscles. That is why, in order to assess the effects of abdominal muscles training, measurements of the trunk flexors torque should be performed in the lying position.

Key words: torque, EMG, measuring position, trunk muscles

Introduction

Measuring muscle torques is one of the most frequently used methods of assessing the effects of training and of selecting the correct loads both in physiotherapy and in sports. While measurement methodology of flexor and extensor torques of the hip and knee joints is well defined [1–5], the torques of trunk flexors and extensors are measured either in a sitting or standing position. This is often a result of the way the measuring equipment is constructed. Flexion and extension of the trunk are characterized by many degrees of freedom and consequently engage many muscle groups. It is apparent for flexion of the trunk that its first phase is realized mainly by abdominal muscles (m. rectus abdominis, mm. external and internal obliques), which are then joined by hip flexors (m. iliopsoas, m. rectus femoris, m. tensor fasciae latae), the main actuators in the last phase of flexion. This is a result of the variation of the muscle lever arm and consequently of the torque produced. The external effects of muscle action, the torques produced, are the sum of all the actions of a given muscle group. The value of the maximal torque as a function of the joint angle is therefore different not only in individual joints but also at different angular positions of the same segment. There are a lot of experimental data concerning this effect for major joints of the upper and lower extremities [6].

The interest in measuring trunk muscle torques is a result of the constantly increasing number of people suffering from the low back pain syndrome (LBP) [7, 8]. A special role in preventing LBP should be attributed to strengthening the muscle groups which are jointly referred to in the literature as muscle corset. These muscle groups include, among others, abdominal muscles and m. erector spinae, and their role consists in

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stabilizing the spine during activity of the muscles responsible for appropriate execution of all the movements. The stabilizing function of muscles is based on their static activity when activated muscles do not change their length, which is a result of the muscular torque being equal to the external torque.

According to the literature cited in previous papers [9], exercises like curl-up may be safe and efficient in preventing LBP, because they engage m. rectus abdominis and mm. external obliques in their motor function. In order to assess the effects of training and to program the correct loads during exercises, reliable measurement of strength capabilities of these muscles must be carried out. This criterion is not fulfilled by the measurement of the torque of trunk flexors in the sitting or standing position, because beside abdominal muscles it engages also other muscle groups. That is why, we propose to perform the measurement of the maximal torque of trunk flexors in the lying position with such a range of trunk flexion that would keep the lower tips of scapulae on the support. Adequacy of this measuring position may be verified by electromyography. Therefore, the objective of this study was an assessment of EMG activity of abdominal and spinal muscles during the measurement of muscle torque carried out in the sitting and lying positions. This was helpful in finding the measuring position in which trunk flexion was realized more by abdominal muscles than by flexors of the hip.

Material and methods

Subjects

Thirteen subjects were recruited from among female students of the Faculty of Physical Education of the University School of Physical Education in Wrocław. Their body height and body mass were, respectively, 168.5 cm and 55.5 kg on average. In order to make the results of this study as representative as possible, subjects were selected to be of the same sex (women), of a narrow age interval (21–25 years), and of similar level of motor activity and body type. All the subjects were informed about the aims and procedures of the experiment, and signed an informed consent statement. The experiment was approved by the Commission for Ethics in Scientific Research at the University School of Physical Education in Wrocław.

Experimental procedures

Methods of surface electromyography and measurements of muscle torques under static conditions were used in this study. Both signals were measured according to the rules and principles described in the literature [10, 11]. Synchronous measurements of static muscle torques and of EMG signals were carried out for muscles representing the groups of flexors and extensors of the trunk, i.e. for m. rectus abdominis (RA) and m. erector spinae (ES).

EMG measurements

Surface electrodes were placed on the right and left hand sides of m. erector spinae and m. rectus abdominis, and two more electrodes sites were additionally used on the latter in its upper and lower parts (Fig. 1a). This choice of EMG electrode sites, which included the right, left, but also the lower and upper parts of the muscle, was dictated by its specific shape. A similar approach to assessing activity of this muscle was used by some other authors [12, 13]. The two electrode sites on m. erector spinae were situated at a distance of 3.5 cm from the spinous process of the first lumbar vertebra [10] (Fig. 1b).

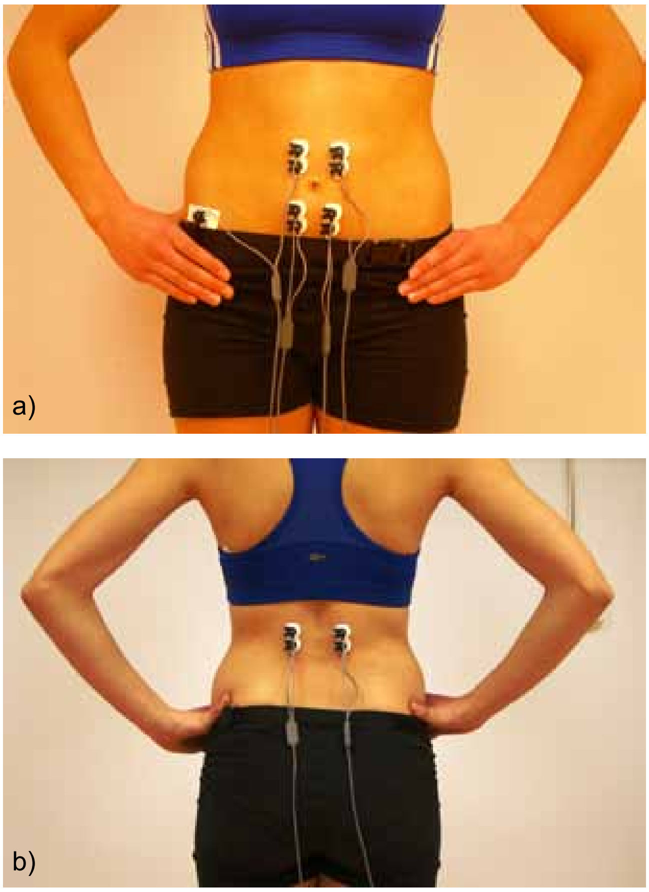

Figure 1. Electrode placement on m. rectus abdominis (a) and m. erector spinae (b)

The surface electrodes were placed according to the principles of best EMG signal reception described in the literature [12, 14, 15], and also based on the lines of action of muscles, which allowed us to take into account the individual anatomy of the subjects. The action potential of the muscles was recorded using solid gel Ag/AgCl surface electrodes (NORAXON Inc. USA) placed in a bipolar configuration on muscle bellies along muscle fibres. The electrode set included 6 pairs of active electrodes and 1 reference electrode, which was placed on the skin at an electrically passive location (anterior superior iliac spine). An 8-channel electromyographic device "Octopus" (Bortec Electronics Inc., Calgary, Alberta, Canada) was used, and signals were sampled at a frequency of 1000 Hz.

Normalization of the EMG signal

For normalization of the EMG signal, at the beginning of the experiment subjects were asked to perform a maximum voluntary contraction (MVC) [12], which required the help of two additional persons.

MVC of m. rectus abdominis (RA) was realized by counterbalancing the external load applied to the chest by the person who assisted in measurements. The subject attempted to lift the trunk from the floor. Her upper extremities were flexed in the elbow joints, and hands were placed at the back of the head. The second assistant was stabilizing the position by holding the feet at the ankles (Fig. 2).

For m. erector spinae (ES) MVC was produced during counterbalancing the external load applied near the scapulae by the person who assisted in measurements. The position of the upper extremities of the subject and trunk stabilization was the same as for m. rectus abdominis (Fig. 3).

The maximum values obtained in these measurements were assumed as reference values in the assessment of activity of abdominal and spinal muscles.

Figure 2. Maximum voluntary contraction (MVC) for m. rectus abdominis

Figure 3. Maximum voluntary contraction (MVC) for m. erector spinae

EMG signal processing

The raw EMG signal and the torque were recorded in a personal computer by using the "BioWare" software. Files with "tbd" extension were exported to the MATLAB environment, which was then used to process the EMG signals. Signal envelope was found by applying an algorithm available in the MATLAB environment in the program *dspenvdet.mdl*. The first step of these calculations was to square and double the EMG signal. Next, the result was filtered by a lowpass linear filter with finite impulse response. Parameters of the transfer function representing the filter were set up to 0, 0.03, 0.1, 1 and 1, 1, 0, 0 for the numerator and denominator, respectively. The envelope was calculated as the square root of the filtered output signal. The maximum of the envelope was the largest value of this square root (Fig. 4).

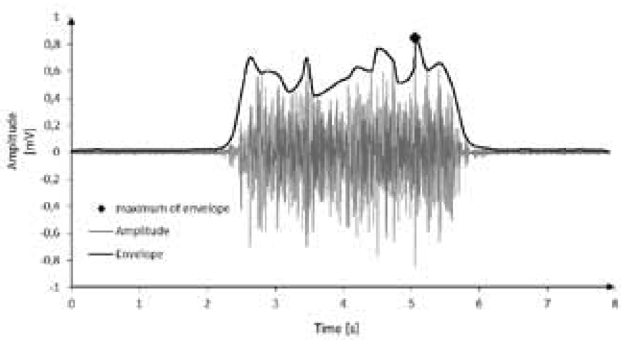

Figure 4. Exemplary envelope of an EMG signal

Measuring stand and experimental procedure

The measurements were carried out on a multifunctional chair (SUMER, Opole, UPR-01 A/S). To meet the needs of the experiment the chair was enhanced in a special way. The enhancement consisted in supplementing the single torque transducer by a second one, and in connecting both transducers with a transversal beam, which forced the subjects to push symmetrically on the measuring levers while producing the maximum torque. Technical characteristics of the measuring stand were described in Szpala et al. [16].

The task of the subjects consisted in producing maximum static torque in response to a cue. The measurements of the torque and the EMG signal from the muscles examined were carried out in both sitting and lying positions.

The sitting position was defined by fixing the hip and knee joint angles at 90°. The axis of the hip joint was aligned with the axis of the dynamometer. In order to eliminate the influence of other muscle groups through the so called muscle torque transfer, upper extremities were held crossed on the chest, and pelvis, thighs and shanks near ankle joints were immobilized with stabilizing belts. The resistance of the measuring device was applied to the front of trunk near the chest for the measurement of the torque of trunk flexors (Fig. 5a), and to the rear of trunk near the scapulae – for the measurement of the torque of trunk extensors (Fig. 5b).

The lying position was defined by the requirement that during the measurement of the torque of trunk extensors the subject was lying on the measuring chair and the hip joint axis was aligned with the axis of the dynamometer. Lower extremities were straight at hip and knee joints and stabilized at the ankles by the assisting person. Hands were placed behind the head. The resistance of the measuring device was applied as in the sitting position (Fig. 6a). During the measurement of the torque of trunk flexors the subject was lying on the measuring chair with shoulders raised up to such a trunk flexion angle that allowed the lower tips of the scapulae to still contact the support. Attention was paid during the measurement to make sure that the head was in its anatomical position and was not pressed towards the chest. The hip joint axis was aligned with the axis of the dynamometer, lower extremities were flexed in the hip and knee joints by 90°, and they were stabilized by the assisting person at the ankles. Upper extremities were held straight along the trunk. The resistance of the measuring device was applied as in the sitting position (Fig. 6b).

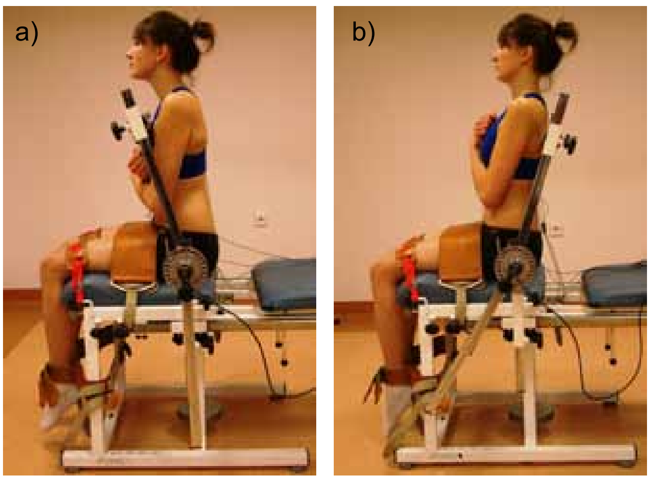

Figure 5. Measurement of torque output and EMG activity in the sitting position for m. rectus abdominis (a) and m. erector spinae (b)

Figure 6. Measurement of torque output and EMG activity in the lying position for m. rectus abdominis (a) and m. erector spinae (b)

The lever arm of the external force was individually selected for each measurement to take into account possible differences in the physical build of the subjects. This approach is in agreement with the generally accepted principles of muscle torque measurements under static conditions [11].

All the measurements within this project were carried out in the Laboratory of Biomechanical Analyses of the Department of Biomechanics of the University School of Physical Education in Wrocław (certificate PN-EN ISO 9001:2001).

Results

In order to assess which measuring position engages abdominal muscles to a greater extent, the amplitudes of action potential and the torque produced by the muscles examined were analyzed. The analysis included both the EMG signals expressed in natural units and the normalized EMG signals (the MVC value was adopted as a reference value during the assessment of activity of abdominal and spinal muscles).

Measuring position and muscle torque output

In order to verify if there is a difference in magnitude between torques measured in the sitting and lying positions, the mean values obtained in those positions were compared.

The maximal muscle torque of trunk flexors in the sitting position (130.6 ± 31.7 Nm) was similar to that obtained in the lying position (129.8 ± 37.9 Nm). Student's t-test for independent data did not show significant difference between the means (t = –0.0883 for df = 56 and p = 0.93). By contrast, the torque of trunk extensors was significantly larger in the sitting position (228.1 ± 76.4 Nm), compared to that measured in the lying position (148.8 ± 25.3 Nm). Student's t-test for independent data confirmed the significance of the differences between the means (t = –5.09 for df = 61 and p = 0.00004). The statistical analysis was carried out at the significance level of $\alpha < 0.05$.

An analysis of flexors to extensors ratio was subsequently performed and it showed that the resultant torque of trunk extensors exceeded by 70% the resultant torque of trunk flexors in the sitting position and by 14% in the lying position. This means that the ratio of the maximal torque of trunk flexors and the maximal torque of trunk extensors in the women examined amounted to 0.572 and 0.872 in the sitting and lying positions, respectively.

Measuring position and EMG activity

In order to identify which measuring position engages abdominal muscles to a greater extent the normalized EMG amplitudes in the two measuring positions were compared. Action potentials of the muscles on both sides of the body were summed up at this stage of analysis, and their levels of engagement were evaluated in all the measuring positions. This approach allowed us to conclude that both muscle groups demonstrated higher electromyographic activity in the lying position (RA: 83.50 ± 8.27%, ES: 87.40 ± 19.0%) than in the sitting position (RA: 60.98 ± 16.39%; ES: 41.00 ± 17.35%). Student's t-test for independent data identified statistically significant differences between activities in the lying and sitting positions for m. rectus abdominis (t = 6.61, for df = 56 and p = 0.00001) and m. erector spinae (t = 10.05 for df = 61 and p = 0.00001).

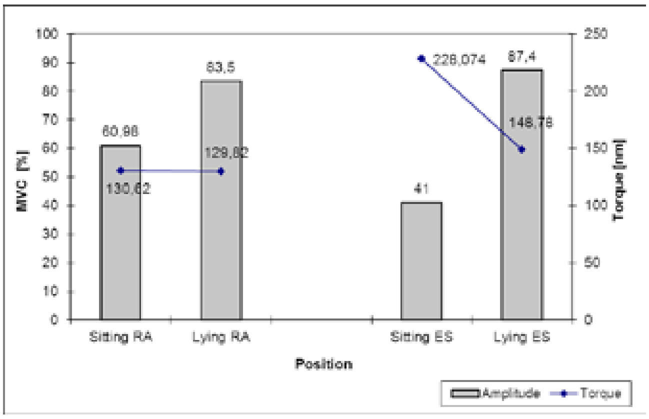

Figure 7. Sum of action potential shown against the background of maximum torque output of the muscles examined: RA – m. rectus abdominis; ES – m. erector spinae

The next stage of analysis considered electromyographic activity of the muscles examined against the background of torque produced. It turned out that both muscle groups showed higher action potentials in the lying position, but higher torques were found in the sitting position (Fig. 7).

Measuring position and symmetry of muscular activity

An analysis of symmetry of muscular activity was performed next. Comparing bioelectric activity of the right and left hand sides of the muscles examined showed symmetry in the EMG amplitude for m. rectus abdominis (RA) and asymmetry for m. erector spinae (ES) in the positions analyzed, which followed from Student's t-test for independent data (Tab. 1). The statistical analysis was carried out at the significance level of $\alpha < 0.05$.

The specific shape of m. rectus abdominis required placing the surface electrodes not only on its right and

Table 1. Results of symmetry analysis between the right and left hand sides of the muscles examined in the adopted measuring positions (t – Student's t-test, df – number of degrees of freedom, p – probability level, RA – rectus abdominis, ES – erector spinae). Data not normalized

Measuring position	Muscle		Amplitude 1 (mV)	Amplitude 2 (mV)	t	df	p
Lying position	RA	right side – upper part vs. left side – upper part	0.856	0.902	–1.505	28	0.143
		right side – lower part vs. left side – lower part	0.744	0.711	1.224	28	0.231
Sitting position		right side – upper part vs. left side – upper part	0.708	0.638	2.039	28	0.051
		right side – lower part vs. left side – lower part	0.468	0.444	0.887	28	0.382
Lying position	ES	right side vs. left side	0.953	1.084	–4.656	33	0.00005
Sitting position		right side vs. left side	0.416	0.494	–3.299	28	0.00264

Table 2. Results of symmetry analysis between the upper and lower parts on the right and left hand sides of m. rectus abdominis (RA) in the adopted measuring positions (t – Student's t-test, df – number of degrees of freedom, p – probability level). Data not normalized

Measuring position	M. rectus abdominis (RA)	Amplitude 1 (mV)	Amplitude 2 (mV)	t	df	p
Lying position	right side – upper part vs. right side – lower part	0.856	0.744	2.133	28	0.041
	left side – upper part vs. left side – lower part	0.902	0.711	3.886	28	0.0006
Sitting position	right side – upper part vs. right side – lower part	0.708	0.468	4.071	28	0.00003
	left side – upper part vs. left side – lower part	0.638	0.444	4.268	28	0.0002

left hand sides, but also on its upper and lower parts. Analysis of symmetry between the upper and lower parts, but on the same side of the muscle, identified significant differences in activity of m. rectus abdominis in all the positions considered (Tab. 2).

In this part of the experiment the analysis was based on raw data, instead of those related to the value of the maximum isometric voluntary contraction (MVC). Signals should be normalized when one compares activity of different muscles in different motor tasks. As humans show dynamic asymmetry manifesting itself in differences between the strength of the right and left hand sides of the body, it can be assumed that this asymmetry will manifest itself in EMG activity as well. If normalized EMG signals were used, then possible differences between the sides would not be visible. A similar approach to the analysis of EMG signals from muscles of the right and left hand sides of the body was employed by other authors [17].

Discussion

Electromyography has been applied in increasingly sophisticated biomechanical analyses aiming at trunk muscle force assessment mainly in LBP prevention. Stokes [18] analyzed dependence of EMG signals on trunk muscles effort under isometric conditions. Using an apparatus to stabilize the pelvis, influence of increasing versus decreasing effort on the EMG/effort relationship in the standing position was quantified. It was found that the EMG/effort relationship had a statistically significantly greater gradient as the effort was increasing than when it was decreasing. Gardner-Morse et al. [19] noticed that many problems with the lumbar spine can be attributed to instability. The ligamentous spine (without muscles) is unstable at very low compressive loads. They examined the hypothesis that instability of the lumbar spine is prevented under normal circumstances by the stiffness of spinal musculature, without active responses from the neuromuscular control system. The effect of muscle activity on the stability of the lumbar spine was analyzed for maximum voluntary extension efforts with different spinal postures in the sagittal plane. Ng et al. [8] examined the effect of fatigue on torque output as well as electromyographic frequency and amplitude values of trunk muscles during isometric axial rotation in back pain patients and compared the results with a matched control group of healthy persons. They found that low back patients demonstrated a different activation profile of the trunk muscles during the exertion.

The EMG/torque output relationship is analyzed for trunk muscles, and in many cases this is done under dynamic and not static conditions [7, 20]. However, in accordance with Hill's curve, the maximal strength capabilities can well be quantified under static conditions. Such an assessment is necessary if one wants to identify the effects of a training program both in physiotherapy and in competitive sports. Our experiment concerned the problem of choosing the most appropriate measuring position for assessment of muscle groups being strengthened in back pain prevention programs. The obtained results showed that mm. rectus abdominis and erector spinae demonstrated higher action potential in the lying position, and larger torque output in the sitting position. This information may also be important for rehabilitation procedures in which choosing the lying position can be significant for persons suffering from low back illnesses. The constantly increasing number of scientific publications testifies to the growing interest of researchers in the role of various exercise and training programs in LBP prevention.

In our opinion, it is the flexors to extensors torque ratio that is more significant to LBP prevention than the actual values of the torques of individual muscle groups. Many papers present trunk muscles torque output against the background of the general strength profile of the major muscle groups [21, 22]. However, such an assessment is not useful for LBP prevention. It seems justifiable to adopt an assessment based on agonist to antagonist strength ratio, as it is done for flexors and extensors of the knee joint in competitive sport (in prevention of m. biceps femoris injuries). Such an approach based on using the flexors to extensors ratio for the trunk is suggested by Trzaskoma [21] for injury prevention in competitive sport and for diagnosing patients with different disorders. It follows from the research published in another paper [23] that the flexors to extensors ratio can have similar values even though the maximal torque outputs of flexors and extensors of the trunk differ significantly in women and men with different spinal disorders. For persons with different disorders the flexors to extensors ratio evaluated based on measurements of maximal torque output in the sitting position amounted to 0.445 for women with L4–S1 discopathy, 0.692 for persons using a wheelchair, and 0.818 for patients with rheumatoid arthritis in an early stage. Trzaskoma [21] compared these values with the flexors to extensors ratio for healthy women in the same measuring position, which turned out to be equal to 0.739. In our research, which was carried out using a different measuring apparatus, the flexors to extensors ratio obtained for the same measuring position was equal to 0.572.

The present work brings also an analysis of symmetry of electromyographic activity of the muscles examined as a function of the measuring position adopted. Activity was analyzed of those muscles which normally fulfill motor functions, but can also engage in stabilizing functions while producing maximal forces [24]. That is why, it was assumed that during maximal static effort of mm. rectus abdominis and erector spinae the activity of these muscles should be characterized by symmetry between their right and left hand parts. The statistical analysis indicated a symmetric pattern only in the amplitude of the EMG signal of m. rectus abdominis (RA). A similar characteristic of activity of these muscles (i.e. symmetry of m. rectus abdominis and asymmetry of m. erector spinae) was found when activity was examined under static conditions, but muscles did not have to produce maximal forces [9]. Asymmetry for spinal muscles was also found by Furjan-Mandić et al. [25] when they examined EMG activity of m. erector spinae and trapezius, and detected more pronounced electric activity in the right hand parts of these muscles in the analyzed exercises. By contrast, Axler and McGill [26] found asymmetry in activity of m. rectus abdominis characterized by a predominance of the left hand side.

Conclusions

Higher EMG activity of m. rectus abdominis in the lying position together with the same values of trunk flexors torque output in both measuring positions may suggest that hip joint flexors are more engaged than abdominal muscles in producing maximal torque during measurements performed in the sitting position. That is why, for a reliable assessment of training effects of abdominal muscles, we recommend to carry out the measurement of trunk flexors torque output in the lying position.

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BIOMECHANICAL DIFFERENCES ASSOCIATED WITH TWO DIFFERENT LOAD CARRIAGE SYSTEMS AND THEIR RELATIONSHIP TO ECONOMY

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ABSTRACT
Purpose. To explore relationships between load carriage economy and the kinematics and kinetics of load carriage using both a backpack (BP) and a double pack (DP). **Basic procedures.** Nine participants walked on a treadmill at gradients of between 27% downhill and 20% uphill, and over a force plate on level ground, at a speed of 3 km.h-1. Expired air was collected throughout the treadmill experiment and all experiments were filmed for subsequent biomechanical analysis. The relative economy of load carriage was expressed in terms of the Extra Load Index (ELI). **Main findings.** There was a tendency for the double pack system to be associated with better economy than the BP. The double pack system provoked significantly less forward lean than the backpack and the horizontal displacement of the CoM was also smaller for the double pack system and both of these factors were strongly related to economy. There was, however, a greater range of motion of the trunk in the DP condition and this was also associated with improved economy. **Conclusions.** The results suggest that the DP was associated with smaller perturbations in gait than the BP and that this represents an advantage in terms of economy. In particular freedom of movement of the trunk in the sagittal plane may be an important consideration in the efficiency of load carriage systems.

Key words: load carriage, economy, kinematics, kinetics

Introduction

There is now a considerable body of research relating to human load carriage. Much of the published research has been comparative in nature, considering metabolic (e.g. Abe et al. [1], Bastien et al. [2]), kinematic (e.g. Coombes and Kingswell [3], Attwells et al. [4]), Kinetic (Birrell and Haslam [5], Hsiang and Chang [6]), EMG (e.g. Motmans et al. [7], Hong et al. [8]) and subjective perceptual (e.g. Mackie and Legg [9], Lloyd et al. [10]) differences between load carriage systems. There appears to be some consistency in the literature in relation to the potential advantages of load carriage systems that spread the load around the trunk, and in particular double or front/back pack systems. A number of studies have reported advantages in terms of economy over both traditional backpacks (e.g. Lloyd and Cooke [11] and other carrying methods (e.g. Datta and Ramanathan [12], Legg and Mahanty [13], Coombes and Kingswell [3]). A more limited number of studies have compared either the kinematics (Kinsohita [14]) or the kinetics (Kinoshita and Bates [15], Kinoshita [14], Lloyd and Cooke [16], Hsiang and Chang [6]) of walking whilst carrying a load using a double pack system with either a backpack or unloaded walking. All of these studies have concluded that the perturbations in gait pattern associated with a double pack system are less than those associated with back-loading.

There have been a number of reports in the literature in which empirical data relating to both economy and biomechanical adaptations have been presented (e.g. Quesada et al. [17], Malville et al. [18], Coombes and Kingswell [3]). There are, however, very few papers that have attempted to relate biomechanical changes to measures of economy (Obusek et al. [19], Schiffman et al. [20]). This may be a serious omission as it has recently been suggested that individual variability in load carriage economy may be much greater than previously reported and worthy of further investigation (Lloyd et al. [21]). One way in which this might be achieved is to explore relationships between economy and the acute perturbations to gait associated with different load carriage systems.

The purpose of this paper is, therefore, twofold. Firstly, it will add to the relatively sparse literature relating to the kinematics of double pack systems. Secondly, it will seek to explore relationships between the biomechanical and physiological changes associated with load carriage using both a backpack and a double pack. This will include a reinterpretation of a previously

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published physiological comparison (Lloyd and Cooke [11]) using a measure of relative economy, the Extra Load Index (ELI) (Lloyd et al. [22], based on the earlier work of Taylor et al. [23]. The relationships between ELI, previously reported kinetic changes (Lloyd and Cooke [16]) and new kinematic data will also be considered.

Materials and methods

Participants

Nine healthy volunteers took part in this study, five female and four male. All participants had previous experience of walking with backpack loads. On average the groups were 24.7 ± 4.3 years of age. Average stature and mass were 172.7 ± 11 cm and 73.4 ± 16.4 kg respectively. Body Mass Index (BMI) was, on average, 24.35 ± 2.55 $kg \cdot m^{-2}$ and none of the participants were obese (all BMI < 30). All participants gave informed consent prior to beginning the study, which had received ethical approval from the Leeds Metropolitan University Ethics Committee. A screening questionnaire was administered to ensure that no participants should have been ruled out on health grounds including known musculo-skeletal or neurological conditions that may have impaired their ability to undertake the tests. The participants were of at least average cardio-respiratory fitness with $\dot{V}O_{2max}$ values of 45.46 ± 4.48 $ml \cdot kg \cdot min^{-1}$ for the females and 53.74 ± 9.95 $ml \cdot kg \cdot min^{-1}$ for the males.

Design

Participants were given the opportunity to accustom themselves to both treadmill walking and load carriage with each of the two packs via an habituation session lasting for a minimum of 20 minutes. The study involved participants being tested on five occasions, each one week apart. The first test assessed the participants' $\dot{V}O_{2max}$, the next three tests involved treadmill walking in each of three conditions: unloaded, double pack and backpack. The order in which the loading conditions were undertaken was randomised via a Latin square design with participants randomly assigned (by drawing lots) to one of three groups. Full details of testing protocols and data reduction have previously been published (Lloyd and Cooke [11]). The final test involved participants walking over a force plate and order of loading mirrored that of the preceding three tests. Participants were instructed to look straight ahead whilst walking and to maintain a natural gait. A trial was only deemed acceptable if three conditions were met: the participant's right foot must have landed wholly within the boundaries of the force plate; there must have been no alteration to normal walking gait; and the recorded time for the trial must have been within ± 5% of the target time. If the first of these conditions was not met the starting point of the participant was adjusted accordingly before the next attempt. If the second or third conditions were not met the participant was given suitable advice and asked to repeat the trial. The participant continued to walk unloaded along the runway until three acceptable trials (e.g. Chow et al. [24], Harman et al. [25]) had been achieved. Full details of the protocol for this element are described in Lloyd and Cooke [16].

Equipment

Two packs were used in this study: a double pack (DP) (AARN designs, NZ) and a traditional backpack (BP) (Karrimor Alpiniste, Karrimor, UK). Both packs had a capacity of 65 litres and the double pack came supplied with front balance pockets. The packs were filled with equipment, food and water suitable for a trip lasting one week. Since this load is independent of participant body mass, the total mass of pack and contents was 25.6 kg in all cases. This absolute load equated to an average relative load of 36.2 ± 6.7% Body Mass. Adjustments for differences in the weight of the packs themselves were made by manipulating the food and water rations.

Filming procedures

All filming was performed with a video camera (Panasonic, Japan) operating at 25 Hz. During the force plate experiment the camera was placed perpendicular to the line of walking and 7.5 m from the force plate. Prior to the filming of each subject a marked reference scale was placed on the force plate and filmed to allow for scaling during subsequent analysis. Participants were also filmed standing still on the force plate prior to the start of each loading trial. During the treadmill tests the camera was placed perpendicular to the line of walking at a distance of 5 metres from the treadmill and scaling was achieved via known distances on the treadmill frame.

Data analysis

Video film was digitised field by field, producing an effective sampling rate of 50 Hz, employing the body segment model for adult males according to Dempster

[26] based on 17 points. From the digitised data position of the centre of mass and co-ordinates of the shoulder, hip, knee and ankle joints were then calculated (Mmotion Digit, UK). Data was smoothed via a low pass butterworth filter (6 Hz) prior to analysis. All statistical analyses were performed using SPSS v17.0 (SPSS inc.).

The position of the centre of mass (CoM) for each subject in the standing position was calculated ignoring the mass of the pack. The position of the centre of mass was expressed in relation to the position of the right ankle joint (Mackie and Legg [9]). This was done to eliminate the problems of locating a single reference point for all participants and the slight differences in standing positions. Analysis of the change in position of the centre of mass from the unloaded condition for each pack in both the horizontal and vertical directions was performed using paired sample *t* tests.

Trunk angle has been defined as the angle between the line joining the right hip to the right shoulder and the horizontal, i.e. 90° represents a vertical trunk position, angles less than 90° indicate forward lean. Trunk angles were calculated at the heel strike, mid support and toe off phases of the foot contact with the force plate. They were also calculated for the same points of the gait cycle at the extreme uphill, extreme downhill and level walking conditions of the treadmill protocol. To provide a single value for trunk angle whilst walking the mean value of these three points was calculated. Change in forward lean was defined as the difference between the trunk angle in the unloaded condition and the trunk angle in the loaded condition. Comparison of the changes in forward lean associated with each pack was performed via repeated measures ANOVA. Significant main effects were further explored using pairwise comparisons with a Bonferroni correction

Stride frequency was calculated from the video recordings of the treadmill protocol. The number of frames between right toe off and right toe off were counted for 10 complete stride cycles at each gradient of the treadmill protocol and mean values calculated. Stride length was then calculated based on the known treadmill speed and the relationship between stride length, stride frequency and speed. Differences in stride length were assessed via ANOVA with repeated measures with *post hoc* analysis using the Bonferroni correction.

The relative economy of load carriage in each condition at each gradient was expressed in terms of the ELI and calculated as follows:

$$ELI = \frac{mlO_{2L} \cdot kg\ total\ mass^{-1} \cdot min^{-1}}{mlO_{2U} \cdot kg\ body\ mass^{-1} \cdot min^{-1}}$$

where mlO_{2U} and mlO_{2L} refer to unloaded and loaded oxygen consumption respectively. Differences in ELI were explored via ANOVA with repeated measures and *post hoc* analysis as previously.

Pearsons Product Moment Correlation Coefficients were calculated to explore the relationships between relative economy (ELI values) and various kinematic and kinetic variables for level walking.

Results

Relative economy

Mean + s ELI values are shown in Figure 1. Considering all gradients there was a tendency for the double pack to be associated with lower ELI values (better economy) than the backpack (mean difference 0.076, $p = 0.092$) and this was consistent across all gradients (loading condition × gradient interaction, $p = 0.672$). Figure 1 also indicates that there was considerable individual variation in response. Coefficients of variation for ELI in the level walking condition were 16.1% and 15.2% for DP and BP respectively. Similarly there was individual difference in the response to the two loading conditions with only a very weak, and non-significant relationship between the ELI values (level walking) of $r = 0.373$ ($p = 0.323$).

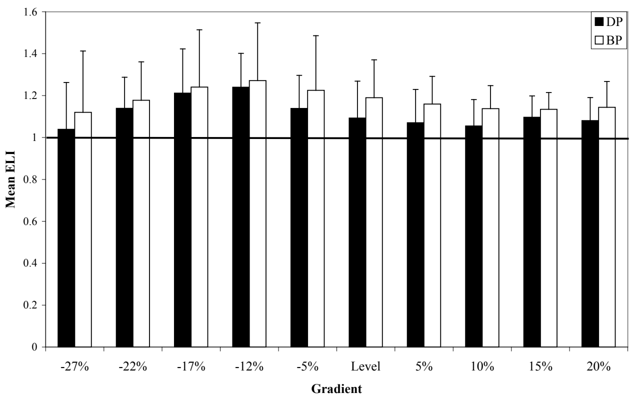

Figure 1. Mean + s ELI values in each condition at each gradient

Stride length

Mean + s values of stride length (m) at each gradient are shown in Figure 2. Considering all gradients, the stride length associated with unloaded walking was on average 5 cm longer than that associated with the DP ($p = 0.010$). It was also longer than that associated with the BP, but not significantly so (mean difference 3.2 cm, $p = 0.203$). Considering all conditions, the stride length during level walking was significantly greater than that

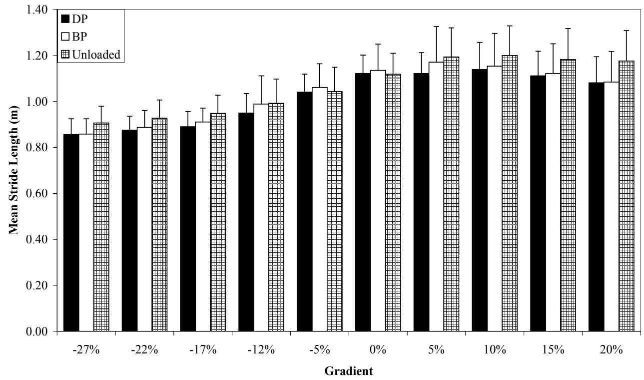

Figure 2. Mean + s stride length (m) in each condition at each gradient

during downhill walking ($p = 0.001$) with the mean differences increasing as the slope became steeper (7 cm at –5% to 25.2 cm at –27%). There was, however, no significant difference between the stride length on the level and any of the uphill gradients ($p = 1.000$). The stride length for the unloaded condition remains relatively stable across all the uphill gradients whilst the two loading conditions are associated with reductions in stride length at the two steepest gradients (loading condition × gradient interaction, $p = 0.006$). The relationship between stride length and ELI during level walking was stronger for the DP ($r = 0.634$, $p = 0.067$) than for the BP ($r = –0.287$, $p = 0.453$). This would suggest that a shorter stride length is associated with better economy in the DP condition.

Position of centre of mass

The horizontal position of the CoM whilst standing moves anteriorly compared to the unloaded condition in both loading conditions. For the DP the change is 1.97 ± 2.76 cm. This is significantly less than the change of 8.28 ± 1.75 cm associated with the BP condition ($p = 0.0001$). The changes in the vertical direction were not significantly different ($p = 0.154$) with, on average, the CoM associated with the DP moving upwards (2.38 ± 3.55 cm) whilst the CoM associated with the BP moved downwards (0.18 ± 4.26 cm). For both conditions there was a significant relationship between the change in horizontal position of the CoM and ELI ($r = 0.755$, $p = 0.030$ and $r = 0.772$, $p = 0.025$ for DP and BP respectively) suggesting that greater changes in forward lean from the unloaded condition were associated with reduced economy in both loading conditions. Relationships were much weaker for vertical changes in the position of the CoM, $r = –0.077$, $p = 0.857$ and $r = 0.220$, $p = 0.600$ for DP and BP respectively.

Trunk angle

The mean ± s trunk angles associated with each loading condition whilst standing still were 93.5° ± 2.5° unloaded , 89.2° ± 3.1° for the AARN pack and 79.8° ± 4.6° for the traditional pack. These increases in forward lean, 4.4° ± 2.9° and 13.8° ± 4.3° for the DP and BP respectively, were significantly different ($p < 0.0005$).

Figure 3 shows the mean increases in forward lean compared to unloaded walking at the heel strike, mid support and toe off phases of the stride cycle, measured whilst in contact with the force plate. The increase in forward lean caused by the packs is significantly different ($p < 0.0005$) at all three points during the contact phase. The BP induces at least 9 degrees more forward lean than the DP pack at all three points. The increase in forward lean between heel strike and mid support was greater for the DP than the BP (2.27° ± 2.54° vs. 1.83° ± 1.42°). Whilst this difference was not

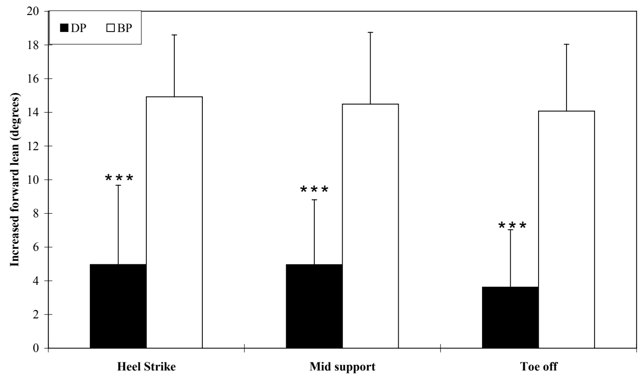

Figure 3. Mean + s increase in forward lean (degrees) above the unloaded condition associated with each pack during walk over the force plate. (*** denotes $p < 0.0005$)

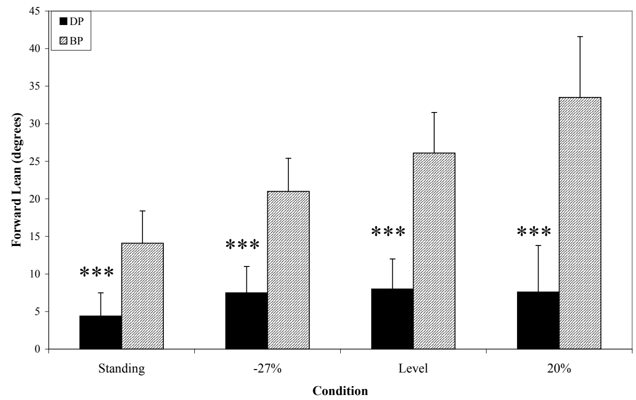

Figure 4. Mean + s increase in forward lean (degrees) above the unloaded condition whilst standing still and walking at various gradients

significant (p = 0.323), the relationship between the increase in forward lean from heel strike to mid support and ELI was significant for the DP (r = –0.867, p = 0.005) but not for the BP (r = 0.454, p = 0.258). This suggests that greater range of motion of the trunk in the early phase of the gait cycle is associated with better economy for the double pack system. In contrast, the differences in trunk angle between the unloaded and BP conditions were strongly related to reduced economy (r = 0.643, p = 0.085 at heel strike, r = 0.670, p = 0.069 at mid support and r = 0.794, p = 0.019 at toe off).

Mean values for increased forward lean whilst walking at the –27%, level and 20% gradients, as well as whilst standing still, are shown in Figure 4.

Considering all three gradients, the BP induced a significantly greater increase in forward lean, on average 13.2°, than the DP (p < 0.0005). The differences between the two packs for increase in forward lean were, on average, 9.1°, 12.7°, and 17.8° for the –27%, level and 20% gradients respectively (p < 0.005). Figure 4 indicates that the extra forward lean induced by the AARN pack remains fairly constant at all gradients whilst the extra forward lean induced by the traditional pack increases as the slope increases.

Relationships between kinetic variable and relative economy

Full results for ground reaction forces have been published elsewhere (Lloyd and Cooke [16]). Considering the DP condition, there were strong relationships between: the magnitude of the first lateral impact peak (r = –0.653, p = 0.079); the difference between the unloaded and loaded first lateral peak force (r = 0.662, p = 0.074); maximum braking force (r = –0.661, p = 0.074); the difference between loaded and unloaded maximum braking force (r = 0.797, p = 0.018) and the times to both the first lateral peak force (r = –0.691, p = 0.058) and the medial peak force (r = –0.798, p = 0.017). For the BP condition the only strong relationships with ELI were in the difference between unloaded and loaded second lateral peak force (r = –0.784, p = 0.021), the time to the same force (r = –0.825, p = 0.012) and the time to maximum braking force (r = –0.624, p = 0.099).

Discussion

Two main approaches have been employed in assessing load carriage economy. The first, and most widely used, is rate of oxygen consumption, usually expressed relative to body mass (e.g. Legg and Mahanty [13], Quesada et al. [17]). The second approach that has been used is the energy cost of walking (Cw) (e.g. Abe et al. [1], Bastien et al. [2]). We would suggest that both of these methods have limitations. The former makes comparison between different studies using different loads and speed of progression very difficult, whilst the latter factors out resting energy expenditure but not the energy expenditure of (unloaded) walking. Both produce values that are difficult to interpret by a non-scientific audience. The ELI, on the other hand, produces a single, dimensionless index, that allows for comparison of different load carriage systems across different studies and also provides a simple to understand ratio that would be useful not only for scientific use but also for manufacturers of load carriage systems, both in development and marketing. From a scientific perspective the ELI has a distinct advantage as it accounts for individual variability in gait. Given that most of the available literature indicates that the cost of carrying extra load is similar to, but slightly greater than, the cost of carrying live mass (e.g. Taylor et al. [23]), then it is likely that the additional element of energy expenditure, above that required simply to support and move the load, is associated with biomechanical changes and that these changes are perturbations from an individual's normal gait pattern. Furthermore, it has been suggested that these normal gait patterns represent the most economical solution for an individual (Martin and Morgan [27]). Thus a measure of loaded economy that accounts for unloaded movement economy has significant utility and merit. In more general terms we would argue that investigations of load carriage, whether they be metabolic, kinematic, kinetic, electromyographic or subjective-perceptual should be referenced to unloaded locomotion.

The ELI values reported here provide further support for the advantage, in terms of physiological cost, associated with double pack systems (e.g. Datta and Ramanathan [12], Legg and Mahanty [13], Coombes and Kingswell [3]). They do, however, indicate that the energy cost of carrying a load in either system is greater than the cost of carrying a unit of body mass.

Previous studies have indicated that back-loading produces only small changes in stride length. Of those that quantified the changes all reported a slight shortening of the stride length relative to unloaded walking or running on the level. Differences have ranged from 1.5% (Thorstensson [28]) to 5% (Cooke et al. [29]). In contrast, Ling et al. [30], Wood and Orloff [31], and Singh and Koh [32] all reported no change in stride length – stride frequency whilst LaFiandra et al. [33] reported a slight lengthening of stride to be associated with two of the three backpacks they studied. Kinoshita

[14] reported no difference in stride length for either a backpack or double pack system. The results of the present study lend support to the view that any changes, at least whilst walking on the level, are small. In contrast to most previous studies, however, the two loaded conditions were associated with a slight increase in stride length during level walking. There was, however, considerable variation between participants with changes in stride length ranging from +12% to –6%. The change in stride length from the unloaded condition increased substantially as the gradient changed from the level in either direction. At the –27% gradient the stride lengths associated with the DP and the BP were, on average, 5.36% and 5.09% shorter than the stride length associated with unloaded walking. At the 20% gradient the reductions were 7.81% and 7.64%.

It has long been established that the stride length–stride frequency combination chosen for a given speed is close to optimum in terms of economy and that relatively large, acute perturbations in stride length–stride frequency result in increases in oxygen consumption (e.g. Cavanagh and Williams [34]). Cooke et al. [29] suggested that a shortening of stride length may be responsible for an improvement in economy with vertical loading as it may lead to a reduction in the vertical oscillation of both the centre of mass and the added load. Given that both increases and decreases in stride length have been associated with increased energy expenditure it might have been expected that the fairly large perturbations evident in the present study, especially at the higher gradients, would have had some effect on economy. There were, however, only two moderate to strong relationships between stride length and ELI. Both were for the DP, suggesting that, on the level, a shorter stride length was associated with improved economy ($r = 0.634$) and that at the 12% downhill gradient, a longer stride length was associated with improved economy ($r = –0.769$). It seems likely then that the perturbations in stride length seen in this, and other studies on load-carriage are insufficient of themselves to explain either the excess energy cost above that required simply to move a unit of live mass (ELI = 1) or to explain differences in economy between load carriage systems.

In terms of the kinematic data presented here it is clear that the single biggest discriminator between the BP and DP conditions is the amount of forward lean provoked by each system. This is consistent with the earlier work of Kinsohita [14]. The magnitude of the forward lean associated with both packs is also consistent with that observed in previous studies. Harman et al. [35] indicated that there was a significant load effect in relation to forward lean associated with walking with a backpack load but no effect of speed. Similarly Polcyn et al. [36], using pooled data from four studies, indicated that 65% of the variance in forward lean could be explained by variance in magnitude of carried load. The load carried in the present study was 25.6 kg, equivalent to, on average, 34.8% bodyweight (BW). The average forward lean whilst walking over the force plate in the BP condition was 12.1°, this is in good agreement with previous studies. Wood and Orloff [31] reported forward lean of 10° whilst carrying a load of 15% BW, whilst Li et al. [37], Hong and Cheung [38] and Singh and Koh [39] reported forward lean of 6.8°, 11.9° and 10.6° respectively when carrying a 20% BW load. LaFiandra et al. [33] reported forward lean of approximately 6° and 12° for loads of approximately 24% and 42% BW, whilst Kinoshita [14] reported forward lean of 11° and 7° for loads of 40% and 20% BW respectively. Data in relation to double pack systems is more scant but Kinoshita [14] reported that the forward lean associated with a double pack system was considerably less than that associated with a double pack. This was not quantified, although inspection of figures showing average trunk inclination across the gait cycle suggest it was of the order of 2.5° which is very similar to the 2.1° of forward lean for the DP observed in this study.

Forward lean during level walking was measured on two occasions in the present study, walking on level ground during the force plate experiment and during the treadmill protocol. The forward lean associated with both loading conditions was greater during the level section of the treadmill protocol than during the force plate experiment. The forward lean associated with the double pack was 2.1° during the force plate protocol and 6.2° during the level section of the treadmill protocol, while for the backpack the increases in forward lean were 12.1° and 18.9° respectively. The forward lean in the unloaded condition remained fairly constant, changing by only 0.4°. There would seem to be a number of possible explanations for this. It may be that the artificial nature of the force plate experiment might have had some effect on posture. Participants were instructed not to look down, had to concentrate on their stride pattern in order to accurately step on the force plate without making adjustments and had to meet the requirements for speed. A number of studies have, however, reported that the kinematics of treadmill and level ground walking are very similar (e.g. Riley et al. [40], Lee and Hidler [41], Parvataneni et al. [42]), even when kinetic or metabolic parameters differ, although none have assessed forward lean. It is likely that a stricture to keep looking ahead will have a greater effect on forward lean than most other kinematic parameters. Alternatively, given that the forward lean for the treadmill protocol was measured at the end of 4 minutes walking, whilst the force plate experiment involved walking only 10 metres, muscular fatigue and/or habituation may have played a part. Two studies have considered this in relation to backpacks (Li et al. [37], Wood and Orloff [31]) and concluded that changes in forward lean across time are minimal. However, both of these studies considered initial measurements after one minute of walking. In the present study a further measure of forward lean was taken, whilst standing still. The forward lean associated with this static condition was 0.8° for the DP and 10.2° for the BP. This finding that static forward lean is smaller than dynamic forward lean, is again consistent with previous research (Singh and Koh [39], Anderson et al. [43]). It has been argued, logically, that, for back-loading in the static condition, the only requirement for stability is that posterior movement of the CoM, caused by the additional load, be countered by the anterior movement of the body's CoM, via increased forward lean, resulting in the system CoM remaining above the base of support (Goh et al. [44]). It has been suggested, however, that this is not a sufficient condition for stability in dynamic conditions (Pai and Patton [45]) and that the horizontal velocity of the CoM needs also to be considered (Hof et al. [46]). Singh and Koh [39] support this theory based on data that suggested that as forward lean increased, walking speed decreased. This is, however, problematic as the causal factor in the speed reduction was additional load, the increased forward lean being a consequence of this. Furthermore, if Hof et al. [46] are correct, it would be anticipated that increasing speed of locomotion would increase forward lean. This is in contrast to the empirical data of Harman et al. [47] and Harman et al. [35] and suggests that, in load carrying, this does not apply.

One striking finding, illustrated in Figure 4, is that the increase in forward lean above the unloaded condition associated with the DP remains fairly constant at all gradients, whilst that for the BP increases with increasing gradient. This observation is consistent with Harman et al. [48] who demonstrated increasing forward lean as the gradient increased from –8% to +8%. The differences in response between the BP and DP are most likely related to changes in the position of the centre of mass. The anterior displacement, relative to the unloaded condition, of the centre of mass whilst standing, was much greater for the BP than for the DP, 8.28 cm as opposed to 1.97 cm. The load itself was discounted in the calculation of the position of the centre of mass. Since addition of mass to the back will result in a posterior displacement of the centre of mass of the whole system, the anterior displacements of the body reported here reflect the compensation necessary for the centre of mass of the whole system to remain over the base of support. This compensation is achieved, for the most part, by increasing the forward lean of the trunk. In addition, and for the same reasons, forward lean increases when walking uphill. Thus walking uphill in the backpack will result in disproportionate increases in forward lean.

One area of particular interest is the range of motion of the trunk through the gait cycle. Despite the much greater magnitude of forward lean associated with the BP than the DP, the change in forward lean during a single foot contact, from heel strike to mid support, was greater in the DP than the BP condition. There is some contrasting data in the literature in relation to this range of motion. Harman et al. [49] suggest that both forward lean and range of motion increase with increasing load, whilst LaFiandra et al. [33] suggest that range of motion decreased with load. Polcyn et al. [36] concluded there was no relationship between trunk range of motion and load (r = 0.33). It would seem likely that as load increases there would be a tendency to resist changes in posture given the energy requirements to accelerate and decelerate the load as it deviates from a neutral position. Harman et al. [25] suggested that a smaller range of motion for the trunk was beneficial as it was closer to unloaded walking. The current data would suggest the opposite. Both the DP and the unloaded conditions were associated with a greater change in forward lean between heel strike and mid support than was the case for the BP condition. This may be particularly important as this change in trunk angle was significantly related to improved economy for the DP condition. Moreover, we have previously argued that it is the momentum associated with this change in trunk ankle that contributed to the requirement for a lower peak propulsive force (Lloyd and Cooke [16]). This may well be one of the energy saving mechanisms that provide advantages for a DP system.

Given that there were strong relationships between increase in forward lean, associated with the horizontal excursion of the CoM, and economy, it is worthwhile examining the physiological cost of this forward lean. Although not directly assessed in the present study, a number of authors have investigated this. Most authors concur that loading the back reduces erector spinae activity at the expense of increased rectus abdominus activity. Carlsöö [50] investigated muscle activity in a variety of loading conditions and found that loading the back relieves the deep muscles of the back, counterbalancing the trunks tendency to fall forward which is normally resisted by the erector spinae muscle, and loads the abdominal muscles. He noted, however, that the activity in the erector spinae increased as forward lean increased. Bobet and Norman [51] found similar decreases in erector spinae activity when the back was loaded but point out that the erector spinae is not the only muscle involved in load carriage and that small changes in the position of the trunk may transfer load from the erector spinae to other muscles. Gordon et al. [52] argued that the increased forward lean associated with loading of the back imposed a greater stress on muscle groups not accustomed to the required work during walking. Specifically forward lean would be resisted by eccentric contracture of the hamstring and semispinalis muscle groups. Motmans et al. [7] considered a number of loading systems and concluded that a doublepack system was the closest to unloaded walking, with very little change in either erector spinae or rectus abdominus activity. This was in contrast to back-loading which caused a significant reduction in erector spinae activity with a concomitant increase in rectus abdominus activity (Motmans et al. [7]); a finding which was consistent with that reported by Al-Khabbaz et al. [53]. Given the trade off in muscular activity associated with forward lean, and the relatively low absolute level of activity in the postural muscles, it would seem unlikely that forward lean is directly responsible for the differences in economy observed. It is likely that the interaction between forward lean and other joint positions, with consequent change in lower limb muscle activity, may be more important and worthy of future comparative study.

It is possible that the effects of any changes in kinematics are not simply additive, but that an interaction exists that may explain differences in economy. Thus, in the present study the combination of changes in stride length and forward lean, and possibly other factors such as the disturbances in the kinematics of the foot (Kinoshita [14]) may result in muscles operating on different parts of their force–velocity and force–length relationships, implying that a greater volume of muscle would be necessary to generate the same force, and changes in mechanical advantage, implying that a greater muscle force will be required to produce the same ground reaction force (Heglund and Taylor [54]).

The finding that, with the double pack, the centre of mass moved upward, by 2.4 cm, relative to the unloaded condition was somewhat unexpected. Further investigation indicated that this may be explained, at least to some extent, by two factors. There appears to be greater knee flexion in the unloaded condition than in the DP condition, the knee to ankle distance was on average 1.2 cm greater in the DP condition, and a raising of the shoulders, the hip to shoulder distance was on average 2.1 cm longer in the DP condition. It is not clear why this might be the case but participant comments indicated that the DP system made them feel as if they were standing up much straighter than normal. Thus the reduced knee flexion and raising of the shoulders may have acted as mechanisms to further reduce static forward lean.

The relationships between kinetic variables and economy are interesting. For the DP condition better economy was associated with a smaller lateral impact peak force and a smaller maximum braking force. In addition, the difference between these forces and the unloaded forces was even more strongly related to economy, with a smaller loaded–unloaded difference being associated with improved economy. This would seem to provide further support for the contention that assessment of load carriage systems should be referenced to unloaded walking and the notion that, for an individual, normal walking gait represents an optimal solution in relation to economy (Martin and Morgan [27]). Reducing these impact peaks may, however, have a further advantage as it has been suggested that it is impact forces that are most closely associated with injury (Polcyn et al. [36]).

Conclusions

The study revealed a number of small, but consistent differences between the double pack and the backpack in kinematic variables. Significant differences included a smaller increase in forward lean and displacement of the centre of mass associated with the double pack. Both of these factors were related to improved economy. These findings can be summarised as showing that the double pack is associated with smaller perturbations from unloaded gait patterns, mainly as a result of significantly less forward lean. These differences suggest that a load carriage system which allows loads to be distributed between both the back and the front of the trunk may be more appropriate for carrying relatively heavy loads than a system which loads the back only, both in terms of injury prevention and economy.

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DO MEN AND WOMEN USE SIMILAR ADAPTIVE LOCOMOTION TO CLEAR STATIC AND DYNAMIC OBSTACLES?

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ABSTRACT
Purpose. The purpose of this study was to analyze the influence of gender on the adaptive locomotion in the clearance of obstacles. Specifically, it was evaluated if there are differences in the space-temporal parameters between male and female in the clearance of and dynamic obstacles moving at both slow and fast speeds. **Basic procedures.** Five young male adults and five young female adults took part in this study. The task was performed in three conditions: static obstacle and dynamic obstacle – clearance perpendicular to the participant's trajectory at slow speed (1.07 m/s) and at fast speed (1.71 m/s). The trials were recorded by two digital cameras and spatial-temporal information was obtained. **Main findings.** The dynamic obstacle conditions required more visual inspection. The results showed different adaptive locomotion between the sexes. The distinct gait patterns were evidenced for the spatial and temporal variables and cadence in the three conditions. **Conclusions.** The women presented a more conservative behavior, which was evidenced by the increase of the length in the penultimate step and in the toe clearance.

Key words: adaptive locomotion, dynamic obstacle, gender

Introduction

The difference between the sexes is extensively discussed in the literature. Men and women show differences in the anthropometric and constitutional characteristics [1 – 3], neuromuscular characteristics [4 – 6] and in physical capacities [7–8], among others. As for the gait, a comparison between the sexes has pointed to the similarity in the gait speed and differences in the step length (shorter for women), cadence (faster for men) and movement patterns [1, 3, 9, 10]. However, it has not been clarified how men and women program and execute locomotor adaptations in the clearance, especially the transposition of dynamic obstacles.

Adaptive locomotion is understood as the ability to adjust the basic locomotion pattern according to the environmental features, considering the individual's conditions and the task's objective, aiming to maintain the dynamic balance. Adaptive locomotion strategies are indicated by alterations in the base of support amplitude adopted to maintain balance, in the proper adjustment to the feet positioning before the clearance and in the safety margin over the obstacle [11]. The programming of strategies in the obstacle transposition takes into consideration the characteristics of the obstacle [12 – 15]. Obstacle speed affects the locomotor behavior and strategies were distinct in the obstacle avoidance phases [16]. Accordingly, the current study aims at clarifying the following questions: Are the adaptive locomotor strategies used by men and women different? Which spatial-temporal parameters are important to explain the strategies used? Are the strategies used the same for static and dynamic obstacles?

The aim of this study was to analyze the influence of sex on the adaptive locomotion in the obstacle avoidance task. Specifically, it was evaluated if there are differences in the spatial-temporal parameters between men and women in negotiating static and dynamic obstacles at slow and fast speeds. The hypothesis in this study is that the strategies used are different between the sexes, once the constitutional, genetic and physical abilities interfere in the gait [1 – 3, 7].

Material and methods

Participants

Five young male adults and five young female adults took part in this study (Tab. 1). All participants were right footed. They gave their informed consent to the experimental procedure as required by the Declaration of Helsinki and the institutional Research Ethics Committee (Protocol# 004387/2003). The exclusion criteria were the presence of skeletal or neuromuscular damage

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Table 1. Participants' characteristics and obstacle height for the groups of men and women

	Age (years)	Body Mass (kg)*	Height (m)*	Lower limb length (m)*	Height of obstacle (m)
Men	23.37 ± 2.13	68.16 ± 8.02	1.74 ± 0.05	0.90 ± 0.04	0.50 ± 0.02
Women	22.40 ± 1.04	60.56 ± 9.94	1.66 ± 0.05	0.87 ± 0.02	0.47 ± 0.03

*statistical difference between sexes ($p < 0.05$)

and/or vision problems not corrected by the use of glasses or lenses.

Task

The task consisted in walking along a corridor (8 m long and 0.5 m wide) and crossing an obstacle (50 cm long and 0.5 cm wide) with the right leg [16] (Fig. 1). The height of the obstacle (Tab. 1) was personalized for each participant corresponding to the knee's height to compensate the anthropometric difference between the groups. The initial comparison between sexes indicated higher values of body mass ($F_{1,48} = 8.85$, $p < 0.05$), height ($F_{1,48} = 26.11$, $p < 0.0001$) and right lower limb length ($F_{1,48} = 11.97$, $p < 0.001$) for the male group (Tab. 1).

Each participant carried out the task in three conditions: (1) static obstacle; (2) clearance perpendicular to the trajectory of the participant at slow speed (1.07 m/s); (3) clearance perpendicular to the trajectory of the participant at fast speed (1.71 m/s). These speeds were established on the basis of the adult unobstructed gait speed (1.33 m/s; deviation of nearly 20%) [17]. Three familiarization trials were made for each condition. Fifteen trials per participant were collected, in blocks of five trials for each condition. The presentation order of the blocks was randomized among the participants.

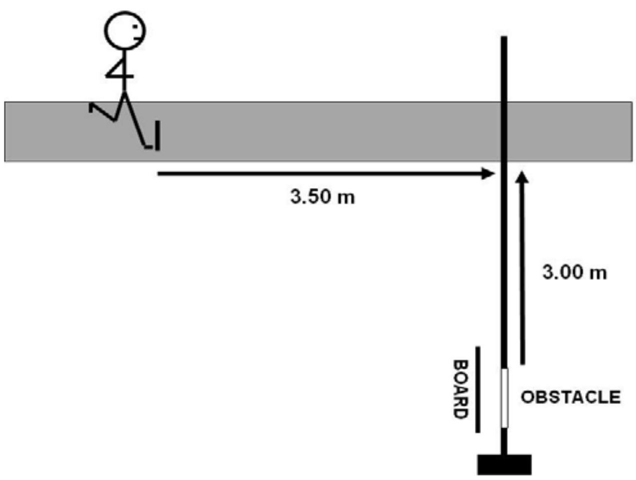

Figure 1. Representation of the experiment

The static obstacle was placed 5 m from the participant's starting point. In the dynamic obstacle task, the obstacle was attached to a cart and conducted along the rails. The cart's control box commanded an engine (WEG, model 71, 0.33 cv, tri-phase; 1.6 A, 60 HZ; 220 v; 1720 RPM) with a frequency inverter (TOSHIBA, model VF-SX, 220v, 0.75 kW) whose panel registered the rotation of the engine [16]. The key to direct the obstacle motions was attached to the inverter. The obstacle motion started when the participant crossed a mark 3.5 m distant from the rail. To eliminate the perception of the obstacle acceleration, a screen (1 m × 0.80 m) was placed at the beginning of the obstacle's trajectory.

Procedures

Reflective markers (of 15 mm diameters) were attached to the distal phalanx of the fifth metatarsal and lateral side of right and left calcaneus. A marker was also attached to the superior edge of the obstacle. The trials of the participants were recorded by two digital cameras (JVC – model GR-DVL 9800) with shutter speed of 1/250 and frequency collection of 60 Hz. The cameras were placed at an angle of 90° between them in order to record all of the markers and right-sided strides. The images were analyzed by DVIDEOW software [18]. The Direct Linear Transformation (DLT) method [19] was used to obtain the tridimensional coordinates of each marker. The calibration of the collection place was made by a volumetric object (1.5 × 1 × 4 m) of known measurements. The applied reference system was oriented along *z* axis in vertical direction (upwards); *y* axis with direction and orientation of the participant's gait (orthogonal to *z*) and *x* axis with direction and orientation defined by the vector product of *y* and *z*. The experimental error was measured by accuracy test [16, 20] and the calculated error value was 16 mm.

Dependent variables

Ten dependent variables were used to describe the subjects' locomotor behavior. The spatial and temporal variables analyzed in this study were: last step length

(N-1) and penultimate step (N-2) length (horizontal distance between the right and left heels' markers in the last and penultimate steps before the obstacle approach); take-off and landing distance (horizontal distance at the moment when the marker of the fifth metatarsus of the leading limb loses contact with the ground before and after the clearance); toe clearance (vertical distance between the marker of the fifth metatarsus of the leading limb and the top of the obstacle at the moment when the foot is over it); N-1 and N-2 duration (time between the contacts of right and left heels in the last and penultimate steps); clearance duration (time in which the right foot loses contact with the ground before the obstacle until the next contact after the obstacle); cadence (number of steps per minute); and average gait speed (distance which was covered in the last step divided by its duration). Distance parameters (N-1, N-2, take-off and landing distance, toe clearance, cadence and average gait speed) were normalized by the subject's body weight [21].

Statistic analysis

Data was filtered by the 4th order Butterworth digital filter under a cut frequency of 5 Hz through MATLAB 6.5© software. The Shapiro-Wilk test showed that the distributions used for the analysis did not depart from the norm ($p > 0.05$). Three multivariate analyses of variance were carried out – MANOVA – (2X3), i.e. two genders and three conditions (obstacle at fast and slow speeds and static position) as factors. The condition factor was treated as repeated measurements. The first MANOVA analyzed the spatial variables (N-1; N-2; take-off distance; landing distance; and toe clearance). The second one analyzed the temporal variables (N-1 and N-2 duration; and clearance duration) and the third one analyzed the cadence and the average gait speed variables. When the MANOVA pointed out significant difference, Tukey univariate tests were carried out, as proposed by Zar [22]. In all the statistics analysis, a significance level of $\alpha < 0.05$ was established. Software SPSS 10.0© was used for these analyses.

Results

As for the spatial variables, the MANOVA revealed that the locomotor behavior was affected by sex (Wilks' Lambda = 0.21, $F_{5,39} = 29.04$, $p < 0.0001$) and condition (Wilks' Lambda = 0.08, $F_{10,34} = 37.53$, $p < 0.0001$), without interaction between the factors. The univariate analysis showed bigger N-2 for the three conditions of the study ($F_{1,43} = 31.24$, $p < 0.001$), N-1 ($F_{1,43} = 4.25$, $p < 0.04$) and toe clearance ($F_{1,43} = 17.655$, $p < 0.0001$) for the group of women (Fig. 2).

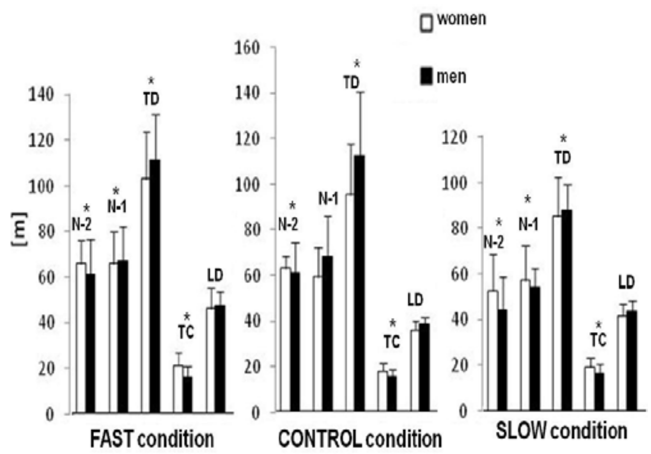

Figure 2. Average and standard deviation of spatial variables for the group of men and women. N-2 = N-2 length; N-1 = N-1 length; TD = take-off distance; TC = toe clearance; LD = landing distance.
* statistical difference between sexes ($p < 0.05$)

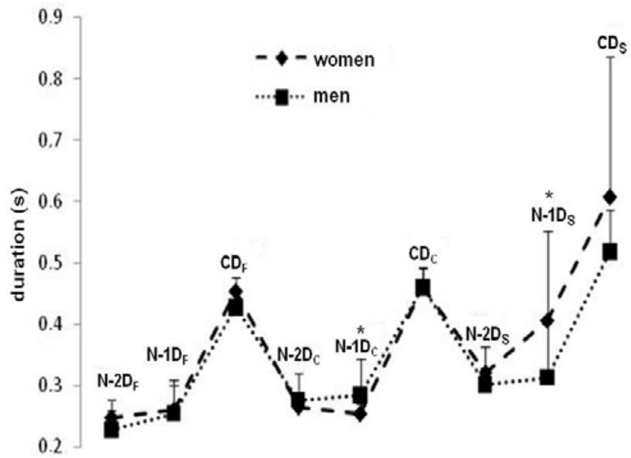

Figure 3. Average and standard deviation in the temporal variables for the groups of men and women. F = obstacle condition in fast speed; C = obstacle condition in stationary position; S = obstacle condition in slow speed; N-2D = N-2 duration; N-1D = N-1 duration; CD = clearance duration.
* statistical difference between sexes ($p < 0.05$)

The temporal variables were also affected by sex (Wilks' Lambda = 0.69, $F_{6,32} = 5.03$, $p < 0.005$) and condition (Wilks' Lambda = 0.19, $F_{6,32} = 22.74$, $p < 0.0001$). An interaction between the factors (Wilks' Lambda = 0.57, $F_{6,32} = 3.95$, $p < 0.005$, Fig. 3) was revealed. For sex, women presented bigger N-2 duration for the slow ($F_{37,74} = 7.14$, $p < 0,05$) and fast conditions ($F_{37,74} = 6.31$, $p < 0.05$), and N-1 and clearance duration for the slow

Table 2. Average and standard deviation of the average speed and cadence for the groups of men and women in the three study conditions

	Average gait speed (m/s)			Gait cadence (steps/s)		
	fast	control	slow	fast*	control	slow*
Men	2.59 ± 0.28	2.28 ± 0.41	1.62 ± 0.27	2.14 ± 0.35	1.84 ± 0.31	1.67 ± 0.25
Women	2.54 ± 0.34	2.36 ± 0.32	1.54 ± 0.40	1.98 ± 0.14	1.94 ± 0.10	1.43 ± 0.27

*statistical difference between sexes ($p < 0.05$)

condition ($F_{37,74} = 10.59$, $p < 0.05$; $F_{37,74} = 6.41$, $p < 0.05$, respectively).

MANOVA revealed that the average speed and cadence were affected by sex (Wilks' Lambda = 0.869, $F_{2,36} = 7.87$, $p < 0.001$) and condition (Wilks' Lambda = 0.13, $F_{4,34} = 55.23$, $p < 0.0001$). An interaction between the factors (Wilks' Lambda = 0.57, $F_{4,34} = 6.36$, $p < 0.001$) was also revealed. For sex, the speed was higher for men in slow condition ($F_{37,74} = 6.15$, $p < 0.05$) and fast one ($F_{37,74} = 7.21$, $p < 0.05$), not indicating any difference in the cadence between the groups (Tab. 2).

Discussion

The results of this study confirm the hypothesis: adaptive locomotor strategies are different between the sexes. Distinct strategies were evidenced for the spatial and temporal variables and cadence in the three task conditions proposed in the study.

For the spatial variables, women presented conservative locomotor strategies evidenced by an increase in the penultimate step length (N-2), last step length (N-1) and in the toe clearance. The greater step length for women is in contradiction to the studies that found greater step length for men [9, 10]. The strategy of increasing the length of the N-2 and N-1 must have been used by women as a way to adjust the movement to the given task [14]. The adjustment in the toe clearance reveals the women's safe attempt to avoid contact and fall while overcoming the high obstacle, the strategies not conventionally used in the studies [12, 23]. These spatial strategies can be understood as a difficulty for the women to couple the motor and the sensorial systems, once the coupling of these systems is essential for the success of the task [13, 24–26]. However, the use of the same strategy for the three-task conditions indicates a reliable standard for the women and can be applied in several gait conditions.

Unlike the women, the men chose to maintain the spatial variables. The men used the same strategy for all tasks. This strategy can be related to the preoccupation in maintaining the stability in the sequence of the action. Still, this adaptation can be related to a greater flexibility of women in comparison to men – as they have a greater hip flexion [27]. Therefore, men choose to keep the movement pattern to accomplish the task safely adopting a more challenging strategy.

Temporal variables data confirm the conservative strategy of women and the difficulty of coupling the systems. Women showed the need of more visual analysis time in dynamic obstacle conditions represented by an increase of the N-2 and N-1 duration in slow speed condition in comparison to men. Generally, an increase in the duration of the steps with a consequent increase in the time of vision for the planning of the action is a strategy used to increase the time to explore and obtain more relevant information [28]. Specifically, it seems that for the fast speed condition, women increased the clearance time to adjust their movements to the task's speed. As for the slow condition, the increase in the N-2 and N-1 duration and in the clearance indicates that the women decided to wait for the obstacle, they anticipated the obstacle and required some information to adjust the movement to the task. Differently, the men tried to modify the speed as a way to adapt it to the task, confirming earlier findings [1]. An increase in the speed is an adjustment to avoid the increase in the step length [1, 3], which shows that the men's strategy was opposite to that of the women.

For the control condition the women did not modify temporarily their strategy while the men increased the N-2 and N-1 duration. This strategy used by the men can indicate either that their attention on the control condition was not the same as on the other conditions or that the temporal adjustment was prioritized. It is still probable that the men have underestimated the task in the control condition, as the dynamic obstacle conditions offered more risks and required more attention [29].

The different adaptive locomotor strategies used by men and women can be explained by the body constitutions and the sensorial and motor integrations. The differences between men and women regarding constitution and anthropometry, which were revealed in this study and confirmed in other studies [1–3], can affect the strategies. Women have wider hips and the physiological inclination to knock-kneed legs which help relocate the center of gravity downwards [30], making it possible for them to carry out more conservative strategies than men. As for the integration between sensorial and motor systems, it is probable that men and women have used different ways to obtain and use relevant information for the motor planning, which made the online adjustments different, indicating that men were more capable of integrating the information and the movement to achieve the task's goal, requiring fewer adjustments.

Conclusions

We can therefore conclude that the adaptive locomotor strategies used by men and women are different, considering that women are more conservative and need more time to program the action. For the spatial variables, the N-2, the N-1 and the toe clearance were relevant to the efficacy of static and dynamic clearance. As for the temporal variables, the step duration was relevant for the women in the dynamic obstacle conditions, while the men used speed for adjustment.

The lack of analysis of the visual gaze and of the relation between the speed of the individual and the speed of the obstacle was a limitation of the study as it could have revealed other strategies which were not evidenced in this study and could be important for the obstacle negotiation for men and women.

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EFFECT OF ADDED WEIGHTS ON THE CHARACTERISTICS OF VERTICAL GROUND REACTION FORCE DURING WALK-TO-RUN GAIT TRANSITION

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ABSTRACT
Purpose. In this study, the effect of added weights on the various force and time related characteristics of vertical ground reaction force (VGRF) during the last five steps prior to walk-to-run transition was studied. **Basic procedures.** Experimental set up consisted of a force platform embedded treadmill. Sixteen college students performed experimental trials by carrying 0%, 10%, 20% and 30% of their body weight. During each trial, after walking for about 30 seconds the speed of the treadmill was increased manually at a rate of 0.089 m/s/s (0.2 miles/hour) until the participant started running. **Main findings.** A significant interaction (weights × steps) was observed for the first peak of VGRF. The trough, second peak, impulse, and rate of force development of VGRF increased with added weights. During the last five walking steps, most of VGRF parameters changed in a nonlinear fashion. **Conclusions.** Based on the behavior of VGRF parameters and manually recorded preferred transition speed values, we argue that the added weights would reduce the walk-to-run transition speed. We further speculate that a combination of transition determinants actively participate in the reorganization process during the last five walking steps, prompting the gait transition.

Key words: body weight, motor performance, running, walking

Introduction

Walking and running are the two principal gaits used by humans. Walking is the characteristic mode of locomotion at lower speeds (< 2.0 m/s), while running is a preferred mode of locomotion at higher speeds (> 2.0 m/s). Speed at which the walk-to-run transition occurs is known as the preferred transition speed (PTS). Several factors associated with the walk-to-run transition have been studied as the possible gait transition determinants. Some of the extensively studied factors include metabolic cost of locomotion [1 – 3], anthropometric factors such as total body mass, standing height and leg length [4 – 7], mechanical models such as inverted pendulum model [8], local or muscle specific factors associated with the ankle kinematics [9 – 12], and activation of the support and swing related muscles [13].

In addition to the aforementioned transition determinants, the characteristic behavior of the vertical ground reaction force (VGRF) during walking and running have also been associated with the walk-to-run transition. Significantly different VGRF pattern during walking compared to running was reported by the researchers [14 – 15]. Additionally this pattern was reported to be dependent on the locomotion speed [16]. A nonlinear trend in the majority of the VGRF characteristics during the last five steps prior to the walk-to-run transition was observed by Li and Hamill [17]. Based on this observation, they argued that gait transition is not a spontaneous process. Rather human body goes through reorganization process during the last five walking steps prior to the transition. Most interestingly, the critical level of musculoskeletal forces determined as a function of VGRF was reported as the trot-to-gallop transition determinants in horses by Farley and Taylor [18]. They reported that horses switched to galloping at lower speeds but at the same critical level of VGRF when carrying 23% of their body weights.

Based on the equine study of Farley and Taylor [18] and the characteristic association of the various VGRF parameters with walk-to-run transition, the purpose of this study was to evaluate the effect of added weights on the VGRF characteristics. The behavior of the various force and time related characteristics of the VGRF during the five steps before the walk-to-run transition was evaluated. The participants performed the walk-to-run transition by carrying 0%, 10%, 20%, and 30% of their body weights. We hypothesized that added weights would increase the values of the force related VRGF parameters, while maintaining their overall nonlinear behavior.

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Material and methods

Sixteen college students (9 males and 7 females, aged = 21.3 ± 0.9 years, height 172.4 ± 13.2 cm and mass 71.3 ± 12.6 kg), free from lower extremity disorders and with no observable gait abnormalities, volunteered to participate in the experiment. The experimental protocol used was approved by the local Institutional Review Board.

VGRF data were acquired using a treadmill (Kistler Inc., Amherst, NY) embedded with two force platforms. Optical sensors and software integrated within the treadmill system were used to distinguish between the left and right foot's VGRF. The force platforms used had a range of 0–3000 N with a natural frequency of 240 Hz. Time and VGRF data were recorded at a rate of 100 Hz using a microcomputer interfaced to the force platform via an A/D board.

All the participants had previous experience of walking and running on treadmill. After warming up for five minutes by walking and running on the treadmill, two trial walk-to-run transitions were performed to determine the approximate transition speed. This transition speed was used to set up the initial walking speed for each participant such that the transition occured approximately in the middle of the 20 seconds trial. During each trial, after walking for about 30 seconds, the speed of the treadmill was increased continuously at a rate of 0.089 meters/seconds/seconds (0.2 miles/hour) until the participant started running. Such an accelerating treadmill protocol was previously used by Li and Hamill [17]. The speed was increased manually by continuously pressing the increase button on the treadmill's control board, twice a second. In order to maintain a consistent rate of speed increase for all participants, one of the experimenters practiced increasing the speed at constant rate and the same person carried out the "speed increase" procedure throughout the data collection. The participants were instructed to choose their preferred gait patterns, walk or run, with the change of treadmill speed.

VGRF data during the walk-to-run transition at four-weight conditions, 0%, 10%, 20%, and 30% of the body weight, were collected using the above protocol. The order of the weight conditions was balanced to avoid the possible order effect. The additional weights were applied using packs filled with small sand bags weighing one kilogram each. Participants carried two packs: one on the back and the other on the chest. The packs were tied tightly around the participant's trunk using a rope to prevent relative movement.

After each trial, data were reviewed to ensure the existence of at least five steps for both feet before the transition, i.e. five left steps and five right steps. Walking gait was recognized by the overlap of VGRF for the left and the right foot while the absence of overlap indicated running gait. The walking steps prior to the transition were labeled as 5, 4, 3, 2 and 1, and their patterns are shown in Figure 1.

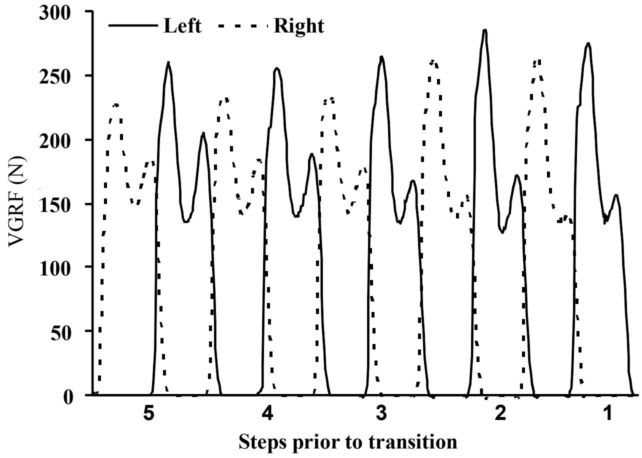

Figure 1. The patterns of VGRF data from the left and right foot for five walking steps prior to transition

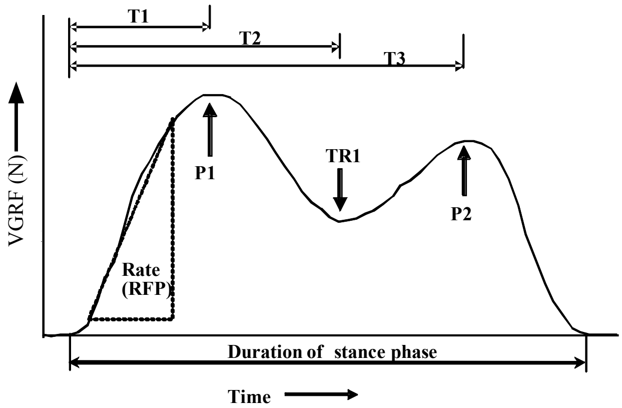

Figure 2. The characteristics of VGRF analyzed in this study. P1, P2, TR1 and T1, T3, T2 are the force and time parameters for the first peak, second peak and the trough, respectively. The rate is the slope of the linear region shown in the figure

Various VGRF parameters as described by Li and Hamill [17] were analyzed during the last five steps. Figure 2 graphically illustrates the examined force and time related VGRF parameters. The force related parameters were expressed relative to participant's body mass, while time-related parameters were expressed as a percentage of the "heel contact to toe off" gait cycle. Statistical analysis was performed using a two-factor (% body weight × step) analysis of variance (ANOVA) model with repeated measures. Bonferroni's adjustment was used to control the type I error and post hoc trend analysis was used when necessary. Significant level was set at alpha = 0.05.

Results

Force related characteristics of VGRF

No difference in the force and time related characteristics of VGRF were observed between the right and left footfalls ($p < 0.05$) and therefore data of right and left side were pooled for the statistical analysis.

The first peak force (P1) increased as the subject approached the walk-to-run transition and the rate of increase was influenced by the additional weights (significant % body weights × steps interaction, $p = 0.031$) (Tab. 1 and 2). The increase of P1 during the last walking step prior to the transition was minimal under normal conditions (no added weights) but exaggerated when additional weights were applied to the subjects (Fig. 3). The P1 values during the last two steps increased by 1.3%, 4.2%, 5.0%, and 4.2% at 0%, 10%, 20%, and 30% weight conditions, respectively. The average P1 during the last steps were 13.2 ± 1.1, 14.9 ± 1.1, 16.6 ± 1.5 and 18.0 ± 1.8 N/kg, respectively.

Nearing the transition, trough (TR1) decreased in a nonlinear fashion [quadratic ($F_{1,60} = 6.0$, $p = 0.017$)] (Tab. 1 and 2). Addition of the weights increased the TR1 ($p < 0.001$). During the last five steps average TR1 increased by 11.2%, 11.1%, and 8.1% with the increase in the weights from 0% to 10%, 10% to 20%, and 20% to 30%, respectively (Fig. 4a).

The second peak (P2) decreased nonlinearly towards the transition [quadratic ($F_{1,60} = 24.91$, $p < 0.001$)]. Application of the weights increased the P2 ($p < 0.001$). For each 10% increase in the weight, the average P2 during the last five steps increased by 15.0%, 4.5%, and 5.6%, respectively (Fig. 4b).

Impulse decreased nonlinearly [quadratic ($F_{1,60} = 5.1$; $p = 0.0277$)] during the last five steps prior to the transition (Fig. 4c). Application of the weights increased impulse ($p < 0.001$). The average impulse during the last five steps increased by 13.0%, 10.4%, and 7.2%, corresponding to an increase in the weights from 0% to 10%, 10% to 20%, and 20% to 30%.

The rate of force development (Fig. 4d) during stance phase increased linearly during the last five steps ($p < 0.001$). Application of the weights increased the rate of force development ($p = 0.021$). Increase in the weights from 10% to 20% and 20% to 30% increased the rate of force development by 15.0% and 12.4%, respectively. However, a minimal increase of 0.22% was observed for the increase in the weight from 0% to 10%.

Table 1. Summary statistics for the observed force and time related characteristics of VGRF

Steps	Variables	0%	10%	20%	30%
5	P1 (N/kg)	12.0 ± 0.9	12.9 ± 1.2	14.6 ± 1.3	15.8 ± 1.8
	TR1 (N/kg)	6.94 ± 0.8	7.70 ± 1.1	8.50 ± 1.0	9.20 ± 1.3
	P2 (N/kg)	10.0 ± 1.0	11.6 ± 0.7	12.3 ± 1.1	13.0 ± 1.1
	Impulse (Ns/kg)	4.76 ± 0.2	5.40 ± 0.4	5.90 ± 0.7	6.35 ± 0.5
	RFD (N/s/kg)	31.6 ± 8.6	33.1 ± 10.2	39.2 ± 20.6	45.5 ± 22.1
	Duration (s)	0.70 ± 0.0	0.71 ± 0.0	0.71 ± 0.0	0.71 ± 0.0
	T1 (% stance)	30.9 ± 3.3	30.5 ± 2.4	30.7 ± 2.7	30.2 ± 3.2
	T2 (% stance)	54.8 ± 3.7	53.2 ± 4.0	55.0 ± 3.9	53.9 ± 3.2
	T3 (% stance)	74.5 ± 3.0	74.8 ± 3.6	75.1 ± 1.5	73.6 ± 3.3
4	P1 (N/kg)	12.5 ± 1.1	13.4 ± 1.2	15.2 ± 1.6	16.3 ± 1.7
	TR1 (N/kg)	6.64 ± 0.8	7.42 ± 1.1	8.10 ± 1.0	8.82 ± 1.2
	P2 (N/kg)	10.1 ± 0.9	11.7 ± 0.8	12.1 ± 1.5	12.9 ± 1.2
	Impulse (Ns/kg)	4.67 ± 0.3	5.31 ± 0.3	5.82 ± 0.5	6.24 ± 0.4
	RFD (N/s/kg)	37.8 ± 11.6	37.0 ± 14.8	45.1 ± 21.3	49.6 ± 19.1
	Duration (s)	0.68 ± 0.0	0.70 ± 0.0	0.69 ± 0.0	0.70 ± 0.0
	T1 (% stance)	29.6 ± 3.4	30.1 ± 2.9	29.8 ± 3.4	29.6 ± 3.1
	T2 (% stance)	54.6 ± 4.0	54.0 ± 4.2	54.5 ± 3.8	53.6 ± 3.7
	T3 (% stance)	74.9 ± 2.0	75.2 ± 3.7	75.0 ± 1.3	74.1 ± 1.7
3	P1 (N/kg)	12.6 ± 1.1	13.8 ± 1.3	15.6 ± 1.5	16.8 ± 1.7
	TR1 (N/kg)	6.37 ± 0.8	7.12 ± 1.1	7.85 ± 1.1	8.55 ± 1.0
	P2 (N/kg)	10.0 ± 1.1	11.7 ± 1.0	12.2 ± 1.5	12.9 ± 1.4
	Impulse (Ns/kg)	4.54 ± 0.2	5.16 ± 0.3	5.76 ± 0.4	6.16 ± 0.4
	RFD (N/s/kg)	41.8 ± 15.3	42.3 ± 15.8	48.5 ± 21.8	55.2 ± 25.4
	Duration (s)	0.66 ± 0.0	0.68 ± 0.0	0.69 ± 0.0	0.69 ± 0.0
	T1 (% stance)	29.9 ± 3.3	28.8 ± 3.0	29.4 ± 2.9	29.2 ± 3.2
	T2 (% stance)	54.2 ± 3.9	53.3 ± 3.9	54.5 ± 3.9	54.5 ± 5.2
	T3 (% stance)	75.4 ± 1.9	74.7 ± 2.6	74.7 ± 2.0	74.3 ± 1.9
2	P1 (N/kg)	13.1 ± 1.0	14.3 ± 1.4	15.8 ± 1.2	17.3 ± 1.8
	TR1 (N/kg)	6.13 ± 0.6	6.84 ± 1.1	7.67 ± 0.9	8.30 ± 1.1
	P2 (N/kg)	9.86 ± 1.2	11.2 ± 1.1	11.9 ± 1.6	12.3 ± 1.6
	Impulse (Ns/kg)	4.47 ± 0.2	5.03 ± 0.3	5.54 ± 0.4	5.92 ± 0.4
	RFD (N/s/kg)	48.5 ± 17.4	46.1 ± 18.4	51.2 ± 18.6	56.0 ± 22.3
	Duration (s)	0.65 ± 0.0	0.66 ± 0.0	0.67 ± 0.0	0.66 ± 0.0
	T1 (% stance)	28.8 ± 3.6	29.2 ± 3.2	29.9 ± 2.3	28.7 ± 4.9
	T2 (% stance)	54.1 ± 3.6	53.8 ± 4.1	55.2 ± 4.3	55.2 ± 4.4
	T3 (% stance)	75.0 ± 2.3	75.3 ± 1.6	74.7 ± 1.6	74.2 ± 3.2
1	P1 (N/kg)	13.2 ± 1.1	14.9 ± 1.1	16.6 ± 1.5	18.0 ± 1.8
	TR1 (N/kg)	6.07 ± 0.8	6.70 ± 1.0	7.58 ± 0.9	8.08 ± 1.1
	P2 (N/kg)	9.53 ± 1.4	10.5 ± 1.3	10.9 ± 1.5	11.7 ± 1.5
	Impulse (Ns/kg)	4.34 ± 0.3	4.84 ± 0.3	5.39 ± 0.4	5.79 ± 0.4
	RFD (N/s/kg)	50.6 ± 17.2	52.3 ± 20.9	57.0 ± 19.9	64.3 ± 25.6
	Duration (s)	0.63 ± 0.0	0.64 ± 0.0	0.65 ± 0.0	0.65 ± 0.0
	T1 (% stance)	29.9 ± 3.6	29.8 ± 2.6	29.5 ± 3.2	29.6 ± 2.6
	T2 (% stance)	55.4 ± 5.0	55.0 ± 5.0	55.8 ± 4.6	56.4 ± 4.4
	T3 (% stance)	74.7 ± 2.6	74.8 ± 1.7	74.4 ± 2.8	73.7 ± 2.4

P1 – value of the first peak of the VGRF.
TR1 – value of the trough between the first and second peak of the VGRF.
P2 – value of the second peak of the VGRF.
Duration – duration of the stance phase.
T1 – time duration between heel contact and the first peak.
T2 – time duration between heel contact and the trough.
T3 – time duration between heel contact and the second peak.
Impulse – impulse of the VGRF during stance phase.
RFD – rate of force development.

Time related characteristics of VGRF

Duration of the stance phase decreased ($p < 0.001$) linearly during the last five steps nearing the transition (Fig. 5a). Application of the weights increased the duration of the stance phase but the increase was statistically insignificant.

Table 2. Statistical analysis for all dependent parameters

	Main effect			Post hoc
	Steps (a)	% body weight (b)	a × b	
P1	N/A	N/A	$F_{12, 176} = 1.95$; $P = .0311$	Linear interaction ($F_{12, 176} = 12.4$; $P < .001$) for % body weight × steps
$P = .0311$	Linear interaction (F12, 176 = 12.4; $P < .001$) for % body weight × steps.		NS	Linear for % body weight ($F_{1, 45} = 113.1$; $P < .001$). Nonlinear for steps [quadratic ($F_{1,60} = 6.0$, $P = .0170$)]
TR1	$F_{4, 60} = 39.8$;		NS	Nonlinear for % body weight [quadratic ($F_{1, 45} = 5.79$; $P = .0203$)]. Nonlinear for steps [quadratic ($F_{1,60} = 24.91$, $P < 0.001$)]
$P < .001$	$F_{3, 45} = 37.8$;		NS	Linear ($F_{1, 45} = 321.8$; $P < .001$) for % body weight. Nonlinear for steps [quadratic ($F_{1, 60} = 5.1$; $P = .0277$)]
$P < .001$	NS	Linear for % body weight (F1, 45 = 113.1; $P < .001$).		Linear ($F_{1, 45} = 10.07$, $P = .0027$) for % body weight. Linear ($F_{1,60} = 127.34$, $P < .001$) for steps
Nonlinear for steps [quadratic (F1,60 = 6.0, $P = .0170$)].			NS	Linear ($F_{1, 60} = 787.4$; $P < .001$) for steps
P2	$F_{4, 60} = 18.2$;		NS	Nonlinear for steps [quadratic ($F_{1,60} = 6.7$; $P = .0118$)]
$P < .001$	$F_{3, 45} = 58.3$;		NS	
$P < .001$	NS	Nonlinear for % body weight [quadratic ($F_{1, 45} = 5.79$; $P = .0203$)].	NS	

PTS – preferred transition speed.
NS – statistically non significant.

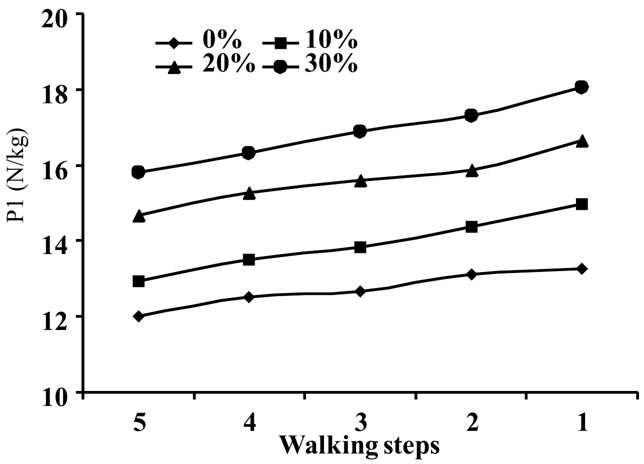

Figure 3. The first peak force increased towards the transition and leveled off during the last walking step for 0% weight condition. For the added weight condition, the first peak values increased towards the transition and the increase was more pronounced during the last walking step

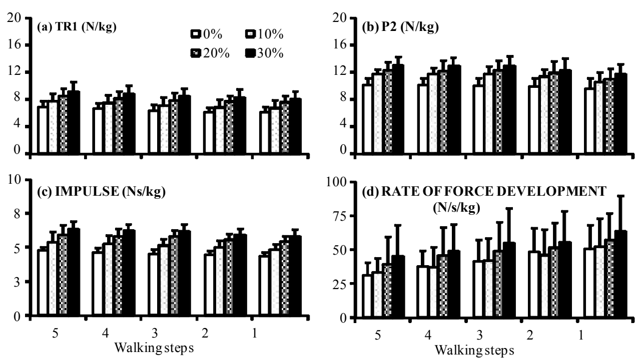

Figure 4. Effect of additional weights on the behavior of the various force related characteristics of VGRF during the last five steps before the transition. TR1 (a), P2 (b), and impulse(c) decreased nonlinearly, while rate of force development (d) increased linearly nearing the transition. All the variables showed increasing trends with the application of weights

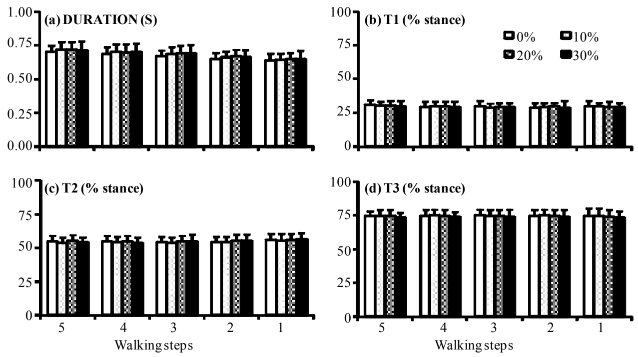

Figure 5. Effect of additional weights on the behavior of the various time related characteristics of VGRF during the last five steps before the transition. Duration (a) decreased linearly and (b) T1 decreased nonlinearly during the last five steps. T2 (c) and T3 (d) values showed no consistent trend during the last five steps. Neither of this time related characteristics of the VGRF were affected by the additional weights

Time duration between heel contact and first peak (T1) decreased nonlinearly during the last five steps [quadratic ($F_{1,60}$ = 6.7; p = 0.011)] (Fig. 5b). No consistent trend was observed for the time durations between heel contact and trough (T2) and heel contact and second peak (T3). See Fig. 5c and 5d for more details. Additional weight had no significant impact on the T1, T2, and T3 values.

Discussion

The observed trend in the force and time related characteristics of VGRF under added weigh conditions supported our hypothesis. The values of force related characteristics of VGRF increased with the increase in the weights carried. The first peak values were affected by both the added weights and walking steps (with significant interaction). Trough, second peak, impulse, and rate of force development increased with the application of weights. All the force related parameters, except rate of force development, changed in the nonlinear fashion towards the transition. Among the time related characteristics, time-to-first peak decreased nonlinearly towards the transition, while duration of the stance phase decreased linearly towards the transition. Added weights had no significant effect on the time related characteristics of the VGRF. The observed trend in the behavior of various VGRF characteristics during the last five steps before the transition at no load condition is in agreement with the observations of Li and Hamill [17] and Nilsson and Thorstensson [16].

First peak of VGRF showed an interaction with added weights during the last five walking steps. Under no weight conditions, the first peak force increased towards the transition and leveled off during the last walking step. However, at the added weight conditions, the first peak values increased towards the transition and the increase was more pronounced during the last walking step. The values increased by 1.3%, 4.2%, 5.0%, and 4.2 % at 0%, 10%, 20%, and 30% weight conditions, respectively. In the equine study performed by Farley and Taylor [18], the musculoskeletal forces, determined as a product of the VGRF and the effective mechanical advantage (EMA), were considered as the primary trot to gallop transition determinants. They reported that horses switched to galloping at the lower speed under added weigh condition but at the same critical levels of musculoskeletal forces. It was concluded that the "safety factors" set by the body to prevent the risk of injuries due to the increase in the musculoskeletal forces beyond a critical limit trigger the trot to gallop transition [18]. In the case of humans, application of the weights increased the VGRF (first peak) values and the rate of increase during the last walking step was relatively higher compared to the unloaded condition (Fig. 3). Change of gait to running was observed to decrease the EMA for the knee extensor by 68% and to increase it by 18% and 23% for the hip and ankle extensors, respectively [19]. Therefore, the musculoskeletal forces (first peak of VGRF × EMA for the lower extremities) could be reduced by making a transition from walk to run (since the overall EMA values would reduce). Thus, if we consider that human also transits at a critical level of musculoskeletal forces similar to the equines [18], then human would also transit at a lower speed with the application of the weights.

Lower walk-to-run transition speed with the application of weight would also be supported by the following gait transition hypothesis:

1. Overexertion or fatigue hypothesis: Decrease in the activities of a muscle or group of muscles while walking at PTS compared to running at the PTS was proposed as probable walk-to-run gait transition trigger. Based on the decrease in the activities of the small ankle dorsiflexor muscle group (especially tibialis anterior muscle) which operates close to their maximum capacity when walking at PTS, Hreljac and his colleagues [9–11] stated that a sense of overexertion by these muscles trigger the walk-to-run transition. Along the same argument, Prilutsky and Gregor [13] observed that the activities of swing related muscles (tibialis anterior, rectus femoris and bicep femoris) decreased during running compared to fast walking. Further building on Hreljac's and Prilutsky and Gregor' argument, most recently Bartlett and Kram [20] evaluated the PTS by

reducing the demands on dorsiflexors (tibialis anterior) and hip flexors (rectus femoris) and by increasing the demands on the planter flexors (soleus, medial and lateral gastrocnemius). They reported that decreased demands in the dorsiflexors and hip flexors increased the PTS while increased demand in the planter flexors decreased the PTS. The planter flexor muscles are active during the stance phase and play major role in supporting the body. The application of weights increased the first peak, second peak, and trough values, further increasing the joint moment and the demand in planter flexor muscles predicting a lower transition speed.

2. Improved force generation or contractile capability hypothesis: Neptune and Sasaki [12] reported that the lower ankle joint velocity when running at PTS compared to walking, improved the contractile capability of the ankle plantar flexors (soleus and gastrocnemius) allowing them to enhance their force production. The soleus and gastrocnemius are primarily classified as the support related ankle plantar flexor muscles. The addition of weights could increase the energetic demands on these muscles requiring them to achieve their enhanced force production at relatively lower speed predicting lower PTS.

3. Inverted pendulum model: According to the inverted pendulum model the centripetal force (mV^2/L) required to keep the body's center of mass in contact with the ground is provided by the gravitational force (mg), i.e. $mV^2/L = mg$. Thus, at a critical speed, the feet loose contact with the ground because centripetal force (mV^2/L) exceeds the gravitational force (mg) requiring participants to change their gait from walk to run. Both the centripetal and gravitational force depend on the mass (m) and the model appears insensitive to the increased weights. However, based on the concept of the virtual stance limb a decreased PTS with the application of the weights could be predicted using this model. The virtual stance limb length was defined as the distance between the point of foot–ground contact and the center of mass [21] which is proportional to the leg length (L). The virtual stance limb length was reported to decrease by 26% during running at speed near the gait transition than walking [21]. It is possible that the addition of weights could further increase this compression of the virtual stance limb decreasing the L in the equation $V^2/L = g$ (derived from $mV^2/L = mg$) and thus decreasing the V.

Based on a nonlinear behavior of VGRF observed during the last five steps before the walk-to-run transition under normal conditions (no added weights), Li and Hamill [17] speculated that walk-to-run transition is not a spontaneous event and human body goes through a reorganization process. The results of this study show that not only under normal conditions, but also under added weight conditions, most of the VGRF characteristics changed in nonlinear fashion, further supporting the findings of Li and Hamill [17]. Furthermore, reduced PTS under added weight conditions was supported by most of the existing walk-to-run gait transition hypotheses indentifying the possibility that walk-to-run transition is induced by more than one factor. Thus, considering the possibilities of reorganization process associated with the observed nonlinearity and the multiple triggers associated with the walk-to-run gait transition under added weight conditions, we would like to further speculate that a combination of transition determinants actively participate in the reorganization process during the last five walking steps, meeting the limitations set by the musculoskeletal system, prompting the gait transition. However, future studies evaluating the effect of the additional weights on the multiple triggers and the PTS are essential to clearly understand this reorganization process. In addition to the VGRF data, kinematic as well as EMG data from the various lower extremity muscles could also be evaluated. Such studies would provide a better understanding of the changes in the various factors associated with the walk-to-run gait transition, e.g. demands of the trigger muscles, their contractile capabilities, dimensions of the virtual stance limb, etc., further enhancing our understanding of this reorganization process and the roles of the multiple triggers in this process.

In support to our argument of reduced PTS under added weight conditions, the manually recorded (visual inspection) PTS from the treadmill's display was also found to decrease with the application of weights (Fig. 6). A linear regression line fitted to the manually recorded PTS data has a negative slope of 0.4537 ($R^2 = 0.9121$). The manually recorded PTS of 2.05 ± 0.15 m/s observed under unloaded conditions in this study is close to the PTS reported in the literature. PTS of 1.98 ± 0.38 m/s, 1.94 ± 0.20 m/s, 1.96 ± 0.17 m/s, 2.10 ± 0.20 m/s, and 1.89 m/s was reported by Kram et al. [8], Hreljac et al. [10], Neptune and Sasaki [12], Prilutsky and Gregor [13] and Li and Hamill [17] respectively. However, considering the sudden nature of walk-to-run transition, possibilities of errors in recording the exact PTS cannot be neglected.

Conclusion

In this study the effect of additional weights on the force and time related characteristics of the VGRF was evaluated. Based on the effect of the additional weights

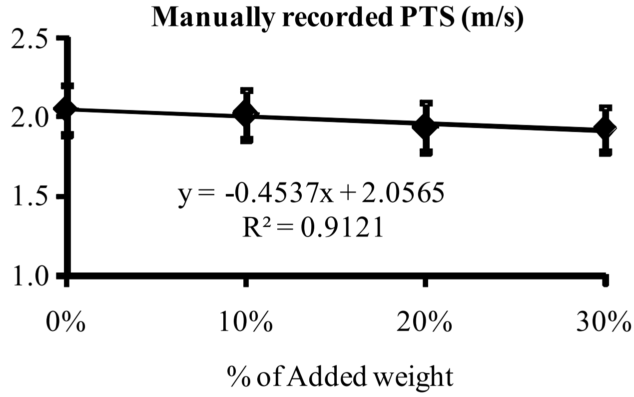

Figure 6. Manually recorded PTS decreased with the application of weight

on the first peak of the VGRF and the safety factor hypothesis presented by Farley and Taylor [18] we argue that the added weights would reduce the PTS. Our argument of the reduced PTS under added weight conditions is supported by (1) overexertion or fatigue hypothesis, (2) improved force generation or contractile capability hypothesis, and (3) inverted pendulum model, and (4) manually recorded PTS data. Moreover, we have once again observed the previously reported nonlinearity in the VGRF characteristics during the last five walking steps prior to the walk-to-run transition. Our data support the notion that a combination of transition determinants actively participate in the reorganization process during the last five walking steps, prompting the gait transition.

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CIRCULATORY AND RESPIRATORY RESPONSE TO EXERCISE WITH ADDED RESPIRATORY DEAD SPACE

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ABSTRACT
Purpose. Assessment of circulatory and respiratory response to separate exercise tests under the condition of increasing the volume of added respiratory dead space by 200 cm^3 at a time. **Basic procedures.** Human volunteers performed 10 minutes of cycle ergometer exercise on nine occasions, with the increasing volume of added dead space at the intensity of 100 Watt. **Main findings.** The ventilatory parameters tended to increase proportionally to the volume of added dead space. VE, VT, RF increased from 29.35 ± 4.01; 1.62 ± 0.29; 18.52 ± 4.76 (at 0 cm^3) to 62.42 ± 8.33; 2.43 ± 0.24; 26.00 ± 5.51 (at 1600 cm^3), respectively. There were not any significant differences among the post-exercise values of LA, pO_2, HCO^-_{3act}, BE(B) and HR. All the values of O_2 SAT ranged between 94.87 ± 1.19 and 95.72 ± 0.76, and the values of HCO^-_{3std} between 25.23 ± 1.36 and 24.00 ± 0.78. The post-exercise values of pH decreased, and pCO_2 increased proportionally to the volume of added dead space, from 7.41 ± 0.01 (at 0 cm^3) to 7.33 ± 0.03 (at 1600 cm^3) and from 40.89 ± 2.27 (at 0 cm^3) to 51.13 ± 3.39 (at 1600 cm^3), respectively. **Conclusions.** Added respiratory dead space evokes: increase in pulmonary ventilation, mainly in tidal volume; increase in arterial carbon dioxide pressure and decrease in pH, proportionally to the increase in dead space volume. Added dead space neither evokes hypoxemia nor intensifies anaerobic reproduction of ATP.

Key words: added dead space, pattern of breathing, circulatory and respiratory response to tube breathing, hypercapnia

Introduction

There has been ample research into added respiratory dead space influence on human body activity. Most studies have focused on three aspects: increase in pulmonary ventilation (O'Donnell et al. [1], Takahashi et al. [2]), respiratory airway resistance (Maruyama et al. [3], Poon [4, 5]) and arterial carbon dioxide pressure (Koppers et al. [6], Toklu et al. [7]).

These reactions are caused by the application of added dead space by means of a tube. Therefore, during breathing through the tube, a part of the expired air remains in the tube and mixes with the freshly inspired air.

Thanks to the application of the tube the respiratory airway is lengthened, which causes an increase in respiratory resistance. The smaller the diameter of the airway and the bigger the velocity of the moving air, the bigger the increase.

Respiratory airway resistance evokes changes in ventilation patterns. It has been proved that at the same values of end-tidal carbon dioxide partial pressure ($PetCO_2$) breathing through the tube always causes a greater increase in ventilation than inhaling hypercapnic gas without a tube (Maruyama et al. [3], Poon [4, 5]).

The application of added dead space leads to the increase in CO_2 partial pressure in blood and alveoli, which is manifested by the respective increase in the values of pCO_2 and $PetCO_2$. This was confirmed by the research into added dead space carried out by Koppers et al. [6], Toklu et al. [7], Moosavi et al. [8], Khayat et al. [9] and indirectly by Syabbalo et al. [10]. In the experiments of the last ones, breathing under the condition of hyperoxia caused an increase in ventilation only when the subjects were applied added dead space. It follows that the ventilatory pattern during breathing through a tube is not determined by peripheral chemoreceptors. Their findings were confirmed by Takahashi et al. [2], Krishnan et al. [11].

It is well known that the application of added dead space and the subsequent increase in respiratory resistance and CO_2 partial pressure produce an increase in pulmonary ventilation. Most researchers claim that the increase in ventilation results mainly from the increase in tidal volume rather than the increase in breathing frequency (Kelman and Watson [12], Smejkal et al. [13], Kurotobi et al. [14], O'Donnell et al. [1], Toklu et al. [7]).

The scientific literature is still lacking in a comprehensive study of an added dead space. No detailed re-

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search on an effect of increasing volume of added dead space on the respiratory and circulatory systems of human body has been reported yet. Therefore, the reason of this work is to examine the reactions of the cardiorespiratory system on separate physical exercises in the environment of the increasing volume of dead space by 200 cm^3 at a time.

Material and methods

Human volunteers: Twelve healthy male students of the University School of Physical Education in Wrocław, Poland, aged 20.4 ± 0.5 took part in the study. The mean height and body mass values were 180.4 ± 9.3 cm and 75.4 ± 11.46 kg, respectively. On account of the study, the volunteers declared the level of physical activity of 2 h per day, on average.

Exercise test: At weekly intervals all the volunteers performed nine 10-minute separate exercise tests on cycle ergometer (Sport Excalibur, Lode) at the intensity of 100 Watt. On the day of the research, the subjects refrained from any other extra physical effort. A seven-day interval between the given research was used to eliminate the possibility of adaptation to dead space and overlap of training stimuli in successive research sessions.

After the first control exercise the participants breathed through a plastic tube, whose diameter was 3 cm. The volume of dead space was increased from 200 cm^3 (in exercise test no. 2) to 1600 cm^3 (in exercise test no. 9).

All the volunteers had signed a written consent to participate in the study, which was approved by the local research ethics committee.

The experiments took place in an air-conditioned room (24°C or 75.2°F), all at the same time of day.

Blood parameters: Before and three minutes after the exercise the participants underwent fingertip blood sampling. Arterial plasma lactate by means of enzymatic method, using Dr Lange LP-400 apparatus, was measured. Then, by means of Bayer 248 apparatus: carbon dioxide partial pressure (pCO_2), arterial oxygen pressure (pO_2), hydrogen ion concentration (pH) were measured, then oxygen saturation (O_2 SAT), standard bicarbonate concentration (HCO^-_{3std}), actual bicarbonate concentration (HCO^-_{3act}) base excess/deficit (BE(B)) were calculated.

The cardiorespiratory values: “Breath by breath” registration of breathing frequency (Rf), tidal volume (VT) and pulmonary ventilation (VE) parameters was carried out for three minutes before, during and five minutes after the exercise using Quark b^2, Cosmed. Simultaneously, heart rate (HR) was measured by using heart rate monitor made by Polar.

The sampling line of gas analyzer was placed at the end of the plastic tube.

On the grounds of measuring limitation of the apparatus, the registration of respiratory parameters VO_2, VCO_2 and RQ was omitted in the research. There was some risk that not the whole expired breath reached the sampling line. On the other hand, an attempt to place the sampling line at the proximal end of the plastic tube worsened the measuring conditions.

Statistical analysis: All the circulatory and respiratory values measured at rest, during exercise and recovery were averaged. All the calculations were performed using the Statistica software (2008). Standard statistical methods were used for the calculation of means and standard deviations. The ANOVA variant analysis was used for repeated measurements and the post hoc Duncan test to identify significant differences.

For the base excess BE(B), the median was calculated, followed by Friedman’s rank test and Wilcoxon’s test to identify significant differences.

The statistical significance was set at $p = 0.05$.

Results

Cardiorespiratory response

The changes in the breathing frequency (Rf) are shown in Figure 1. The distribution of significant differences is shown in Table 1. Rf tends to increase proportionally to the volume of added dead space, from 18.52 ± 4.76 (at 0 cm^3) to 26.00 ± 5.51 b/min (at 1600 cm^3). Rf/Rf_{0cm^3} at 1600 cm^3 equals 1.4 (Tab. 6). It follows that Rf increases by 1.4 times from 0 cm^3 to 1600 cm^3.

The changes in the tidal volume (VT) are displayed in Figure 2. The distribution of significant differences is shown in Table 2. VT tends to increase proportionally to the volume of added dead space, from 1.62 ± 0.29 (at 0 cm^3) to 2.43 ± 0.24 l (at 1600 cm^3). VT/VT_{0cm^3} at 1600 cm^3 equals 1.5 (Tab. 6). It follows that VT increases by 1.5 times from 0 cm^3 to 1600 cm^3.

The changes in the Rf/VT ratio are presented in Table 6. The Rf/VT ratio increases to 400 cm^3, then decreases. Its value at 1600 cm^3 is lower than at 0 cm^3.

The changes in the pulmonary ventilation (VE) are shown in Figure 3. VE tends to increase proportionally to the volume of added dead space, from 29.35 ± 4.01 (at 0 cm^3) to 62.42 ± 8.33 l/min (at 1600 cm^3). The distribution of significant differences is shown in Table 3. Except for the difference between 1000 cm^3 and 800 cm^3, all the differences are significant.

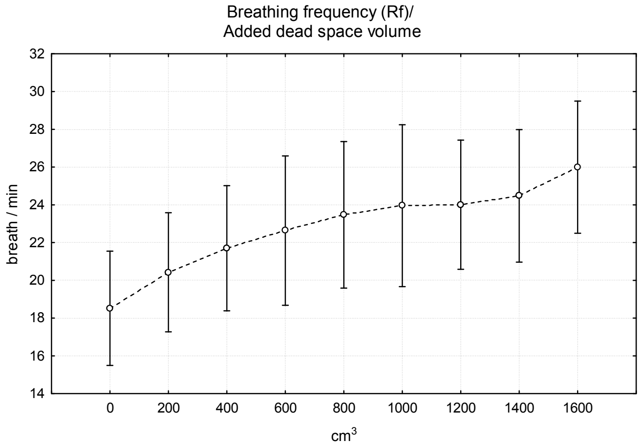

Figure 1. Breathing frequency (Rf) in consecutive sessions with added dead space (mean values ± SD)

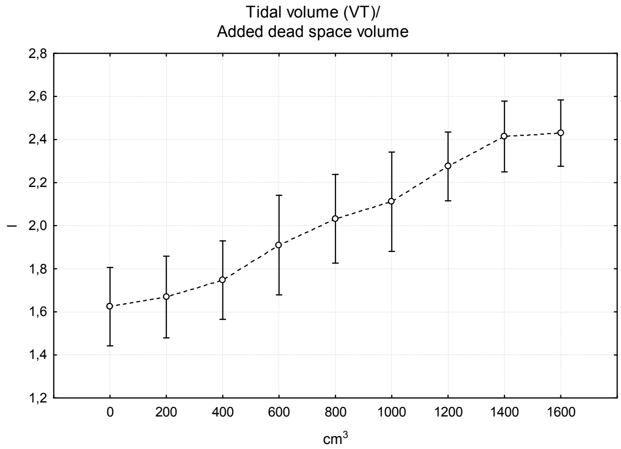

Figure 2. Tidal volume (VT) in consecutive sessions with added dead space (mean values ± SD)

Table 1. Distribution of significant differences among breathing frequency (Rf) values in consecutive sessions with added dead space

Breathing frequency Rf								
cm³	0	200	400	600	800	1000	1200	1400
0								
200	*							
400	*	–						
600	*	*	–					
800	*	*	*	–				
1000	*	*	*	–	–			
1200	*	*	*	–	–	–		
1400	*	*	*	*	–	–	–	
1600	*	*	*	*	*	*	*	*

* denotes a statistically significant difference

Table 2. Distribution of significant differences among tidal volume (VT) values in consecutive sessions with added dead space

Tidal volume VT								
cm³	0	200	400	600	800	1000	1200	1400
0								
200	–							
400	*	–						
600	*	*	*					
800	*	*	*	*				
1000	*	*	*	*	–			
1200	*	*	*	*	*	*		
1400	*	*	*	*	*	*	*	
1600	*	*	*	*	*	*	*	–

* denotes a statistically significant difference

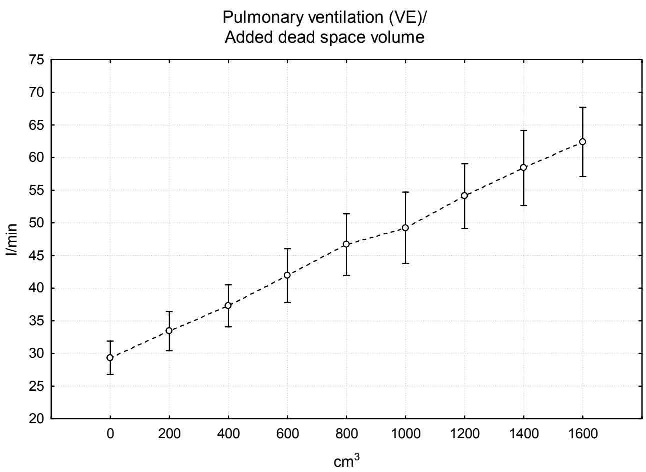

Figure 3. Pulmonary ventilation (VE) in consecutive sessions with added dead space (mean values ± SD)

Table 3. Distribution of significant differences among pulmonary ventilation (VE) values in consecutive sessions with added dead space

Pulmonary ventilation VE								
cm³	0	200	400	600	800	1000	1200	1400
0								
200	*							
400	*	*						
600	*	*	*					
800	*	*	*	*				
1000	*	*	*	*	–			
1200	*	*	*	*	*	*		
1400	*	*	*	*	*	*	*	
1600	*	*	*	*	*	*	*	*

* denotes a statistically significant difference

The changes in the heart rate (HR) are shown in Table 6. All the differences in the values of HR are statistically insignificant.

Blood parameters

The post-exercise values of pH are presented in Figure 4.

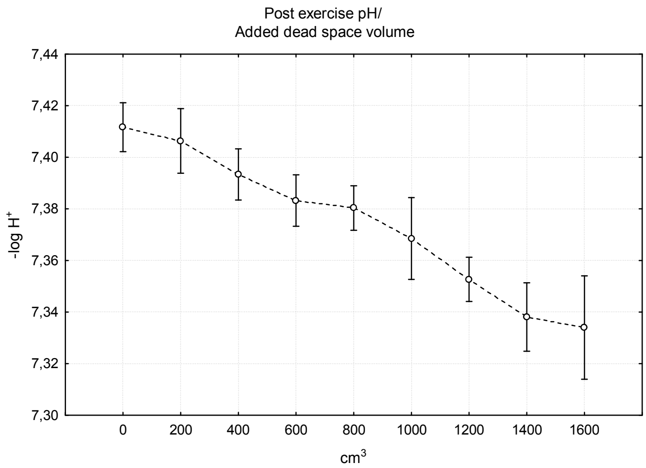

Figure 4. Post-exercise values of pH in consecutive sessions with added dead space (mean values ± SD)

The distribution of significant differences is shown in Table 4. pH decreases proportionally to the volume of added dead space, from 7.41 ± 0.01 (at 0 cm^3) to 7.33 ± 0.03 (at 1600 cm^3).

Table 4. Distribution of significant differences among post-exercise pH values in consecutive sessions with added dead space

Post-exercise pH								
cm^3	0	200	400	600	800	1000	1200	1400
0								
200	–							
400	*	*						
600	*	*	–					
800	*	*	*	–				
1000	*	*	*	*	*			
1200	*	*	*	*	*	*		
1400	*	*	*	*	*	*	*	
1600	*	*	*	*	*	*	*	–

* denotes a statistically significant difference

The post-exercise values of arterial carbon dioxide partial pressure (pCO_2) are shown in Figure 5. The distribution of significant differences can be seen in Table 5. pCO_2 increases proportionally to the volume of added dead space, from 40.89 ± 2.27 (at 0 cm^3) to 51.13 ± 3.39 mm Hg (at 1600 cm^3).

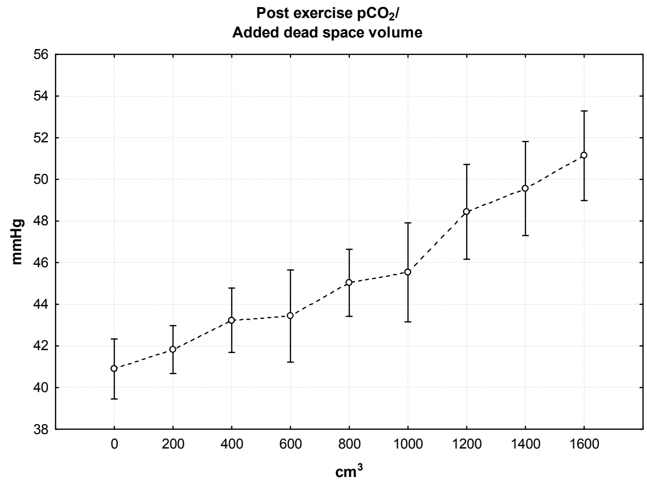

Figure 5. Post-exercise values of arterial carbon dioxide partial pressure (pCO_2) in consecutive sessions with added dead space (mean values ± SD)

Table 5. Distribution of significant differences among post-exercise arterial carbon dioxide partial pressure (pCO_2) values in consecutive sessions with added dead space

Post-exercise pCO_2								
cm^3	0	200	400	600	800	1000	1200	1400
0								
200	–							
400	*	–						
600	*	–	–					
800	*	*	–	–				
1000	*	*	*	*	–			
1200	*	*	*	*	*	*		
1400	*	*	*	*	*	*	–	
1600	*	*	*	*	*	*	*	–

* denotes a statistically significant difference

The changes in the post-exercise values of arterial plasma lactate (LA) are shown in Table 7. All the differences in the values of LA are statistically insignificant.

The changes in the post-exercise values of standard bicarbonate concentration (HCO^-_{3std}) are shown in Table 7. All the values of HCO^-_{3std} ranged between 25.23 ± 1.36 and 24.00 ± 0.78 mmol/l.

The changes in the post-exercise values of actual bicarbonate concentration (HCO^-_{3act}) can be seen in Table 7. All the differences in the values of HCO^-_{3act} are statistically insignificant.

The changes in the post-exercise values of base excess (BE(B)) are shown in Table 7. All the differences in the values of BE(B) are statistically insignificant.

The changes in the post-exercise values of arterial oxygen saturation (O_2 SAT) are presented in Table 7. The values of the parameter do not display any tendency.

All the values of O_2 SAT ranged between 94.87 ± 1.19 and 95.72 ± 0.76%.

Table 6. Mean (± SD) values of HR, and ratios of: Rf/VT, Rf/Rf_{0cm^3}, VT/VT_{0cm^3}, calculated from Rf and VT mean values

Added Dead Space Volume		HR b/min	Rf/VT	HR Rf/Rf_{0cm^3}	VT/VT_{0cm^3}
0 cm³	mean	106.18	11.43	1.00	1.00
	SD	*15.06*			
200 cm³	mean	112.68	12.23	1.10	1.03
	SD	*12.62*			
400 cm³	mean	110.46	12.40	1.17	1.08
	SD	*11.22*			
600 cm³	mean	111.93	11.85	1.22	1.18
	SD	*11.12*			
800 cm³	mean	113.63	11.56	1.27	1.25
	SD	*11.97*			
1000 cm³	mean	112.07	11.35	1.29	1.30
	SD	*15.33*			
1200 cm³	mean	109.39	10.53	1.30	1.41
	SD	*13.47*			
1400 cm³	mean	113.1	10.16	1.32	1.49
	SD	*14*			
1600 cm³	mean	115.04	10.70	1.40	1.50
	SD	*12.82*			

The changes in the post-exercise values of arterial oxygen pressure (pO_2) are shown in Table 7. All the differences in the values of pO_2 are statistically insignificant.

Discussion

The objective of this study was to assess the response of circulatory and respiratory systems to separate exercises under the condition of increasing volume of dead space by 200 cm³ at a time.

As regards acid-base equilibrium aspect, it was discovered that added dead space does not evoke hypoxemia or increase in anaerobic reproduction of ATP. The characteristic symptoms of hypoxemia are decreased values of pO_2 and O_2SAT (Lawler et al. [15], Martin and O'Kroy [16], Woorons et al. [17], Ogawa et al. [18]).

In this experiment the post-exercise values of LA, HCO^-_{3std}, HCO^-_{3act}, BE(B), pO_2, O_2SAT remained practically unchanged and did not exceed the standard rest values, regardless of the increasing dead space (Tab. 7). These findings are in agreement with those of Koppers et al. [6], who claim that there is no decrease in O_2SAT during breathing through added dead space of about 3000 cm³ for 10 min.

The post-exercise values of pH decreased, while pCO_2 increased proportionally to the volume of added dead space, from 7.41 ± 0.01 to 7.33 ± 0.03 and from 40.89 ± 2.27 to 51.13 ± 3.39 mm Hg, respectively. The increased blood partial pressure of CO_2 results from the suppressed diffusion of CO_2 to alveoli. It occurs on account of increased CO_2 in the tube and alveoli, thereby decreasing the CO_2 pressure gradient between

Table 7. Blood post exercise mean (± SD) values, and median of BE(B)

Added Dead Space Volume		pO_2 (mm Hg)	O_2SAT (%)	LA (mmol/l)	HCO_{3act} (mmol/l)	HCO_{3std} (mmol/l)	BE(B) (mmol/l)
0 cm³	mean	78.94	95.65	1.56	25.45	25.13	0.45
	SD	*6.38*	*0.97*	*0.44*	*1.48*	*1.17*	*Median*
200 cm³	mean	79.43	95.72	1.3	25.73	25.23	1.05
	SD	*5.17*	*0.76*	*0.47*	*1.56*	*1.36*	*Median*
400 cm³	mean	76.51	95.07	1.39	25.78	24.98	0.55
	SD	*5.88*	*0.95*	*0.6*	*1.44*	*1.13*	*Median*
600 cm³	mean	81.28	95.71	1.28	25.32	24.52	–0.6
	SD	*5.71*	*0.8*	*0.33*	*2.24*	*1.67*	*Median*
800 cm³	mean	79.34	95.43	1.32	26.07	24.9	0.4
	SD	*4.17*	*0.54*	*0.33*	*1.43*	*1.08*	*Median*
1000 cm³	mean	79.05	95.14	1.36	25.33	24.38	–0.55
	SD	*6.21*	*1.1*	*0.43*	*1.57*	*1.23*	*Median*
1200 cm³	mean	80.25	95.13	1.29	26.28	24.53	–0.05
	SD	*6.08*	*0.95*	*0.37*	*1.77*	*1.25*	*Median*
1400 cm³	mean	79.53	94.86	1.69	25.98	24	–0.2
	SD	*4.7*	*0.88*	*1.21*	*1.17*	*0.78*	*Median*
1600 cm³	mean	80.47	94.87	1.53	26.59	24.38	0.1
	SD	*6.71*	*1.19*	*0.42*	*1.92*	*1.75*	*Median*

blood and alveoli. Increased CO_2 partial pressure provokes a decrease in pH and respiratory acidosis (Kato et al. [19]). This is caused by carbonic acid dissociation, synthesized from carbon dioxide and water. This effect is well known mainly by the researchers who are involved in the study of hypercapnia, which is triggered by inhalation of hypercapnic gas. According to their findings, an increase in CO_2 leads to environmental acidosis, thereby inhibiting phosphofructokinase (PKF) and glycolysis (Hollidge-Horvat et al. [20], Kato et al. [19]). Furthermore, they report that during exercise the blood lactate level under hypercapnia is lower than under normocapnia (Graham et al. [21, 22], Kato et al. [19]).

It was proved as well that under acute hypercapnia skeletal muscle contractility is reduced (Vianna et al. [23], Mador et al. [24]).

The relation between pulmonary ventilation and volume of added dead space is directly proportional, which is consistent with the results obtained by Kelman and Watson [12], Smejkal et al. [13], Kurotobi et al. [14], O'Donnell et al. [1], Toklu et al. [7], Zhao et al. [25], Koppers et al. [6] and the researchers studying the effects of hypercapnic gas inhalation.

The increase in pulmonary ventilation is mainly caused by the increase in CO_2 blood partial pressure. On the other hand, it was proved that an increase in ventilation during breathing through a tube is also related to respiratory resistance (Maruyama et al. [3], Poon [4, 5]). They found that at the same values of $PetCO_2$, breathing through a tube always causes a greater increase in ventilation than inhaling hypercapnic gas. Most of the researchers involved in studying added dead space application claim that the increase in pulmonary ventilation is mainly due to the increase in tidal volume rather than breathing frequency (Kelman and Watson [12], Smejkal et al. [13], McParland et al. [26], Krishnan et al. [11], Toklu et al. [7]). This relation most probably results from the reaction of pneumotaxic and apneustic centers, which typically modify the breathing pattern during an increase in respiratory resistance, thus bringing about an increase in tidal volume and decrease in frequency.

In the present study, both the tidal volume and breathing frequency grew proportionally to the volume of added dead space. However, as is shown in Table 6, the Rf/VT ratio decreased after the 400 cm^3 volume of added dead space. Its value at 1600 cm^3 was lower than during the control exercise. Furthermore, using Rf/Rf_{0cm^3}, VT/VT_{0cm^3} ratios (Tab. 6): the VT value increased 1.5 times (by 50%) from the control exercise to the 1600 cm^3 volume of added dead space, while Rf increased 1.4 times (by 40%). It follows that this study's results confirm the common opinion.

Heart rate was not influenced by the application of added dead space. The parameter did not reach the statistical significance. This result is in accordance with those obtained by researchers studying the effects of hypercapnic gas inhalation (Graham et al. [21], Kato et al. [19]). In the experiment of the latter, at the end of the exercise performed in hypercapnia HR was not significantly different from the same exercise performed without hypercapnia.

It is well known that standard respiratory muscle training provokes hyperventilation and decrease in CO_2 blood partial pressure. Breathing through a tube prevents this from happening. According to Koppers et al. [6] added dead space may turn out to be an alternative respiratory muscle training method.

Conclusions

Increasing dead space volume causes a directly proportional increase of pulmonary ventilation, mainly thanks to the increase in tidal volume.

Added dead space produces neither hypoxemia nor the intensification of anaerobic reproduction of ATP.

Increasing dead space volume causes a directly proportional increase in CO_2 blood partial pressure and decrease in pH. Respiratory acidosis occurs.

Breathing through a tube may become an inexpensive and easy to carry out method of respiratory acidosis instigation and an alternative respiratory muscle training method.

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COMPLEMENT PROTEINS (C1EST, C4, C6), CIRCULATING IMMUNE COMPLEXES AND THE REPEATED BOUT EFFECT

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ABSTRACT
Purpose. To determine if the complement system is activated following strenuous eccentrically-biased exercise. Secondly, to determine if complement activation is attenuated (repeated bout effect) following a second bout of the same exercise. **Basic procedures.** Healthy, active but untrained males performed 2 × 60 min bouts of downhill running, 14 days apart. Samples were taken pre, immediately post (IP), then every hour for twelve hours, and at 24, 48, 72, 96, 120 and 144 h post exercise. Concentrations of C1est, C4, and circulating immune complexes (CIC's) were determined using standardised nephelometery. C6 was determined using radial immunodifusion. The variables were analysed using a repeated measures ANOVA, with significance set at $p < 0.05$. **Main findings.** A significant ($p < 0.01$) run effect was observed for C1est, C4, C6 and CIC's with the concentrations elevated after run 2 compared with run 1. C1est and C4 exhibited significant time effects ($p < 0.001$). **Conclusions.** The complement system is activated following a strenuous bout of downhill running. Complement proteins and circulating immune complexes do not exhibit the same traditional 'repeated bout effect' as many other common markers of muscle damage/inflammation. The increase in complement proteins following the second bout may indicate enhanced innate immune function and/or an amplification of the immune response to tissue damage through interaction with the adaptive immune system.

Key words: inflammation, eccentric exercise, complement, muscle damage

Introduction

Exercise that is prolonged, intense or eccentric in nature has been shown to elicit structural damage to muscle [1, 2]. It has been well documented that a subsequent bout of the same exercise that induced muscle damage, results in less damage and delayed onset of muscle soreness (DOMS) [3 – 5]. This is known as the repeated bout effect. The precise mechanism(s) underlying the beneficial adaptive process associated with the repeated bout effect are not well understood. There have, however, been a number of theories postulated, including neural, cellular and mechanical adaptation theories (for review, see [6, 7]). An aspect relating to cellular adaptations that has received considerable attention within the literature is that of the inflammatory response [8].

Complement proteins are found in plasma throughout the body and upon activation, react with each other through an enzymatic cascade [9, 10]. The complement system is intricately involved in inflammatory processes. More specifically, complement proteins are responsible for the manifestation of key inflammatory related actions: (a) changing vascular permeability, (b) altering vascular flow, (c) chemotaxis, and (d) extravasation of leukocytes [11]. Increase in complement proteins C1est, C4, C6 and circulating immune complexes indicates upregulation of the inflammatory response and as such provides insight into the body's response to tissue injury; in this case benign exercise-induced muscle damage.

To the best of the authors' knowledge, no other study has investigated the effects of repeated eccentric exercise on complement proteins and circulating immune complexes. Therefore, the aims of this study were firstly to determine if the complement system is activated following a strenuous bout of eccentrically biased exercise. Secondly, to determine if this response would be

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attenuated after a second bout of the same exercise, i.e. a repeated bout effect.

Material and methods

Subject selection and screening

Healthy, active but untrained, males (n = 11) were recruited for the study (age: 19.7 ± 0.37 years; weight: 78.5 ± 30.6 kg; body fat: 14.6 ± 3.2%; VO_2max: 47.8 ± 3.6 ml/kg/min). Height and weight were recorded using a calibrated medical height gauge (stadiometer) and balance scale (Detecto, Webb City, Missouri, USA). Harpenden skinfold callipers were utilised to measure subcutaneous fat. Body composition was assessed using the Drinkwater-Ross method [12]. Selection criteria included the following: age between 18–30 years; no history of leg injury or any other medical condition that would be exacerbated by two bouts of downhill running; no current or regular usage of anti-inflammatory medication. The protocol as well as an informed consent were approved by the Tshwane University of Technology Ethics Committee.

Study method and design

VO_2max

Subjects performed a VO_2max test (Bruce protocol) in the exercise-testing laboratory (ETL), a minimum of two weeks before the first downhill run. The treadmill speed that elicited 75% of the subjects VO_2max was then calculated as the speed for both downhill runs.

Downhill run

The subjects performed two bouts of downhill running spaced 14 days apart (run 1 and run 2). On both occasions the subjects arrived at the ETL at the same time of day and in a fasted state. Laboratory conditions (temperature/humidity) were the same for both run 1 and run 2. Subjects warmed up for 5 min running on a level grade. The treadmill was then lowered to –13.5% and subjects ran for 60 min at their predetermined 'relative' speeds. The subjects abstained from all physical activity for at least 72 h before run 1, and for the entire duration of the study.

Blood sampling

A venipunture was performed to obtain the baseline blood sample. Following the 60 min downhill run a venous catheter (22 gauge, 2.2 cm) was inserted which was kept patent using saline solution. Blood was drawn at the following times: pre-exercise, immediately post exercise (IP), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 h after (14 samples × 15 ml per sample = 210 ml blood over approximately 14 h). In addition, subjects were required to return to the ETL at 24, 48, 72, 96, 120 and 144 h post exercise, for additional blood draws (6 days × 15 ml = 90 ml). The same procedure was followed after 14 days.

Blood was allowed to stand at room temperature for 30 minutes (serum) and was then as spun down for 20 minutes at 1000 × g. Aliquots were frozen and stored at –70°C in .5 ml eppendorf tubes until analysed. Subjects remained in the ETL for 12 h after run 1 and run 2. They were provided with food and encouraged to drink *ad libitum*.

Blood analysis

Validity and reliability

All blood samples were analysed in duplicate. A coefficient variation of less than 10% between the duplicate samples was required for all measures.

Complement proteins

C1est and C4

Determination of serum complement proteins C1est and C4 was performed using specific anti-sera to C1est and C4. The immune complexes formed were measured in a Behring nephelometer (Behring Diagnostics, Germany) and the amount of C1est, and C4 was calculated by comparison with standards of known concentration.

C6

C6 was determined by radial immunodiffusion (The Binding Site, UK). The assay was performed by adding serum and controls of known C6 concentrations to radial immunodiffusion plates containing non-specific antibody in an agarose gel. The diameter of immunoprecipitating antigen-antibody complexes radiating out of the wells was measured and compared against a calibrated curve drawn from a range of samples of known concentration.

Circulating immune complexes

The levels of circulating immune complexes (CIC) were determined by particle-enhanced nephelometry. The assay utilised polystyrene particles coated with human C1q, which was added to the subjects' sera. Light scatter due to agglutination of the C1q coated particles in the presence of CIC was measured in a Behring nephelometer (Behring Diagnostics, Germany) whereby the concentration of CIC was determined in relation to the amount of agglutination detected.

Data analysis

Each dependent variable was analysed before and after the two conditions (run1/run2), using a repeated measures analysis of variance, with significance set at $p < 0.05$. Where significance was found for main or interaction effects, a Bonferroni *post hoc* analysis was performed.

Results

A significant ($p = 0.0009$) run effect was observed for C1esterase inhibitor, with the concentrations being elevated by 7% after run 2 compared with run 1. C1est was significantly elevated at 9 h and 10 h post exercise (time effect). No significant difference in the resting concentrations before each run was observed for C1est. By 24 h post exercise, C1est levels had returned to pre-exercise concentrations in both runs (Fig. 1).

C4 exhibited a significant ($p < 0.0001$) run effect, being elevated by 17% after run 2 compared with run 1. C4 was significantly elevated at 7 h and 9 h post exercise (time effect, $p < 0.001$). There were no differences in the resting levels of C4 before each run. At 24 h post exercise, C4 levels had returned to baseline concentrations after both runs (Fig. 2).

A significant ($p < 0.0001$) run effect was observed for C6, with concentrations being significantly elevated by 4% after run 2 compared with run 1 (Fig. 3). There were no differences in the resting levels of C6 before each run.

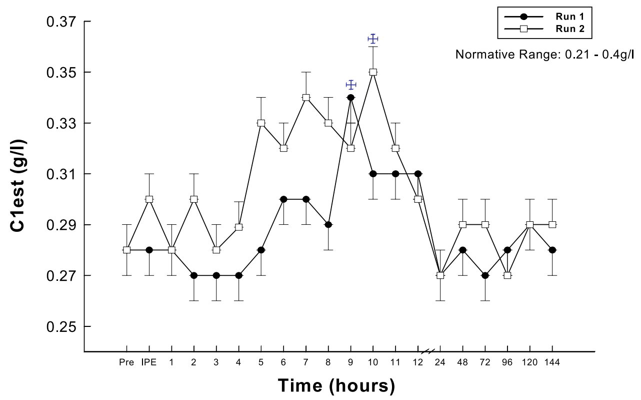

Figure 1. C1est concentrations measured before and then at hourly and 24 hour intervals following two bouts of downhill running. Data are means ± SE. Significant ($p < 0.001$) time effect compared to baseline (pre) concentrations. The symbol "//" on the X axis signifies a change in time interval (samples no longer measured at hourly intervals). Pre = 30 min before the run; IPE = immediately post exercise

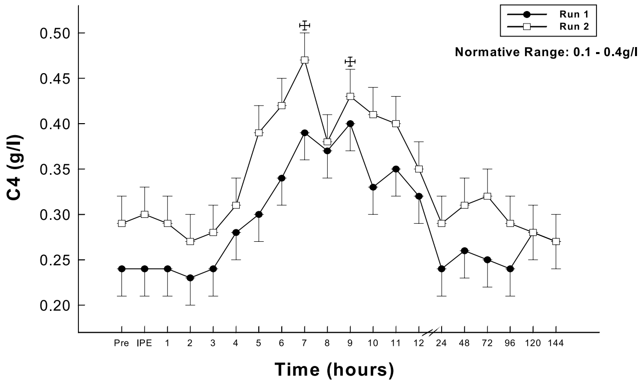

Figure 2. C4 concentrations measured before and then at hourly and 24 hour intervals following two bouts of downhill running. Data are means ± SE. Significant ($p < 0.001$) time effect compared to baseline (pre) concentrations. The symbol "//" on the X axis signifies a change in time interval (samples no longer measured at hourly intervals). Pre = 30 min before the run; IPE = immediately post exercise

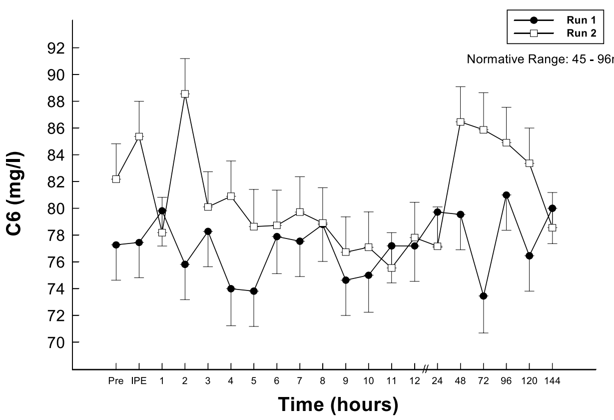

Figure 3. C6 concentrations measured before and then at hourly and 24 hour intervals following two bouts of downhill running. Data are means ± SE. The symbol "//" on the X axis signifies a change in time interval (samples no longer measured at hourly intervals). Pre = 30 min before the run; IPE = immediately post exercise

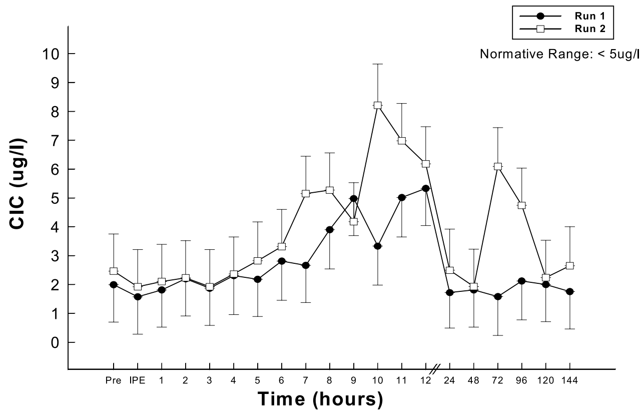

Figure 4. Concentrations of circulating immune complexes measured before and then at hourly and 24 hour intervals following two bouts of downhill running. Data are means ± SE. The symbol "//" on the X axis signifies a change in time interval (samples no longer measured at hourly intervals). Pre = 30 min before the run; IPE = immediately post exercise

Circulating immune complexes were significantly ($p = 0.007$) elevated by 42% after run 2 compared with run 1. Peak concentrations after run 1 and run 2 were observed at 12 h and 10 h post exercise, respectively (Fig. 4). Differences in the resting concentrations before run 1 and run 2 were statistically non-significant.

Discussion

The aim of this study was to determine (a) if the complement system is activated by eccentrically-biased exercise (downhill running), and (b) if the manifestation of this response would be attenuated after a second bout of the same exercise, i.e. a repeated bout effect.

Complement proteins C1est, C4 and C6 as well as circulating immune complexes (CIC) all exhibited a significant elevation after the second run when compared to the first run (bout effect). Increases in complement proteins and immune complexes would imply the manifestation of a more pronounced pro-inflammatory response following the second bout. It is arguable that the increased complement could in part be attributed to the elevated immune complexes, since complement may facilitate the removal of these complexes from circulation [11]. The increase in C4 implies that the classical pathway of complement was activated while the 'simultaneous' elevation of C1est suggests the regulation of this pathway via the enzyme inhibiting activity of C1est [13].

Despite the classical repeated bout effect being produced for creatine kinase (reported elsewhere [14]) the complement proteins failed to show the same phenomenon. Recently, the study by Hubal et al. [15] produced similar observations. In their study a number of inflammatory genes were upregulated following a repeated bout of 300 lower limb eccentric-concentric actions.

The question still remains as to why a pro-inflammatory response was seemingly exacerbated after run 2 compared to run 1? Although speculative, an explanation for this observation may be related to an enhancement of the immune/inflammatory response to the second bout of tissue damaging exercise via an innate:adaptive immunity interaction or collaboration. Recent research provides support for this hypothesis. Specifically, Chan et al. [16] have proposed that injured tissue (ischemic) expresses neoepitopes that are recognised by natural antibodies. The subsequent binding of the natural antibodies to these novel antigens results in the formation of immune complexes (antigen:antibody) which in turn activate complement. This interaction may help explain the results of the present study. Following the first bout of downhill running there may have been the 'liberation' of novel antigens (neoepitopes) as a result of the muscle damage. Weiser et al. [17] have postulated that these antigenic determinants may be exposed as a result of 'subtle alterations in plasma membranes'. Natural antibodies, specifically natural IgM, would then bind to these epitopes and activate the classical pathway of complement [9]. Additional synthesis of IgM following exposure to these antigens would result in an elevation of natural antibodies (i.e development of immune memory). On exposure to the second bout of downhill running the elevated IgM (memory) would facilitate a more pronounced inflammatory response through an enhanced activation of the classical pathway of complement. In support of this, C4, which is indicative of classical pathway activation, was significantly elevated after the second run.

Conclusion

Based on our findings, the premise that inflammation as a whole is down regulated or suppressed following a repeated bout of muscle damaging exercise is questionable.

Significant elevations after run 2 compared with run 1 were observed for C4, C6, C1est and CIC. Thus, 60 min of downhill running followed by an identical bout two weeks later, fails to 'dampen' the systemic inflammatory response. This is in contrast to what has been observed for creatine kinase and other indirect markers of muscle damage. Overall, the surprisingly minor changes in complement proteins, in response to a relatively severe bout of eccentric exercise suggests that either (a) little muscle damage was incurred (which based on CK responses [14] did not seem to be the case), or (b) changes in systemic complement protein concentration may not be sensitive markers of what is occurring in skeletal muscle. These results warrant further investigation as this is the first study to report such an effect and participant numbers were limited.

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