Ergonomics in sports and at work

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Abstract. This paper addresses issues related to ergonomics in sports and at work. Ergonomics and sports science disciplines are interrelated. Workers and athletes operate in demanding environments requiring a high level of performance. Thus, a branch of ergonomics focuses on quantifying motor strategies in order to optimize human performance and prevent injuries. These goals can be pursued by (i) assessing human characteristics and capabilities in relation to certain motor tasks, (ii) achieving optimal efficiency and improving the overall level of performance, (iii) reducing discomfort level, and (iv) ensuring safety. This paper reviews recent studies and presents novel methods used to assess human performance.

Keywords. Human factors, Motor performance, Physical activity.

1. Background

Ergonomics and sports science are closely tied together when taking human performance in consideration. Both workers and athletes have to optimize the level of their performance in relation to e.g., the external demands. The assessment of sensory-motor interactions is vital as healthy workers or athletes obviously perform better than injured workers or athletes. Typically, musculoskeletal injuries are accompanied by discomfort and pain in the deep structure tissues (muscles, ligaments, tendons and connective tissues). For example, both workers and athletes engaged in activities requiring repetitive arm movement such as butchers and elite swimmers report moderate to high level of pain intensity (Madeleine, P., 2010; Hidalgo-Lozano, A., Fernandez-De-Las-Penas, C., Calderon-Soto, C., Domingo-Camara, A., Madeleine, P., & Arroyo-Morales, M., 2013). These musculoskeletal injuries do not only affect the individual but have also negative consequences on a number of socio-economic factors. As such, both physical and psychosocial factors can play a role in the development of musculoskeletal injuries. This paper focuses exclusively on physical factors.

No one can achieve "world-class" performance in a poor ergonomic environment (Reilly, T., 2010). Thus, ergonomics design can advantageously contribute to e.g., the design of sports equipment, workplace interventions, and training regimes. Such design should not only promote and support a high level of performance but also prevent the development of injuries. These are the specific goals of an ergonomist engaged in sports and occupational research (Reilly, T., 2010). These goals can be fulfilled by (i) assessing human characteristics and capabilities in relation to certain motor tasks, (ii) achieving optimal efficiency and improving the level of performance, (iii) reducing discomfort level, and (iv) ensuring safety (figure 1). Following Prof Thomas Reilly efforts, this paper reviews recent studies and presents novel methods used to assess sensory aspects such as discomfort and pain as well as biomechanical adaptations by surface electromyography (SEMG), mechanomyography (MMG), kinetic (force), and kinematic (movement) measurements in both work and sport arenas. In conclusion, the assessment of human performance in laboratory and field settings can be used to understand or resolve issues related to both the environment and the capacities or capabilities of the humans operating in it.

2. Assessing human characteristics and capabilities

Individuals' characteristics and capabilities are important to monitor as these are closely tied to the required level of efficiency in demanding environments. Such evaluations are not intended to be discriminative by identifying and selecting only highly capable and injury-resistant individuals (Taylor, N. A. S., 2013). These assessments should on the contrary be seen as a mean to measure physiological attributes of workers and athletes providing scientific basis for their improvements.

Discomfort and pain are often reported and assessed by means of questionnaire and numeric scales in relation to physical activity. Furthermore, the information of the individuals' muscle tenderness and pain are of interest. The sensitivity of deep structure to pressure can be assessed by pressure algometry. Pressure pain thresholds are measured as the pressure when the sensation first changes from pressure to pain. In that context, we have developed a new imaging technique called pressure pain mapping (Fernandez-Carnero, J., Binderup, A. T., Ge, H. Y., Fernandez-De-Las-Penas, C., Arendt-Nielsen, L., & Madeleine, P., 2010; Binderup, A. T., Arendt-Nielsen, L., & Madeleine, P., 2010). The technique enables the visualization of heterogeneity in muscle pressure sensitivity and mechanical hyperalgesia (increased pain sensitivity) in specific regions of the body in both workers and athletes (Domínguez-Martin, M. A., López-Ruiz, F, Valenza, G., Fernández-De-Las-Penas, C., & Madeleine, P., 2013; Binderup, A. T., Holtermann, A., Sogaard, K., & Madeleine, P., 2011).

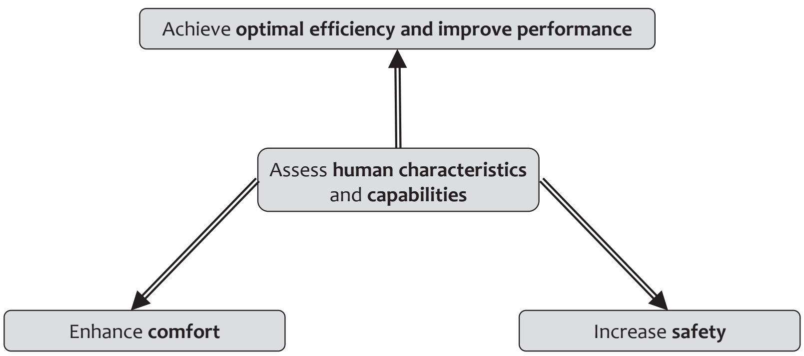

Figure 1. An ergonomic model for sports and occupational research.

Anthropometric and biomechanical measurements are complementary to the mentioned sensory assessments. The existence of databases can facilitate the ergonomists work, but supplementary recordings are often needed. Biomechanical recordings enable a precise quantification of individuals' characteristics in relation to a specific movement (Madeleine, P., Samani, A., de Zee, M., & Kersting, U. G., 2011). Heart rate, SEMG, MMG, kinetics and kinematics recordings can be associated with investigating the work load and biomechanics of a motor task in relation to for instance muscular fatigue and pain. Human movements can be divided in two categories: (i) static or isometric movement and (ii) dynamic or anisometric movement. Similar to pressure pain mapping, multi-channel SEMG or MMG recordings can be used to reveal spatial heterogeneity in muscle activation reflecting specific or altered recruitment strategies in static conditions (Madeleine, P., Leclerc, F., Arendt-Nielsen, L., Ravier, P., & Farina, D, 2006; Madeleine, P. & Farina, D., 2008). Biomechanical assessments including SEMG, kinetics and kinematics recordings can also be used to characterize sex aspects providing novel information about motor control in men and women during activity of daily living (Rathleff, M. S., Olesen, C. G., Moelgaard, C. M., Jensen, K., Madeleine, P., & Olesen, J. L., 2010; Johansen, T. I., Samani, A., Antle, D. M., Cote, J. N., & Madeleine, P., 2013). Moreover, other type of assessments, i.e. the variability of SEMG can be used as objective outcomes of self-reported clinical status (Rathleff, M. S., Samani, A., Olesen, J. L., Roos, E. M., Rasmussen, S., Christensen, B. H., & Madeleine, P., 2013; Svendsen, J. H., Svarrer, H., Laessoe, U., Vollenbroek-Hutten, M., & Madeleine, P., 2013). Finally, the assessments of the sensory and motor capabilities, i.e., functional connectivity among muscles can be used to determine and develop specific training regimes for rehabilitation programs (Madeleine, P., Samani, A., Binderup, A., & Stensdotter, A. K., 2011).

3. Achieving optimal efficiency and improve performance

At work or on the sports scene, efficiency is a crucial issue when individuals are required to have a high level of performance. Depending on the task to accomplish, ranging from e.g. gross body movements in manual handling task to high precision tasks in biathlon, shorter or longer period of learning and/or training are allowed to achieve a high level of performance. A similar pattern is present in sports where motor learning and motor variability constitute an integral part of highly-skilled athletes (Bartlett, R., Wheat, J., & Robins, M., 2007). Similar to what was exposed in the previous section, sensory and motor assessments can be used to ensure an optimal level of performance.

Pressure pain mapping can be advantageously applied in relation to e.g. repeated eccentric exercise at high intensity. Unaccustomed eccentric exercise leads to muscle soreness. Interestingly, a second bout of eccentric exercise does not result in the same extent of muscle soreness (Delfa de la Morena, J., Samani, A., Fernandez-Carnero, J., Hansen, E. A., & Madeleine, P., 2013; Kawczynski, A., Samani, A., Fernandez-De-Las-Penas, C., Chmura, J., & Madeleine, P., 2012). Physical training can thus be considered as a mean to obtain a protective response enabling a high level of performance.

Similarly, the assessment of motor activity in highly experienced workers or expert athletes can be used to describe the role of expertise level on motor performance. Furthermore, such approach can be used to provide information concerning specific motor strategies explaining why some individuals are more prone to contract musculoskeletal injuries than others. The study of motor coordination and muscle synergies in relation to the level experience show that motor variability is both decreasing and increasing (Madeleine, P., 2010). Experienced workers or expert athletes are characterized by more variable motor patterns resulting in important functional implications e.g., protecting workers from musculoskeletal injuries and enabling world-class level of performance for athletes (Madeleine, P., 2010; Kristiansen, M. V., Madeleine, P., Hansen, E. A., & Samani, A., 2013). Ergonomists need to acknowledge that individualized motor strategies have to be taken into account to ensure a high level of performance.

4. Reducing discomfort

Another crucial aspect when seeking optimal human performance is the reduction of discomfort level. Prolonged constrained activity results in increased discomfort and sometimes pain. A way to develop actions aiming at reducing discomfort at work is to benchmark the effects of discomfort on biomechanical outcomes. Long-lasting sitting results in increased discomfort associated with changes in the dynamics of the seating postural control (Søndergaard, K. H. E., Olesen, C. G., Søndergaard, E. K., de Zee, M., & Madeleine, P., 2010). Consequently, ergonomically designed chairs should aim at promoting a dynamic seating posture in order to prevent the development of discomfort and other adverse effects (Madeleine, P., 2012).

In parallel, the development of new equipment should not result in a loss of skills, safety and comfort. A good example of such innovations is the use of artificial turf in football. Third generation artificial turf does not as such increase the risk of musculoskeletal injuries in football players (Ekstrand, J., Hagglund, M., & Walden, M., 2011) but is often associated with increased discomfort especially during the transition from natural grass to artificial turf among young elite players (Kaalund, S. & Madeleine, P., 2013). The effects of long-term exposure to artificial turf can also be addressed by studying pressure pain mapping. Lower pressure pain threshold are reported among elite footballers playing on artificial turf compared with players used to play on natural grass underlining the progress achieved in designing artificial sports surface (Domínguez-Martin, M. A., López-Ruiz, F, Valenza, G., Fernández-De-Las-Penas, C., & Madeleine, P., 2013). In conclusion, the reduction of discomfort is not only ensuring a continuous high level of performance, it also most likely contributes to the prevention of musculoskeletal injuries in sport and at work.

5. Ensuring safety

The final aspect of the proposed ergonomics model is related to safety. The optimization of performance can result in increased risk of injuries (Reilly, T., 2010). This should be combatted as injured individuals will not perform and will have to go through expensive and extensive rehabilitation programs. So safety is definitively a matter of interest and protective clothing and equipment are developed to maintain a high level of performance (Reilly, T., 2010). Coaches can for instance adapt recovery procedures after a football game. Eccentric-based recovery procedures have proven to be effective in that way by decreasing the extent of muscle soreness and thereby reducing the need for recovery in professional football players (Kawczynski, A., Mroczekl, D., Frackiewicz, D., Chmura, P., Becella, L., Samani, A., Madeleine, P., & Chmura, J., 2013). Ergonomic interventions are also of interest as such approaches can reduce the risk of injury in athletes and workers. The use of shock-absorbing insoles is reducing the discomfort and the pain reported during catering and training football on artificial turf (Kersting, U.G., Janshen, L., Böhm, H., Morey-Klapsing, G.M. & Brüggemann, G-P., 2005; Kaalund, S. & Madeleine, P., 2013). Similarly, the implementation of ergonomic guidelines among cleaners is resulting in a decrease in both cardiovascular and musculoskeletal load (Samani, A., Holtermann, A., Sogaard, K., Holtermann, A., & Madeleine, P., 2012). Biofeedback and musculoskeletal models can be used to respectively redistribute muscular loads and adjust workstations (Samani, A., Holtermann, A., Sogaard, K., & Madeleine, P., 2010; Pontonnier, C., de Zee, M., Samani, A., Dumont, G., & Madeleine, P., 2014).

In conclusion, the presented approach offers new perspectives for human factors professionals based on the assessment and enhancement of the level of performance while reducing discomfort and maintaining safety.

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References

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics, 6,* 224-243.

Binderup, A. T., Arendt-Nielsen, L., & Madeleine, P. (2010). Pressure pain threshold mapping of the trapezius muscle reveals heterogeneity in the distribution of muscular hyperalgesia after eccentric exercise. *European Journal of Pain, 14,* 705-712.

Binderup, A. T., Holtermann, A., Sogaard, K., & Madeleine, P. (2011). Pressure pain sensitivity maps, self-reported musculoskeletal disorders and sickness absence among cleaners. *International Archives of Occupational and Environmental Health, 84,* 647-654.

Delfa de la Morena, J., Samani, A., Fernandez-Carnero, J., Hansen, E. A., & Madeleine, P. (2013). Pressure pain mapping of the wrist extensors after repeated eccentric exercise at high intensity. *Journal of Strength and Conditioning Research, 27,* 3052.

Domínguez-Martin, M. A., López-Ruiz, F., Valenza, G., Fernández-De-Las-Penas, C., & Madeleine, P. (2013). Differences in pressure pain sensitivity of elite male soccer players on artificial turf and natural grass. *Sports Technology, 6,* 22-28.

Ekstrand, J., Hagglund, M., & Walden, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *American Journal of Sports Medicine, 39,* 1226-1232.

Fernandez-Carnero, J., Binderup, A. T., Ge, H. Y., Fernandez-De-Las-Penas, C., Arendt-Nielsen, L., & Madeleine, P. (2010). Pressure pain sensitivity mapping in experimentally induced lateral epicondylalgia. *Medicine & Science in Sports & Exercise, 42,* 922-927.

Hidalgo-Lozano, A., Fernandez-De-Las-Penas, C., Calderon-Soto, C., Domingo-Camara, A., Madeleine, P., & Arroyo-Morales, M. (2013). Elite swimmers with and without unilateral shoulder pain: mechanical hyperalgesia and active/latent muscle trigger points in neck-shoulder muscles. *Scandinavian Journal of Medicine & Science in Sports, 23,* 66-73.

Johansen, T. I., Samani, A., Antle, D. M., Cote, J. N., & Madeleine, P. (2013). Gender effects on the coordination of subdivisions of the trapezius muscle during a repetitive box-folding task. *European Journal of Applied Physiology, 113,* 175-182.

Kaalund, S. & Madeleine, P. (2013). Effects of shock-absorbing insoles during transition from natural grass to artificial turf among young soccer players: A randomized controlled trial. *Journal of the American Podiatric Medical Association, Accepted*.

Kawczynski, A., Mroczekl, D., Frackiewicz, D., Chmura, P., Becella, L., Samani, A., Madeleine, P., & Chmura, J. (2013). Effects of two recovery procedure after a football game on sensory and biochemical markers. *The Journal of Sports Medicine and Physical Fitness, In press*.

Kawczynski, A., Samani, A., Fernandez-De-Las-Penas, C., Chmura, J., & Madeleine, P. (2012). Sensory mapping of the upper trapezius muscle in relation to consecutive sessions of eccentric exercise. *Journal of Strength and Conditioning Research, 26,* 1577-1583.

Kersting, U.G., Janshen, L., Böhm, H., Morey-Klapsing, G.M. & Brüggemann, G-P. (2005). Modulation of mechanical and muscular load by footwear during catering. *Ergonomics, 48,* 380-398

Kristiansen, M. V., Madeleine, P., Hansen, E. A., & Samani, A. Inter-subject variability of muscle synergies during bench press in power lifters and untrained individuals. *Scandinavian Journal of Medicine & Science in Sports,* doi: 10.1111/sms.12167. 2013.

Madeleine, P. (2010). On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. *Acta Physiologica, 199,* 1-46.

Madeleine, P. (2012). Dynamics of seated computer work before and after prolonged constrained sitting. *Journal of Applied Biomechanics, 28,* 297-303.

Madeleine, P. & Farina, D. (2008). Time to task failure in shoulder elevation is associated to increase in amplitude and to spatial heterogeneity of upper trapezius mechanomyographic signals. *European Journal of Applied Physiology, 102,* 325-333.

Madeleine, P., Leclerc, F., Arendt-Nielsen, L., Ravier, P., & Farina, D. (2006). Experimental muscle pain changes the spatial distribution of upper trapezius muscle activity during sustained contraction. *Clinical Neurophysiology, 117,* 2436-2445.

Madeleine, P., Samani, A., Binderup, A., & Stensdotter, A. K. (2011). Changes in the spatio-temporal organization of the trapezius muscle activity in response to eccentric contractions. *Scandinavian Journal of Medicine & Science in Sports, 21,* 277-286.

Madeleine, P., Samani, A., de Zee, M., & Kersting, U. G. (2011). Biomechanics assessments in sports and ergonomics. In V. Klikka (Ed.), *Theoretical Biomechanics* (Chap 16, pp. 335-360). Rijeka, Croatia: Intech.

Pontonnier, C., de Zee, M., Samani, A., Dumont, G., & Madeleine, P. (2014). Strengths and limitations of a musculoskeletal model for an analysis of simulated meat cutting tasks. *Applied Ergonomics, 45,* 592-600.

Rathleff, M. S., Olesen, C. G., Moelgaard, C. M., Jensen, K., Madeleine, P., & Olesen, J. L. (2010). Non-linear analysis of the structure of variability in midfoot kinematics. *Gait & Posture, 31,* 385-390.

Rathleff, M. S., Samani, A., Olesen, J. L., Roos, E. M., Rasmussen, S., Christensen, B. H., & Madeleine, P. (2013). Neuromuscular activity and knee kinematics in adolescents with patellofemoral pain. *Medicine & Science in Sports & Exercise, 45,* 1730-1739.

Reilly, T (2010). Ergonomics in sport and physical activity: Enhancing performance and improving safety. Champaign, Human Kinetics.

Samani, A., Holtermann, A., Sogaard, K., Holtermann, A., & Madeleine, P. (2012). Following ergonomics guidelines decreases physical and cardiovascular workload during cleaning tasks. *Ergonomics, 55,* 295-307.

Samani, A., Holtermann, A., Sogaard, K., & Madeleine, P. (2010). Active biofeedback changes the spatial distribution of upper trapezius muscle activity during computer work. *European Journal of Applied Physiology, 110,* 415-423.

Søndergaard, K. H. E., Olesen, C. G., Søndergaard, E. K., de Zee, M., & Madeleine, P. (2010). The variability and complexity of sitting postural control are associated with discomfort. *Journal of Biomechanics, 43,* 1997-2001.

Svendsen, J. H., Svarrer, H., Laessoe, U., Vollenbroek-Hutten, M., & Madeleine, P. (2013). Standardized activities of daily living in presence of sub-acute low-back pain: A pilot study. *Journal of Electromyography and Kinesiology, 23,* 159-165.

Taylor, N. A. S. (2013). Thematic reviews: Series II-physiological employment standards. *European Journal of Applied Physiology*, 113, 2433.