2020 Safety Day

Malattie professionali e infortuni in agricoltura: stato dell'arte e sviluppi futuri

Nuovi strumenti per la valutazione del rischio biomeccanico

Draicchio Francesco
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Focus

VALUTAZIONE DEL RISCHIO DA MOVIMENTAZIONE MANUALE DEI CARICHI NEI SETTORI AGRICOLI DELLA FRUTTICOLTURA E ORTICOLTURA

A. Silvetti*, A. Papale**, F. Draicchio*

* *Istituto Superiore per la Prevenzione e la Sicurezza del Lavoro (ISPESL), Dipartimento Medicina del Lavoro, Laboratorio di Fisiologia ed Ergonomia, Monte Porzio Catone, Roma*

** *ISPESL, Dipartimento Processi organizzativi, Roma*

FIGURA 2 - L'operatrice effettua il trasferimento delle cassette sulla pedana

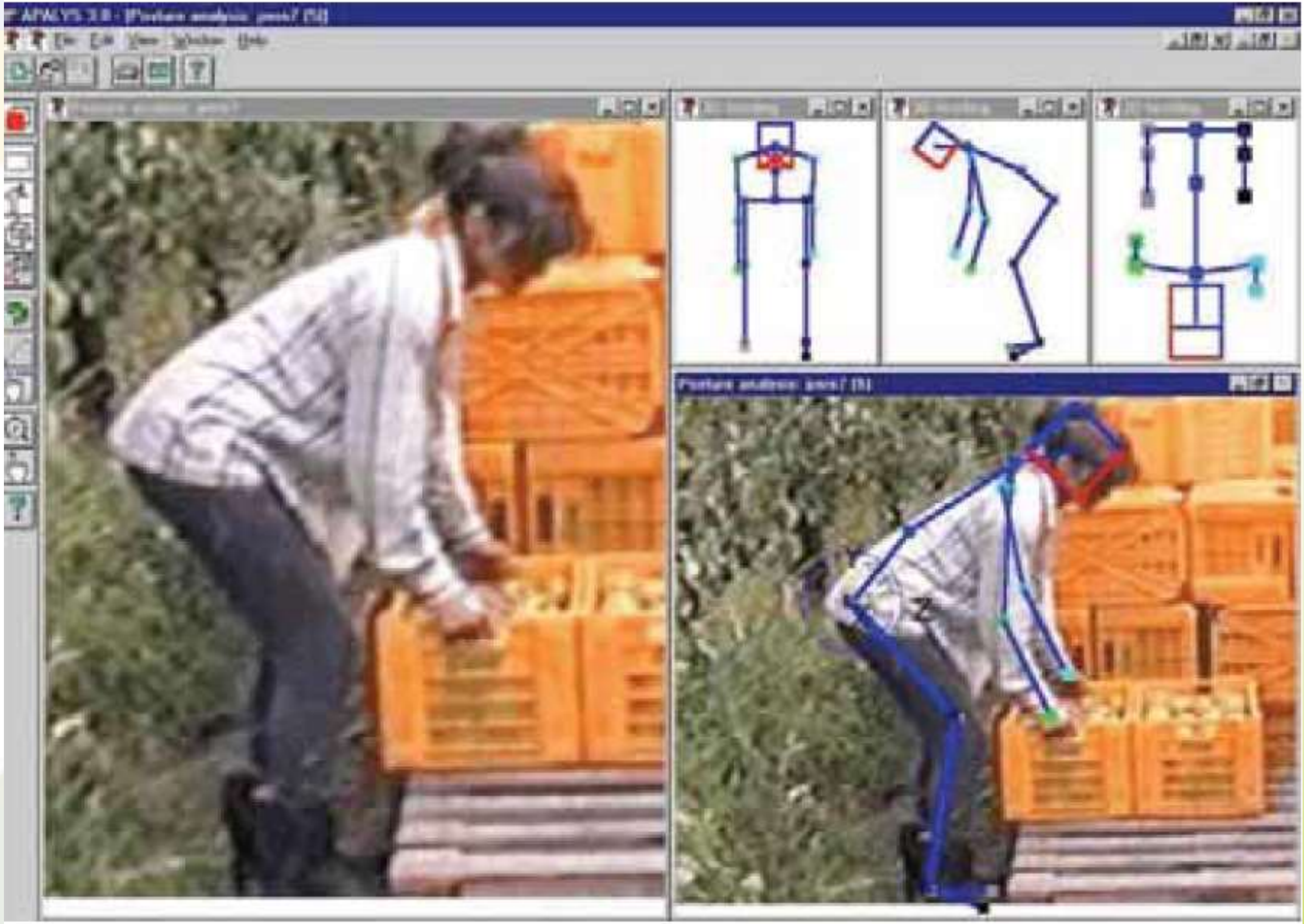
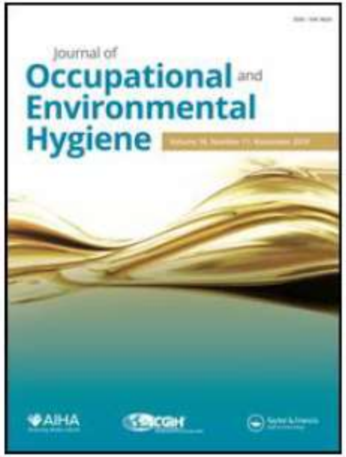


FIGURA 3 - L'immagine mostra l'attività di trasferimento delle cassette sulla pedana e ne evidenzia la cattiva postura assunta dall'operatrice (distanza dal tronco)

Ambienti di lavoro sani e sicuri



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Biomechanical factors during common agricultural activities: Results of on-farm exposure assessments using direct measurement methods

Nathan B Fethke, Mark C Schall Jr, Howard Chen, Cassidy A Branch & Linda A Merlino

Biomechanical factors during common agricultural activities: Results of on-farm exposure assessments using direct measurement methods

Nathan B Fethke[a], Mark C Schall Jr[b], Howard Chen[c], Cassidy A Branch[d], and Linda A Merlino[a]

[a]Occupational and Environmental Health, University of Iowa, Iowa City, Iowa; [b]Industrial & Systems Engineering, Auburn University, Auburn, Alabama; [c]Mechanical Engineering, Auburn University, Auburn, Alabama; [d]Public Policy Center, University of Iowa, Iowa City, Iowa

ABSTRACT

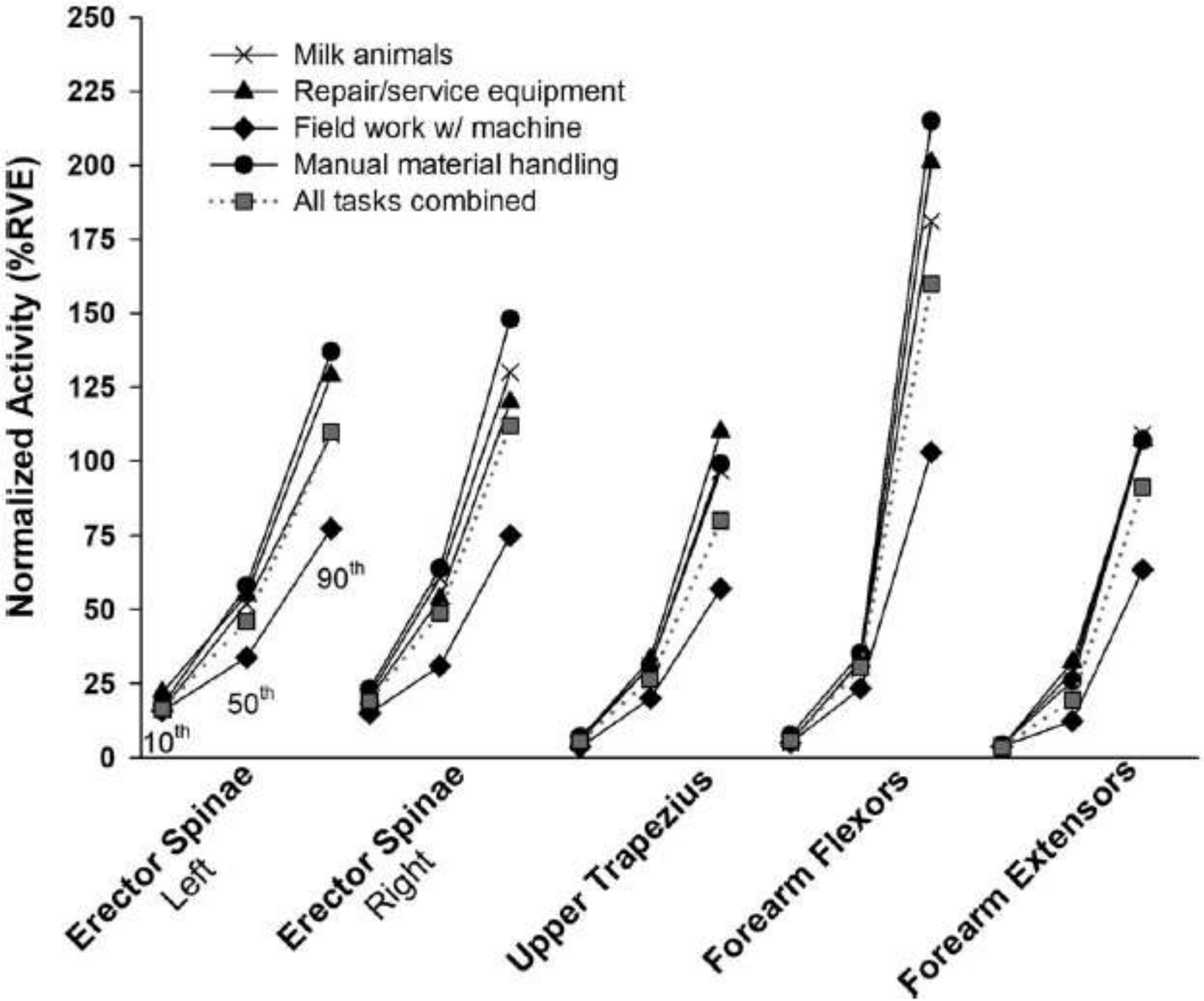
Agricultural work is associated with increased risk of adverse musculoskeletal health outcomes. The purpose of this study was to quantify exposure to biomechanical factors among a sample ($n = 55$) of farmers in the Midwest region of the U.S. while they performed a variety of routine agricultural activities, and to compare exposure levels between these activities. Surface electromyography was used to estimate activity levels of the erector spinae, upper trapezius, forearm flexor, and forearm extensor muscle groups. Simultaneously, inertial sensors were used to measure kinematics of the trunk, upper arm, and wrist. In general, lower muscle activity levels, less extreme postures, and slower movement speeds were observed during activities that involved primarily the use of agricultural machinery in comparison to manual activities, suggesting a potential advantage of mechanization relative to musculoskeletal health. Median wrist movement speeds exceeding recently proposed exposure thresholds were also observed during many manual activities, such as milking animals and repairing equipment. Upper arm postures and movement speeds did not appear to confer excessive risk for shoulder-related outcomes (on the whole), but interpretation of the results is limited by a sampling approach that may not have captured the full extent of exposure variation. Not surprisingly, substantial variation in exposure levels were observed within each agricultural activity, which is related to substantial variation in the equipment, tools, and work practices used by participants. Ultimately, the results of this study contribute to an emerging literature in which the physical demands of routine agricultural work have been described on the basis of sensor-based measurements rather than more common self-report or observation-based approaches.

KEYWORDS
Agriculture; ergonomics; kinematics; surface electromyography

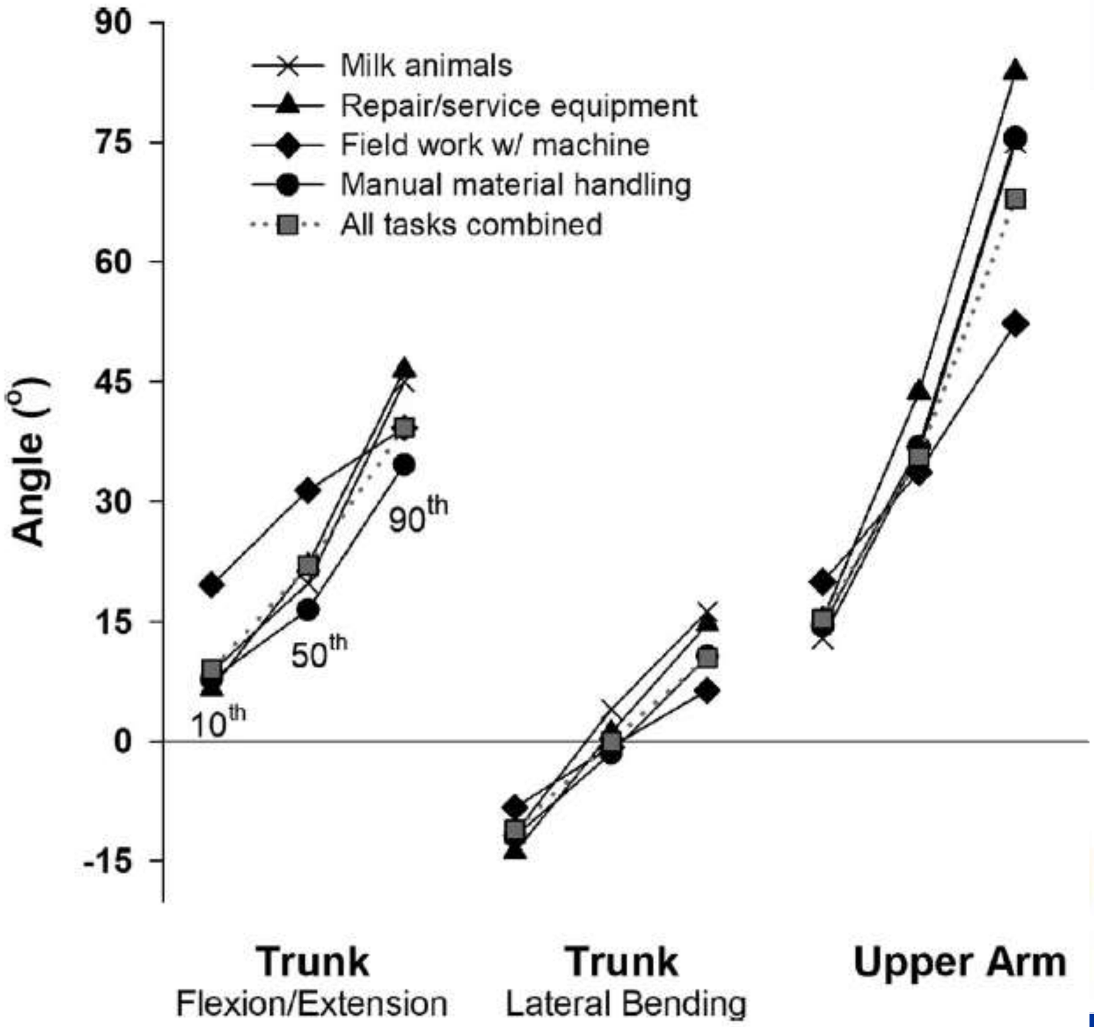
- **Instrumentation and data processing: Muscular loading EMG signals were recorded from the dominant side forearm flexors, forearm extensors, and upper trapezius, as well as bilaterally from the erector spinae (T9 level).**
- **Instrumentation and data processing: Posture and movement Postures and movement speeds of the trunk, dominant upper arm, and dominant wrist were estimated using inertial measurement units (IMUs)**

Table 1. Classification of common agricultural activities.

Activity classification	Example from on-farm data collection
Field work with a self-powered machine	Using a combine to harvest grain
Repair/service equipment	Servicing hydraulic system of a tractor in a machine shed
Repair/service buildings or structures	Repairing a fence using manual tools
Handle/store harvested crops	Using an auger to transfer grain from a storage bin to a truck
Manual material handling	Lifting bags of fertilizer from a pallet to a storage rack
Powered material handling	Using an end-loader to transfer feed into a mixer
Feed animals	Dispersing feed to chickens by hand from a bucket
Move/load/sort animals	Moving (herding) hogs from barn to pasture
Treat/tag animals	Applying salve to treat wounds on cows
Milk animals	Manually prepping cows for milking and attaching milking units
Paperwork/office	Downloading data to computer and examining



Normalized Activity (%RVE)
250
225
200
175
150
125
100
75
50
25
0
Milk animals
Repair/service equipment
Field work w/ machine
Manual material handling
All tasks combined
10th
50th
90th
Erector Spinae Left
Erector Spinae Right
Upper Trapezius
Forearm Flexors
Forearm Extensors



90
75
60
45
30
15
0
-15
Angle (°)
Milk animals
Repair/service equipment
Field work w/ machine
Manual material handling
All tasks combined
10th
50th
90th
Trunk
Flexion/Extension
Trunk
Lateral Bending
Upper Arm

- field work with a self-powered machine generally required lower muscular loads and lower peak kinematic loading in comparison to most other activities, indicating a potential advantage of mechanization but at a cost of greater static kinematic characteristics and, implicitly, increased exposure to whole-body vibration

- Overall, the substantial variability in biomechanical loading between and within agricultural activities indicates a need for sampling strategies designed to more fully capture the temporal patterns of farm work.

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Review

Wearable Monitoring Devices for Biomechanical Risk Assessment at Work: Current Status and Future Challenges—A Systematic Review

Alberto Ranavolo [1,*], Francesco Draicchio [1], Tiwana Varrecchia [2], Alessio Silvetti [1] and Sergio Iavicoli [1]

1 Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, INAIL, Via Fontana Candida 1, Monte Porzio Catone, 00078 Rome, Italy; f.draicchio@inail.it (F.D.); al.silvetti@inail.it (A.S.); s.iavicoli@inail.it (S.I.)

2 Department of Engineering, Roma TRE University, Via Vito Volterra 62, 00146 Rome, Italy; tiwana.varrecchia@uniroma3.it

* Correspondence: a.ranavolo@inail.it

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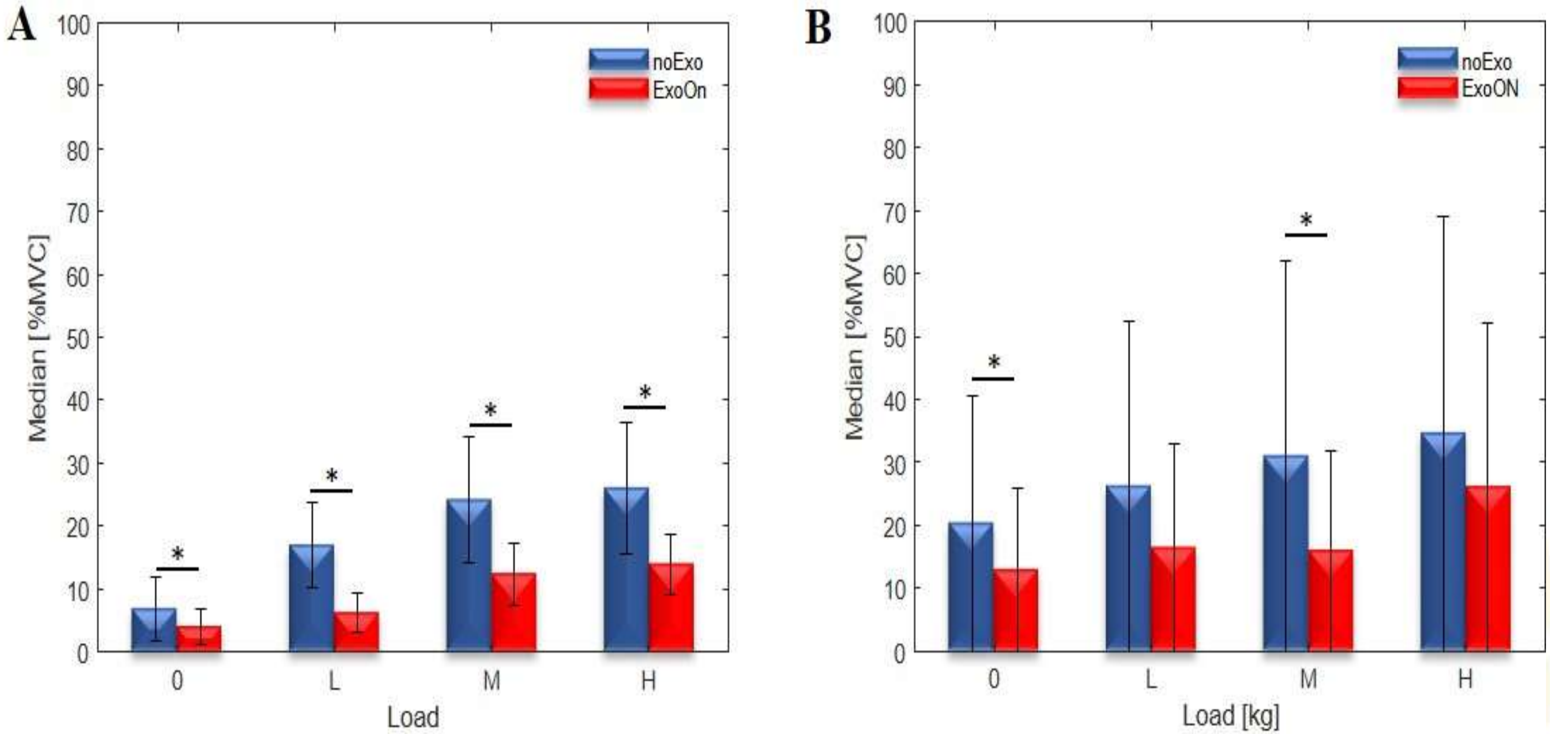
wearable technologies may improve the biomechanical risk assessment

- standardized methods commonly used for biomechanical risk assessment are still mainly based on observational and subjective approaches;
- the presence of the most advanced remotely controlled robot, occupational collaborative robots and wearable trunk and upper-limb exoskeletons will assist more and more workers in performing their tasks reducing their exposure. Are the standardized biomechanical risk assessment methods able to take into account all these new factors?

The histogram blu and red bars represents the mean among all the subjects of the median of the EMG activity with and without the exoskeleton. A and B panels report the results for the ESL with the trunk in upright position and with a trunk bending of 30° respectively

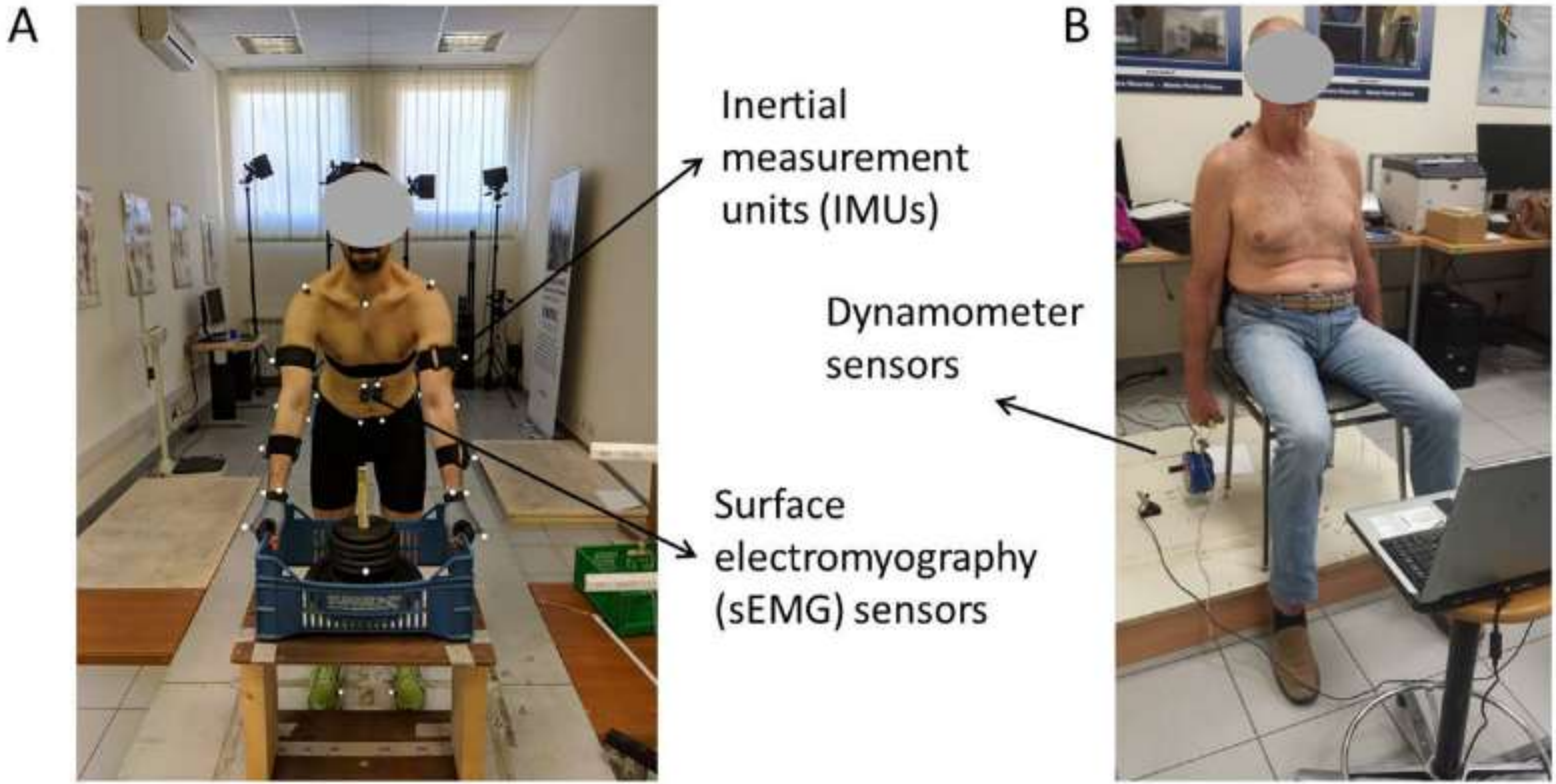


wearable technologies

- innovative wearable technologies and electronic smart devices, without interfering with the work activities performed by workers, have been introduced to improve the biomechanical risk assessment adapting it to all the work conditions and overcoming the limits of the current standardized methods;
- for biomechanical risk assessment wearable wireless sensor networking is still largely underexploited and the state of the art lags dramatically behind the expectations.

wearable technologies

- intelligent work environments may represent the new scenario in which smart wearable sensors with computational capabilities and network connections are sensitive, responsive, adaptive and transparent to workers' movements allowing online, real-time monitoring of work activities (ethics);
- wearabke sensors allow the estimation of biomechanical risk in real-time and could provide a direct feedback to the end-user who would be constantly monitored directly at work.


A
B
Inertial measurement units (IMUs)
Dynamometer sensors
Surface electromyography (sEMG) sensors

Inertial Measurement Units (IMUs)

- measure of orientation, position, velocity and accelerations of each investigated segment and whole body posture;
- usually three orthogonal accelerometers and three orthogonal gyroscopes are embedded within the probe to measure linear acceleration and angular velocity. Angular displacements are obtained from numerical integration of the angular velocity while linear velocity and displacement are estimated from first and second numerical integration of linear accelerations. IMUs can also embed tri-axial magnetic sensors although their use turns out to be more critical in the workplace in presence of electromagnetic fields.


Exoskeleton Support
LOAD (kg)
6
SHOULDER MOMENT
L
0
0:00:00
EXO
18 Nm
14 Nm
ARM ELEVATION
L
5
0:03:19
38°
DIN EN 1005-4
ARM ELEVATION
R
4
0:02:76
36°
DIN EN 1005-4
SHOULDER MOMENT
R
0
0:00:00
EXO
18 Nm
14 Nm

Hand-Held Dynamometers and Grip Force Sensors

- **placed between a fixed place and the subject's body part to assess the isometric muscle (or muscle group) strength;**
- **reliable, easy to use, portable, inexpensive and compact if compared with isokinetic systems;**
- **the measure of the grip force is also provided by instrumented gloves (i.e., equipped by force sensitive resistors) or by force sensor mats applied to handles.**

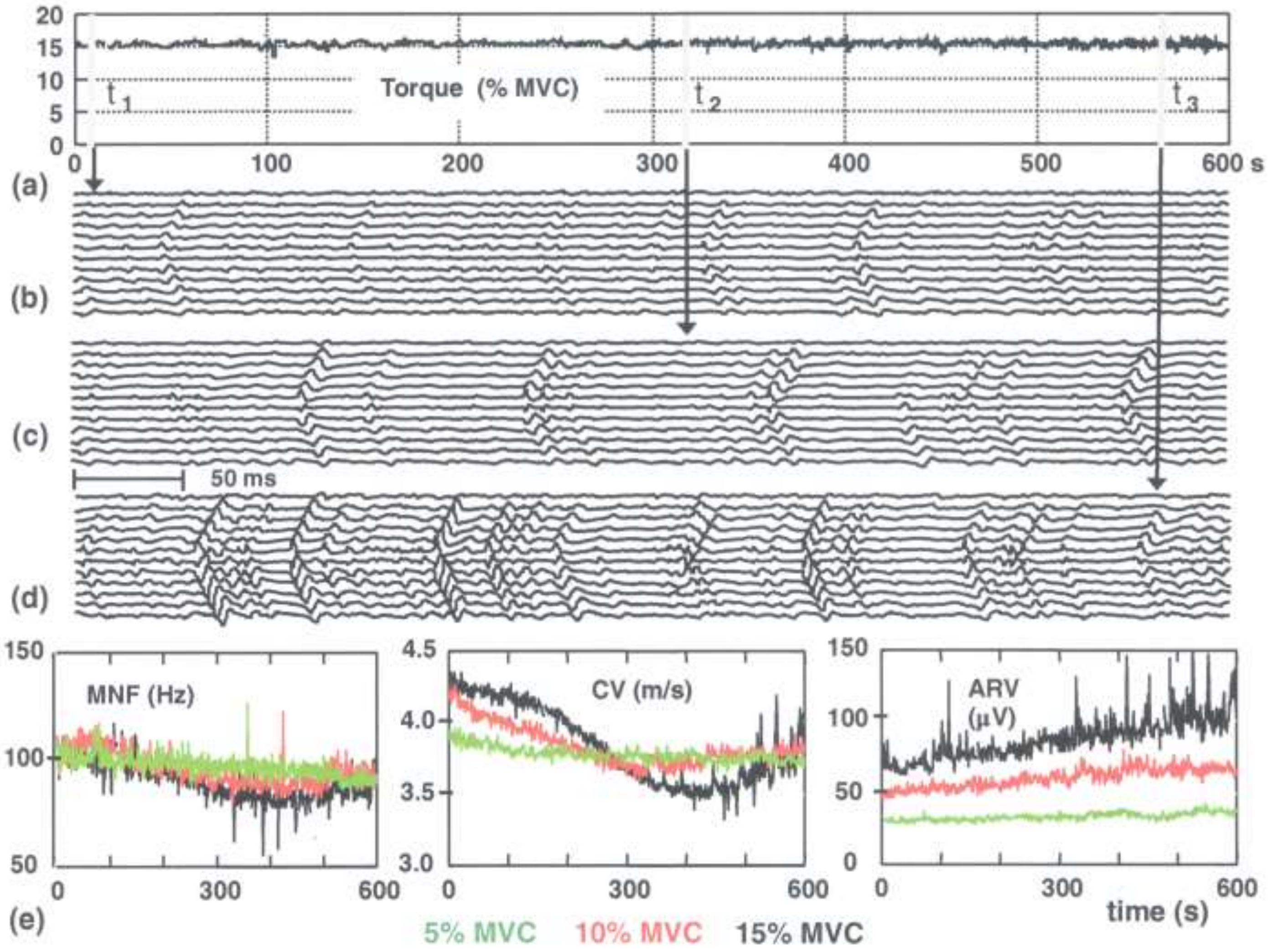
- **role of hand-held dynamometers devices, is to measure the normal and shear forces created between fingers and handles;**
- **in clinical settings to assess muscle integrity to determine the level of any strength deficits associated to clinical physical examination tests (i.e., the diagnosis of shoulder pain).**

sEMG

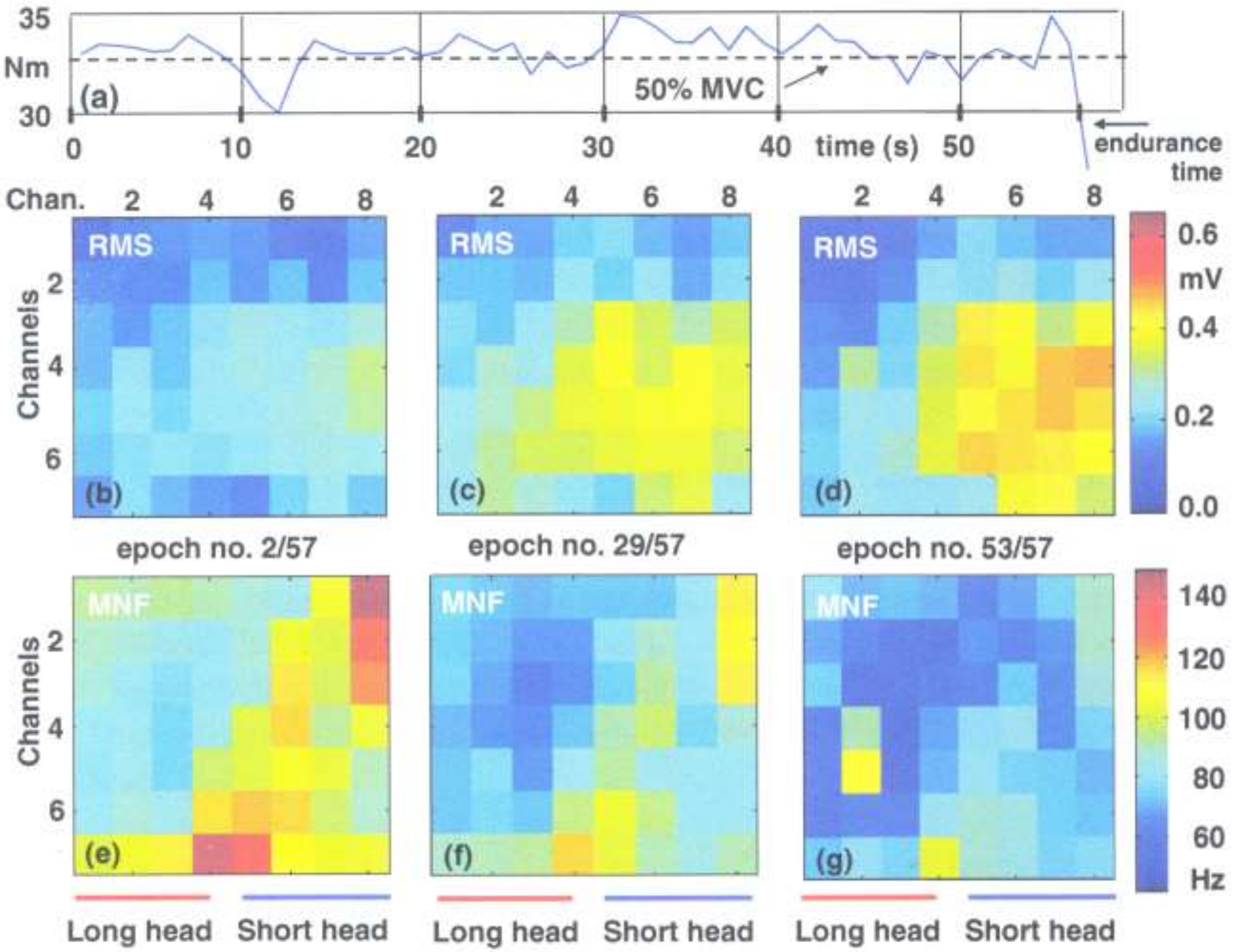
- surface electromyography (sEMG) sensors allow a detailed estimation of muscle behaviors without interfering with the typical movements performed by workers in the workplace.

sEMG

- electrical activity of the muscles. Single- or double differential bipolar sEMG performed by using wet electrodes is widely and easily used in ergonomics for research activities and directly at the workplace;
- the “activation timing”, the amplitude (maximum values, average rectified values or ARVs, root mean square or RMS) and co-activations;
- local muscle fatigue can be estimated by measuring the decrease in the fiber conduction velocity which imply a scaling of the sEMG signal power density towards the lower frequencies and an increase of amplitude;
- multi-channel sEMG performed by means of linear and two-dimensional electrodes arrays (high-density sEMG) allows the estimation of the motor unit action potential analysis, of the myoelectric manifestation of muscle fatigue and the analysis of the instantaneous potential maps.

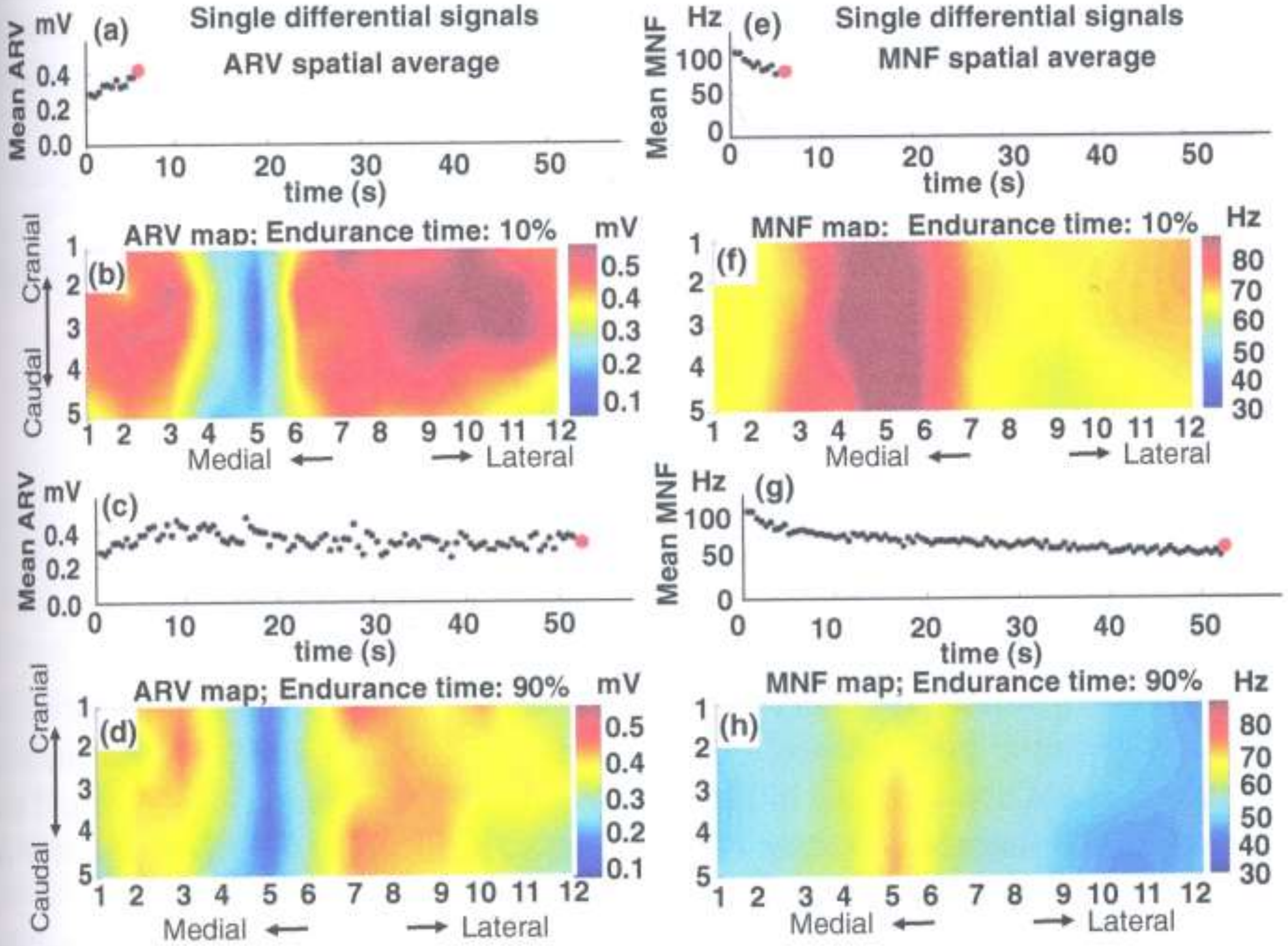


Torque (% MVC)
t1
t2
t3
0
100
200
300
400
500
600 s
20
15
10
5
0
(a)
(b)
(c)
50 ms
(d)
150
100
50
MNF (Hz)
0
300
600
4.5
4.0
3.5
3.0
CV (m/s)
150
100
50
0
ARV (µV)
time (s)
(e)
5% MVC
10% MVC
15% MVC



Contrazione isometrica del flessore del gomito da una matrice di 8x8
Isometric constant torque to the endurance time

b, c e d progressive increase of RMS particolarmente nella regione del **capo breve**



Trapezio superiore
Mappe di ARV e MNF in epoche di 0.5 sec durante una contrazione isometrica al 50% fino all'endurance
Grid 13x5
IED 8 mm

Cabeças, J.M. The risk of distal upper limb disorder in cleaners: A modified application of the strain index method. Int. J. Ind. Ergon. 2007, 37, 563–571

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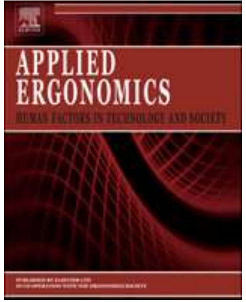
- **Cabeças used sEMG to compute the SI score. The author concluded that, once appropriate trigger levels for the muscular activation are defined, sEMG is a valid alternative to visual inspection in SI computation. This is true in particular when efforts are not clearly associated to hand/wrist movements and when non-cyclical high-frequency activities are assessed.**

Vignais, N.; Miezal, M.; Bleser, G.; Mura, K.; Gorecky, D.; Marin, F. Innovative system for real-time ergonomic feedback in industrial manufacturing. Appl. Ergon. 2013, 44, 566–574



- **The sensor network was composed by IMUs and goniometers and the body posture (joint angles) was assessed by using a ten rigid segment, twenty degrees of freedom biomechanical model. IMUs were placed bilaterally on the upper arm and forearms, on the head, trunk (on the chest) and pelvis (on the sacrum). Goniometers were placed on the hands and forearms to measure wrist motions. Angle values were used as input within the Rapid Upper Limb Assessment (RULA) method, whose global and local scores were continuously computed by a mobile processing unit (a standard laptop) and fed back to the user via a see-through head-mounted display.**

Ranavolo, A.; Mari, S.; Conte, C.; Serrao, M.; Silvetti, A.; Iavicoli, S.; Draicchio, F. A new muscle co-activation index for biomechanical load evaluation in work activities. Ergonomics 2015, 58, 966–979.

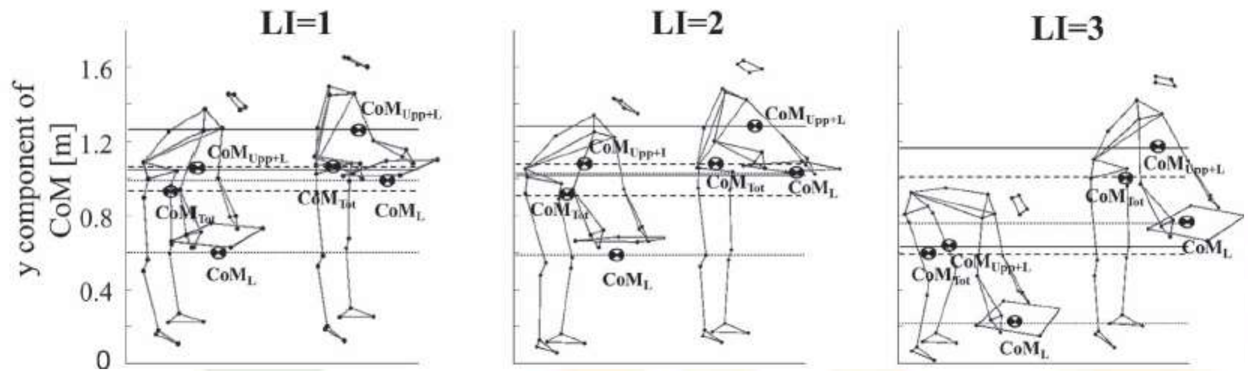
- **calculate the simultaneous activation of trunk muscles is the time-varying multi-muscle co-activation index (TMCi) which includes a sigmoid-weighting factor dependent on relative differences between muscles that do not rely on a priori definitions of agonist or antagonist behavior;**
- **it has been shown that heavier lifting conditions resulted in higher TMCi values and that significant correlations exist between the TMCi and other agonist–antagonist methods.**

Peppoloni, L.; Filippeschi, A.; Ruffaldi, E.; Avizzano, C.A. (WMSDs issue) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts. Int. J. Ind. Ergon. 2016, 52, 1–11.

- **real-time body sensors network composed by IMUs and sEMG sensors has also been used in real-time to monitor workers by measuring muscular efforts and postures (upper limbs have been modeled as a 7-DoF kinematic chain) for WMSD prevention according to the RULA index and the Strain Index. An interesting index considered for this tool is the percentage of time spent in every RULA score range by every worker, considering the whole experiment duration.**

Ranavolo, A.; Varrecchia, T.; Rinaldi, M.; Silvetti, A.; Serrao, M.; Conforto, S.; Draicchio, F. Mechanical lifting energy consumption in work activities designed by means of the “revised NIOSH lifting equation”. Ind. Health 2017, 55, 444–454

- Kinematic data allowed the calculation of a mechanical lifting energy consumption (LEC) index which proved to be significantly growing with the NIOSH LI, discriminating all the risk condition pairs and well correlating with compression and shear forces that determine injuries at the L5-S1 joint. The findings of this study suggest a potential use of IMUs-based lifting tools in indoor and outdoor work environments for risk estima



Brandt, M.; Madeleine, P.; Samani, A.; Jakobsen, M.D.; Skals, S.; Vinstrup, J.; Andersen, L.L. Accuracy of identification of low or high risk lifting during standardized lifting situations. Ergonomics 2018, 61, 710–719.

- IMUs and sEMG sensors have been used to monitor trunk inclination and trapezius and erector spinae muscle activity during the execution of several types of lifting tasks with different weights, horizontal distance and technique executed by male office workers;
- the method allows the automatic identification of the risk levels associated with the lifting activities by a feature vector composed of either the 90th, 95th or 99th percentile of sEMG activity level and trunk inclinations during the task;
- instrumental approach based on subject-specific thresholds.

Le, P.; Aurand, A.;Walter, B.A.; Best, T.M.; Khan, S.N.; Mendel, E.; Marras,W.S. Development of a lumbar EMG-based coactivation index for the assessment of complex dynamic tasks. Ergonomics 2018, 61, 381–389.

- sEMG has been used to develop a sEMG-based multi-muscle coactivation index that resulted usable to continuously assess the neuromuscular effort and resulted significantly sensitive to several factors. In particular the higher the speed, complexity of the motion, the higher the coactivation index value is. Also, in this case this simple approach has been proposed to be used for ergonomic assessments.

Varrecchia, T.; De Marchis, C.; Rinaldi, M.; Draicchio, F.; Serrao, M.; Schmid, M.; Conforto, S.; Ranavolo, A. Lifting activity assessment using surface electromyographic features and neural networks. Int. J. Ind. Ergon. 2018, 66, 1–9.

- sEMG features (i.e., max, ARV, mean and median frequencies) from the trunk muscles were used as input variables of artificial neural network for the prediction of risk levels;
- sEMG time and frequency are significantly related to lifting index for specific trunk muscles. A tool based on these machine-learning techniques and sEMG feature, choosing a proper combinations of input features and a right network architecture, can lead to an improved biomechanical risk classification;
- to implement the integrated approach on electronic smart devices (smartphones, phablets, tablets and smartwatches) would allow a simplified analysis of biomechanical risk at workplace.

discussion

- instrumental-based tool will play an increasingly important role in both direct evaluations and in the rating of standard methods, also considering that several factors implying work-related musculoskeletal disorders interact at the same time;
- therefore, it will be crucial to monitor all of them by using more than one method at the same time ensuring a more thorough evaluation of risk factors;
- on the other hand, a lot of attention must be paid because the use of more than one method can rapidly lead to unacceptably high costs for the practitioner, both from a time and money viewpoint.

two promising indices/approaches proposed in literature for manual lifting

1. the multi-muscle coactivation index;
2. machine-learning techniques based on sEMG;

- the literature shows that the fatigue indices need further elaboration (fatigue indices are used when the assessment is performed by using fatigue estimation before and after the work activity).

IMUs

- a high number of units is required for whole-body bio-mechanical studies in ergonomics, a high data transfer time could be required with both the Wi-Fi and Bluetooth protocols;
- IMUs fail to precisely measure translational motion and suffer from drift;
- IMUs can fail in the presence of magnetic fields in the workplace if they have embedded magnetic sensors.

sEMG main critical factors

- crosstalk muscle signals;
- electrode–skin impedance;
- noise;
- problems related to the electrode location, size, configuration and distance.

- the use of these new innovative technologies for biomechanical risk assessment is only at its initial stage;
- rigorous laboratory and epidemiologic studies, independent research groups and transparent review processes are needed;
- the huge knowledge that will derive from its experimentation will allow the optimization of the current standardized methods or the developments of the new ones.