Angelo Mosso and muscular fatigue: 116 years after the first congress of physiologists: IUPS commemoration

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Di Giulio, Camillo, Franca Daniele, and Charles M. Tipton. Angelo Mosso and muscular fatigue: 116 years after the first congress of physiologists: IUPS commemoration. Adv Physiol Educ 30: 51–57, 2006; doi:10.1152/advan.00041.2005.—At the first International Congress of Physiologists in Basel, Switzerland, the Italian physiologist Angelo Mosso (1846–1910) discussed his findings on muscular fatigue while demonstrating the functioning of an ergograph (work recorder). One hundred sixteen years later, Mosso’s career, scientific accomplishments, and legacy in the study of muscular fatigue were commemorated at the 2005 International Congress of Physiological Sciences. After receiving his degree in Medicine and Surgery from Turin, Italy, in 1870, Mosso was able to study and interact with renowned physiologists as Wilhelm Ludwig, Du Bois-Reymond, Hugo Kronecker, and Etienne Marey. By 1879, he was Professor of Physiology at the University in Turin, where he conducted research pertaining to blood circulation, respiration, physical education, high-altitude physiology, and muscular fatigue. Using tracings from the ergograph (concentric contractions of the flexor muscles of the middle finger that were volitionally or electrically stimulated), he was able to characterize muscle fatigue and to associate its occurrence with central or peripheral influences. He demonstrated that exercise would increase muscular strength and endurance while prolonging the occurrence of fatigue, which he postulated was a chemical process that involved the production of toxic substances such as carbonic acid. The phenomenon of contracture was described, and his collective studies led to the formulation of laws pertaining to exhaustion and to the 1891 publication of La Fatica (Fatigue). Besides La Fatica, Mosso will be remembered as a scientist with a love for physiology, a concern for the social welfare of his countrymen, and as one who sought to integrate physiological, philosophical, and psychological concepts in his experimental studies.

ergograph; physiology; history of physiology; International Union of Physiological Sciences

ANGELO MOSSO [1846–1910 (Fig. 1)] was born in Turin, Italy, on May 30th, 1846, and raised at Chieri, within the province of Turin, during the years after the Unification of Italy (1861). Because of family financial difficulties, he spent many of his childhood and schooling years working with his father, from whom he inherited his manual dexterity while acquiring a passion for constructing instruments (2–4). In 1864, he entered the School of Medicine at the University in Turin, and, 6 years later, he received a degree in Medicine and Surgery “Magna cum Laude.” Subsequently, he was appointed as Medical Official for Firenze, Napoli, Salerno, and Messina in Italy. By 1873, he had moved to Florence, to be in the Laboratory of Physiology of Prof. Moritz Shiff, where he remained for 2 years. He then spent 2 years in Leipzig, Germany, at the Institute of Physiology, which was directed by Prof. Carl Frederick Wilhelm Ludwig (1816–1895), who was studying respiratory gasses and the graphical recordings of respiration. Ludwig suggested to Mosso that he study “kidneys isolated from the body,” from which he had the idea of constructing a plethysmograph for studying volume modifications of organs. At that time, Ludwig was also working on the kymograph, and he donated to Mosso some of his tracings obtained while recording limb volume variations. These aspects stimulated Mosso to assess volume changes in organs (15) using kymographic tracings. Later, Mosso went to Berlin to meet with Emil H. Du Bois-Reymond (1818–1896) and Ernst W. Von Brucke (1819–1892), who had been students of Johannes Muller (1801–1858). Mosso emerged from this meeting with the belief that “With the graphical method the palpitation of the heart, the breathlessness of the breath, the tremor of the muscles, the velocity of the blood, the perception they leave of themselves are indelible traces” (3). Before returning to Italy, he visited and discussed his research ideas with French scientists as Claude Bernard (1813–1878), Charles Brown-Sequard (1818–1894), J. B. Augusie Chauveau (1837–1917), Louise-Antoine Ranvier (1835–1922), and Etienne-Jules Marey (1830–1904), with whom he became close friends. Marey, a student of Claude Bernard and a Professor of Natural History at the College de France, was an expert on graphical methods and photographic techniques who had pioneered cinematography (48) and constructed a series of scientific instruments such as the sphygmomanometer, pneumotacograph, cardiograph, and myograph, which used a stylus writing on a smoked drum to record physiological responses. In 1870, when Mosso assumed his duties as a Medical Officer, he used graphical recording whenever possible to quantify the measurements of soldiers that pertained to heart rate, blood pressure, respiratory rate, and temperature responses. When he showed the tracings obtained from marching soldiers to Queen Margherita of Savoy and King Umberto, he is reported to have stated “when I started studying fatigue I could not imagine that I would have had the honour to speak about my research to your majesties” (18).

In 1875 in Turin, Mosso was appointed Professor of Pharmacology and became active in the reorganization of the academic world in Italy. In those years, Alexander Von Humboldt taught in Bologna and Jacob Moleshott became Director of the Institute of Physiology in Turin. The year 1879 was a notable one for Mosso, as he became a member of the Academy of the Lincei, married Maria Treves, and was appointed Professor of Physiology (at the age of 33 years) to replace Moleshott, who had resigned to accept an appointment in

During his anniversary lecture at the University of Turin, Mosso stated that “The evolution of mechanics is reducing man’s muscular work, which improves, while sparing strength, the abundance and the effectiveness of intellectual work;” he indicated that “mechanical machines” (42) could increase the intellectual needs of individuals because they reduced the amount of time devoted to physical work.

In 1883, he published a text entitled La Paura (Fear), which incorporated physiological explanations for psychological reactions (26). Psychologists like Agostino Gemelli and Mario Ponzo were attracted to the Institute of Physiology to study with him. During this time, Mosso became active in organizing physiology in Italy and conducted the research that was included in the publication La Fatica in 1891 (Fig. 2). Collectively, this enhanced his national status and subsequently brought him international acclaim. As previously mentioned, in 1889, he participated in the First International Congress of Physiologists held in Basel, Switzerland (6, 44). By 1901, he was elected to be president of the Fifth International Congress in Turin, proposed the establishment of an International Physiological Laboratory on Monte Rosa in Italy to study high-altitude physiology, and was successful in having a resolution passed by the Congress that efforts be made for the teaching and research of experimental psychology in those universities where it did not yet exist (6). Physiologists in attendance at the Turin Congress included Bowditch, Blix, Brucke, Chauveau, Du Bois-Reymond, Flechsig, Foster, Golgi, Helmholtz, Einthoven, Langley, Ludwig, Lowey, Marey, Mueller, Waller, and Zuntz (2, 6). Mosso’s interest in high-altitude physiology was highlighted by the publication in 1897 of the text entitled Fisiologia dell’uomo Sulle Alpi [The Physiology of Man on the Alps (16)]. His friendship with Quintino Sella (42), a “gentleman” of politics and science, while founder of the Italian Alpine Club, was instrumental for his studies on climbers’ fatigue and for the construction of the “hut” of the Italian Alpine Club on the Gnifetti summit of Mount Rosa, which contained a scientific laboratory for respiratory investigations. It was located at 4,560 m and was named “Capanna Margherita” after Queen Margherita, who was an enthusiastic mountaineer and ardent supporter of the laboratory. She is also remembered by bringing her two dogs to the inaugural ceremony of the Capanna in 1893. Besides the King of Italy, the laboratory was supported by the Ministry of Public Education and the Italian Alpine Club.

In 1904, Mosso became Senator of the Reign of Italy to facilitate his ideas becoming state laws. Later that year, construction of a laboratory began near the Col D’Olen (Monte Rosa) at a height of 2,901 m near a lake that later became known as “Bowditch” (9). The laboratory was completed within 3 years and became identified with advanced biological, medical, meteorological, and geophysical research activities (2, 3). At the Seventh International Congress of Physiologists (1904) in Brussels, Belgium, Mosso presented the research...
findings from the “Laboratories of Physiology of the Monte Rosa” pertaining to muscular fatigue and to the respiratory changes found with the pneumatic bell or on the mountains. On that occasion, the Col D’Olen Building was dedicated to Mosso as a “Leader in Alpine Physiology” (4, 12). Unfortunately, in July 2000, a fire caused by a lightning strike destroyed the building. Currently, projects exist to transform this site into a museum.

In 1905, Mosso authored the Vita Moderna degli Italiani (Modern Life of Italians) and dedicated it to his daughter with the inscription “. . .To my daughter so that she could learn about her Country and how to love the poor” (19). By that time, he had become regarded as an apostle for sport (5, 31) and an authority on fatigue; hence, he was invited to speak at the Olympic Games and is quoted to have said “. . .in the muscle resistance to fatigue lies most of the future richness of our Country” (5).

During the latter years of his life (1907–1910), Mosso carried out archaeological research in Crete to quantify and correlate anthropometrical data associated with the Escursioni nel Mediterraneo e gli Scavi di Creta (Origin of Mediterranean Civilization) (17). He also participated in excavations in Southern Italy, i.e., in Sicily, Lazio (Tarquinia), and Puglia (Molfetta, Terlizzi, Manfredonia, and Bisceglie), where he discovered underground dolmens and collected ceramics and pottery from ancient cities.

Mosso died on November 24th, 1910, at 64 years of age. He is remembered as an outstanding physiologist and humanitarian, a tireless man, and as an operaio individual who was dedicated to the physical and spiritual well-being of people. He is also remembered as a champion for physical education who advocated a Health in a Healthy Body) (41). It is fitting that the City of Chieri dedicated to him a school and a square that contains the inscription “To Angelo Mosso Physiologist and Archaeologist 1846–1910” (10).

The Legacy of Mosso

Background. The legacy of Mosso began and continues with La Fatica (Fig. 2); however, it was written from the perspective of a scientist whose observations on the social injustices accorded to the common laborer led to the conviction that physiology should strive to improve the lives of humans. He was distressed by the detrimental effects of work on the bodies of children, sulphur miners, and Sicilian farmers and by the physical changes experienced by immigrants seeking work in the United States. Some authors (4, 19) have attributed Mosso’s interest in fatigue to his modest origins as the son of a carpenter and to the poverty experienced during his childhood and youth. In fact, he associated his background with that of Johannes P. Muller when he stated “Muller had come out of a dark shoemaker’s shop” (42). Certainly, Mosso was influenced by the historical period, since during the second half of the 19th century, social development became an objective for scientific research, and topics related to the “richness of the worker’s community” or to the “labourer’s work” were studied. During this time, Italy was an agrarian society that was experiencing a transformation into an industrial one while facing the problems created by poverty, illiteracy, infant mortality, and disease. In fact, he felt that the high infant mortality of the poor was due to the chronic fatigue state of the pregnant workers. While work and its manifestations had became a major concern for Italian society, it created intense social conflicts as demonstrated by workers “fighting” to have their working day reduced to 8 h. Moreover, work became the theme of the sociocultural debates of the era and became included as a subject for scientific research. The large number of accidents at work sites (~2.5 million at the turn of the century), presumably because of fatigue, heightened Mosso’s interest in this subject. This also interested Pope Leone XIII when he addressed the topics of rest, tiredness, human dignity, and physiology in his Encyclical entitled De Rerum Novarum. The Pope stated that “Such rest is necessary for the worker and it has to be proportional to the sum of the strength used” (8).

Mosso was also influenced by his experiences as a Medical Officer in examining men for duty in the military and from examining children who worked in mines. He felt that many men were unacceptable for service because of fatigue-induced physical limitations and that “Young boys and girls less then 11 years of age cannot be employed in underground night and unhealthy works, and daily work for boys aged 9 to 11 years cannot last more than 8 hours” (45). Thus he associated the reduced growth and developmental rates of poor children to the long hours of working in unhealthy conditions.

Finally, because of his public concern for the welfare of the working class, it was no coincidence that the publication of La Fatica occurred on May 1st, 1891, which was the second anniversary of Labor Day.

Features of La Fatica. Mosso was intrigued by the distances flown by migratory birds (quails, swallows, cranes, and storks) and the magnitude of fatigue (tiredness) they exhibited after arriving from Africa. This led him to establish a station for carrier pigeons in his laboratory, which he maintained for 12 years. From his studies with pigeons, Mosso concluded that aging would be associated with decreases in oxygen consumption and in resistance to muscular fatigue. Mosso’s interest in the use of animal models was stimulated by the publication of De Motu Animalium by the Napolitan Giovanni Alfonso Borrelli (1608–1679), who attributed heat production to the friction of blood against vessel walls and linked muscular fatigue to nerves (1). Mosso knew Muller had measured nerve conduction and that Helmholtz had determined that the nervous “agent” could travel 30 m/min. Moreover, he had perfected a myograph, which was used to record frog muscle responses. Mosso was aware of the results of Niels Stensen [1638–1682 (known as Stenone to Mosso)], who had demonstrated that muscles could contract after nerve sectioning if they received direct stimulation. With a stylus and a drum smoked myograph (kymograph), it was possible to obtain tracings that could differentiate a single stimulus from a muscle contraction. Mosso was impressed by this capability and stated that “The graphical method reproduces the particular minutes of movement and it evidences phenomena that otherwise would have remained unknown and confused” (15). In addition, Marey was able to use this new graphical method to determine the “latent excitation time” (35), which represented the time interval between the electrical stimulus and the onset of a contraction. Mosso realized the differences between the traces recorded on frogs and those recorded on dogs and the higher complexity of the same phenomena observed in humans. Indeed, almost all researchers of that time had performed experiments on frog
muscles removed from the body. However, normal muscle function could not be reproduced in frogs, and thus mechanical work in humans could not be imitated. From muscle tracings, Mosso observed that the onset of fatigue could be determined, that the work performed could be measured, and that fatigued muscles remained contracted longer, thus exhibiting longer ascending and descending phase durations.

Motivated by Hugo Kronecker’s studies on muscular fatigue with isolated muscles from experimental animals and convinced that the error of measurement was too great with the use of dynamometers, Mosso “sought to construct an instrument which would measure exactly the mechanical work of the muscles of man and the changes which, as the effects of fatigue, may be produced during the work of the muscles themselves” (38). In addition, he wanted a unit that could record more than the effects of isometric contractions. Consequently, he developed the ergograph (work recorder), which was designed to record and quantify the concentric contractions performed by the flexor muscles of the index finger. It consisted of two parts: one that stabilized the hand and was ~50 cm long and 17 cm wide and one that recorded the contractions. The muscles were isolated by fixing the hand with two brass tubes through an internal lumen between 18 and 22 mm depending on the circumference of the subject’s finger (Fig. 3). The index and ring fingers of the right hand were introduced in the lumen while the second phalange of the middle finger was inserted within a leather ring tied to a gut-like wire (similar to the ones used for violoncellos) passing through a pulley. At the end, a 3- to 4-kg weight was attached. The stylus recorded the degree of flexion of the middle finger on a cylinder rotating following the rhythm of a simple pendulum or metronome (Fig. 4). The smoked paper turned slowly following a clock and recorded the fatigue profile of the experimental subject. Mosso found that each individual had a different fatigue profile depending on the test conditions and reported that the “Ergograph through its ergograms furnishes us the writing of the most intimate of the characteristics of an individual and how some resist to work and how others stop suddenly, in other words the way we get fatigued” (38). Mosso’s favorite experimental subjects were Prof. Aducco and Dr. Maggiora, who performed various fatigue tests for 7 years. In fact, the ergographic tracing of muscular fatigue shown in Fig. 5C has become a “classic”; it is located on the cover of Exercise Physiology: People and Ideas (46) and was obtained...
from Prof. Aducco in 1884. Mosso demonstrated that each individual exhibited typical fatigue curves after a voluntary muscular contraction as well as after an electrical stimulation of the median nerve. In addition, he compared and contrasted his fatigue results with changes in atmospheric pressure, environmental temperature, time of day, nutritional status of the subject, and with the administration of substrate (glucose) during the recovery process.

Although Kronecker in 1870 had demonstrated the phenomenon of contracture in frogs, Mosso was the first to demonstrate its occurrence in humans. After defining it as a contracted muscle that was unable to completely relax, he attributed the condition to a combination of reduced blood flow and a change in neural excitability. He described the phenomenon of contracture after muscle fatigue and compared it with a rheumatic torcicollis or cramp of the writer or of violin or piano players. He said that “The same hysterical or nervous persons that abuse of physical activity is so excitable that only four minutes are enough for them to produce contracture. In hysterical individuals a light compression of muscle is enough for contracture, a waxy flexibility” (20).

At the time when Mosso was conducting his investigations, the prevailing theories concerning the causes of muscular fatigue pertained to a lack of oxygen [associated with Antoine Lavoisier (1743–1794)] and to the presence of poisons [attributed to Edward Pflügler (1829–1910) and Nathan Zuntz (1847–1920)]. Mosso noted early in his studies that washing a fatigued frog muscle with saline reduced “tiredness,” presumably by removing an “X factor of tiredness.” Subsequent studies showed that muscular fatigue is a chemical process involving, rather than the lack of oxygen, the production of toxic substances, among which is carbon dioxide. Indeed, Mosso stated that “The working muscle produces toxic substances that a little bit at a time block the muscle from contracting itself” (20). This was reinforced by an experiment in which he fatigued the muscles of an anesthetized dog by tetanic stimulation before removing blood and injecting it into a nonfatigued dog and observing the cardiac and respiratory responses in this latter animal. Moreover, Mosso was aware that Du Bois-Reymond had shown that muscles became acid with increased muscle activity. Maggiora, after conducting fatigue experiments in Mosso’s laboratory, concluded in 1888 that “work done by a muscle already fatigued acts on that muscle in a more harmful manner than a heavier task performed under normal conditions” (13). This conclusion influenced Mosso to reflect on the roles of the central and peripheral nervous systems in the occurrence of fatigue and to formulate the laws of exhaustion (18). Collectively, they were as follows:

1. Muscle overwork should be considered as a peripheral phenomenon that is independent of will and of the nervous system.
2. Fatigue should be considered as a form of “poisoning” due to the production of waste material that blood flow and increased ventilation tend to remove.
3. The presence of carbonic and lactic acids prevents and reduces muscle contraction.
4. Fatigue reduces the sensitivity of muscles.
5. Fatigue reduces body sensitivity.
6. Fatigue represents the alarm signal for muscles and gives them the time to recover the loss of energy after strenuous contractions.

In the discussions pertaining to the Law of Exhaustion (18), Mosso made it evident that fatigue had a central (the will) as well as a peripheral (muscular) component. Moreover, because it was possible with the ergograph to demonstrate muscular fatigue by volitional means (e.g., central, the will, psychic, or mental) as well as by electrical stimulation, Mosso concluded that central fatigue could be distinguished from peripheral fatigue. However, he acknowledged the inherent difficulties in measuring purely central fatigue by reminding readers that “It is not will, not the nerves, but it is the muscle that finds itself worn out after the intense work of the brain.” He also associated peripheral with central fatigue by the statement that the “fatigue of brain reduces the strength of the muscles” (38).

Mosso devoted three chapters of La Fatica to topics involving central or mental fatigue and its interactions with peripheral or muscular fatigue. The chapters were as follows: attention and its physical conditions, intellectual fatigue, and lectures and examinations. When attention was discussed, he cited G. T. Fechner (20) and his psychophysics perspective, which
indicated that the sensation of mental fatigue had different thresholds (39). Hence, with either exhaustive mental or peripheral fatigue, there will always be a change in mood. Mosso felt that if the brain was “fatigued,” it would be impossible to be attentive and the slower reaction times after repeated physical tasks could be due to a change in the “psychic process” rather than to an alteration in the “rapidity of the movement.” The interrelationship between mental and muscular fatigue and its effects on attention (and memory) is highlighted by his experiences as an alpine climber. He stated, “In my own case I have observed that great muscular fatigue takes away all power of attention and weakens the memory. I have made several ascents... (to Monte Viso and Monte Rosa)... yet, I do not recall anything of what I saw on those summits. It seems that the physical conditions of thought and memory become less favorable as the blood is poisoned by the products of fatigue, and the energy of the nervous system consumed” (20).

He discussed the complex features of intellectual fatigue without effectively defining the condition. Mosso did mention that memory, sensations, sensitivity, imagination, consciousness, reasoning, and visual acuity were involved and related their presence to phenomena occurring in muscles after a long walk. Specifically, “when we are tired by prolonged intellectual work, we cannot without great effort take up our task again” (38). Mosso observed the physical characteristics of colleagues associated with lecturing and examinations and noted that extreme nervousness and physical exhaustion were frequent traits. When Mosso measured the body temperature of himself and colleagues before and after lecturing, he found a temperature increase of 0.5°C, which suggested they had acquired a slight “fever.” With an ergograph and Prof. Aducco and Dr. Maggiora as test subjects, he assessed the effects of presenting a lecture in German at an international meeting or a hygiene lecture in Turin. So, Mosso became convinced that the individual differences among subjects must always be considered. To Mosso, the central or mental fatigue associated with lecturing had two inseparable components: intellectual and emotional. These same components were present when Mosso evaluated Prof. Aducco’s tracings after Aducco served as an oral examiner of 16 students. Aducco performed a fatigue test with the ergometer after half the students were evaluated and the ergometer after 5.5 h later, when the evaluations were completed. The tracings revealed decreases in force, frequency of contractions, and in work performed.

Mosso never failed to acknowledge the contributions of others to his research ideas or projects. Eight years before La Fatica was published and after having vested the Laboratory of Professor Hugo Kronecker in Lipsia, Mosso wrote “It is my duty, or even better I am happy to declare that were those experiences that gave birth in me to the desire of applying myself to studying fatigue; the exactness of the method, the elegance of the machinery, the precision of the results were such that could charm any beginner, those experiences remained so impressed in my memory, that were a model that I have constantly followed” (38).

Thus it was no surprise that Mosso dedicated La Fatica to Prof. Kronecker “…with the gratitude of a pupil and the fondness of a friend” (38). By 1936, La Fatica had been republished seven times and translated into German (1892), Russian (1893), French (1894), and English (1904).
gases in the blood” (32). Furthermore, he proposed supplying balloonists (aeronauts) with compressed oxygen containing 8% carbon dioxide (32, 36). He studied the relations between carbon monoxide intoxication and mountain sickness and felt that mountain sickness occurs due to a lack of carbon dioxide (acapnia) and not to a decrease in oxygen availability (38). Unfortunately, this interpretation created a controversy between Mosso and Paul Bert (1833–1886), a former assistant of Claude Bernard. Therefore, he had an iron decompression chamber constructed within his laboratory so he and colleagues could be subjects as they studied the process of air rarefaction. Besides studying the blood circulation of the brain that was described in La Fatica (38), he investigated its temperature changes (30) and dedicated the work to his former teacher, Jacob Moleschott (1822–1893). The inscription stated: “To You who inspired me in the cult of Science and the love for studying, to You who encouraged and supported me, I owe these honors that render me happy and cheerful in life” (20).

Concluding remarks. More than 116 years ago, Angelo Mosso presented his views on muscular fatigue and demonstrated the functioning of an ergometer to scientists attending the First International Congress of Physiologists in Basel, Switzerland. To commemorate the occasion and to explain the legacy of Mosso, we have joined Gandevia (7), Losano (11), McComas (14), Simonson (47), and Zuntz (49) in presenting his findings, characterizing his research, and profiling his life accomplishments during these times.

Hoping that Mosso’s scientific spirit could be shared by and continue across future generations, we dedicate this work to our students so that they know that “no history can be built without history,” and, to our colleagues, we address Mosso’s own words: “The concepts and the ideas that you express, those which you can hear resounding in this room will open your owen words: “The concepts and the ideas that you express, those which you can hear resounding in this room will open

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