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VIDEO ARTICLE

Moving in Late Medieval Harness: Exploration of a Lost Embodied Knowledge

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This video article presents an interdisciplinary approach dealing with the reconstruction of the lost embodied knowledge of wearers of late medieval harnesses. Our research is based on inquiries surrounding material culture (arms and armours and the relevant clothing), as well as studies of the technical literature known as fight books. The hypotheses drawn from these are then compared to results obtained from experiencing and experimenting modern-day enactments of gestures while wearing an accurate replica of a harness. Once the difference between experiencing and experimenting is explained, we outline and discuss selected results from our research processes.

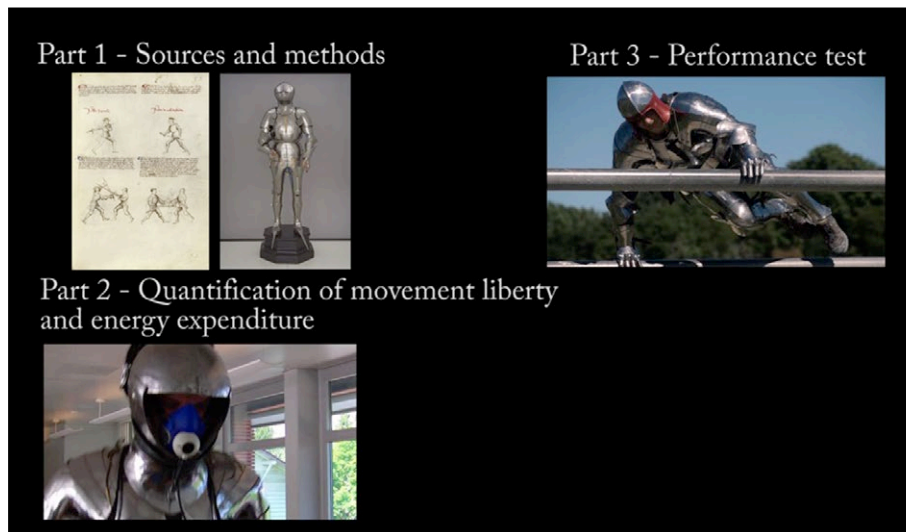
Keywords: martial arts; fight books; historical reconstruction; medieval; armour; experimentation

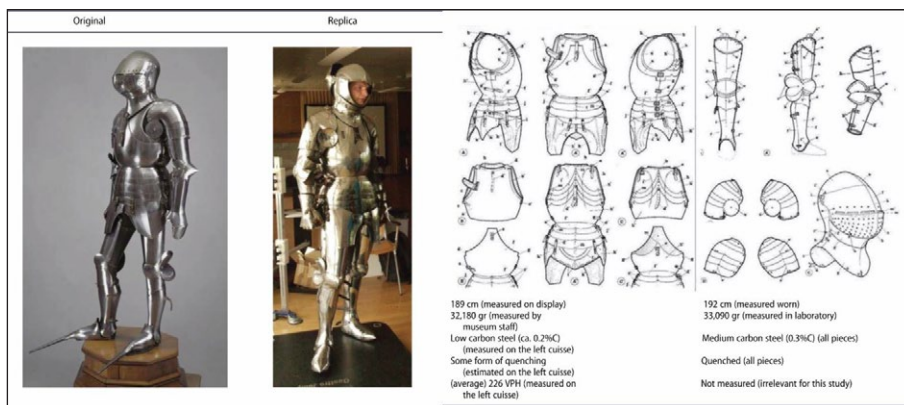
VIDEO ARTICLE

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STILLS FROM THE VIDEO ARTICLE





VIDEO ARTICLE TRANSCRIPT

[00:20]

How well did late medieval armoured fighters move?

[Voice of Daniel Jaquet:]

How well did late medieval armoured fighters move? This question fascinated scholars and amateurs alike.¹ Before even attempting to answer, we, today, have to cut through widespread misconceptions and deal with issues caused

¹ Jaquet, Daniel, *Moving in harness* (Morges, 2016).

by the modern day reception of a fictionalised Middle Ages. As shown by Dirk Breiding and Tobias Capwell² the idea of clumsy warriors encased in steel is a fiction rooted in the Victorian period. Although more known for his successful novel *Tom Sawyer*, Marc Twain wrote in 1889 the novel entitled *A Connecticut Yankee in King Arthur's Court*.³ The strong image of a knight hoisted by a crane on horseback was then invented. It was translated to the screen by the movie industry as early as 1944 as you can see here in the excerpt of the movie *Henry V*.⁴ This is utterly wrong and we intend in this video article to demonstrate why. In order to do so, we rely on research and interdisciplinary approaches dealing with the reconstruction of embodied knowledge.

Our research is based on inquiries on material culture (that is the objects – arms and armours and the clothing), as well as studies on the technical literature known as fight books. These hypotheses drawn from these approaches are then compared to modern-day enactment of gestures, that is experimentation.

How well did late medieval armoured fighters move?

Inquiry into material culture and fight books via experimentation by contemporary enactment

[1:41]

Part 1 – Sources and methods

Part 2 – Quantification of movement liberty and energy expenditure

² Breiding, Dirk H., 'Arms and Armor: A Farewell to Persistent Myths and Misconceptions', in *Perspectives on Medieval Art. Learning through Looking*, ed. by Ena G. Heller and Patricia C. Pongracz (New York: Museum of Biblical Art, 2010), pp. 167–86.

³ Twain, Mark, *A Connecticut Yankee in King Arthur's Court*, (London/New York: Harper & Brothers Publishers, 1889).

⁴ Olivier, Laurence, *The Chronicle History of King Henry the Fifth with his Battle fought at Agincourt in France* (Gaumont Eagle-Lion, 1944).

Part 3 – Performance test

[Jaquet:]

In the first part, we will look into the source material and research methods. In the second part, we will outline a few research results drawn from a study quantifying freedom of movement and energy expenditure caused by wearing armour. In the last part, we show a performance test performed as a tryout and used for scientific mediation in the context of a museum exhibition, and we outline a few data out of the test.

[2:06]

1. Sources and methods

Technical literature

[Jaquet:]

The first fight book preserved dates from the very beginning of the 14th century.⁵ The fight book production intensifies in the 15th and 16th century and lasts until today. It includes various forms, such as manuscripts, prints, and today even video material. You can see an example from the beginning of the 15th century, authored by Fiore dei Liberi.⁶ It uses words and images, whereas other fight books may use one or the other type of media only, text or image. These types of documents form a genre, which belongs to pragmatic literacy or technical literature (*Pragmatische Schriftlichkeit* in German). As argued with colleagues in the recent collective book entitled “Late Medieval and Early Modern Fight Books”,⁷ the fight books form an heterogeneous corpus of manuscripts or prints that would inscribe, describe

⁵ Anonymous, *Liber de arte dimicatoria*, 1305 (Leeds, Royal Armouries, I.33).

⁶ Fiore dei Liberi, *Flower of Battle*, 1410 (Los Angeles, J. Paul Getty Museum, Ms Ludwig XV 13).

⁷ Jaquet, Daniel, Karin Verelst, and Timothy Dawson, eds., *Late Medieval and Early Modern Fight Books: Transmission and Tradition of Martial Arts in Europe (14th–17th Centuries)* (Leiden / Boston: Brill, 2016).

or codify personal fighting techniques as a system of combat often, but not always, involving use of weapons of different sorts.⁸ At the end of the Middle ages, the combat systems are usually broken down as to wrestling, weapon-based systems in civil clothing, weapon based-system in armour on foot, and weapon based-system on horseback.

You can see the example of the fighting techniques in armour on foot with longsword in the treatise of Fiore dei Liberi, here the version kept in Los Angeles, the Getty Museum.⁹ This treatise organises the dialogue between text and images with explicit guidelines and formal signs on the illustration to identify the author of the technique. Even so, it is hard for the 21st century reader to make sense of the fighting techniques, since written documents are not ideal media for the circulation of bodily knowledge. Indeed, bodily techniques are usually transmitted by oral channels, with the classical process of demonstration, imitation and correction. In short, these are not to be considered fighting manuals in the modern sense of the term and the access to the embodied knowledge hidden behind words and images requires a large amount of research and experimentation. This example is one of the many sources investigated in the framework of our research, a list of which is contained in the appendix of our latest article in the *Journal Historical Methods*.¹⁰

[4:20]

⁸ [Several fight books shown as examples:] Anonymous, [Codex Wallerstein, Von Baumanns Fechtbuch], 1450/1470 (Augsburg, Universitätsbibliothek, Cod. I.6.4.2.); Hans Talhoffer, [fight book], 1459 (München, Bayerische Staatsbibliothek, Cod. icon. 394a); Paulus Kal, [fight book], 1468–75 (München, Bayerische Staatsbibliothek, Cgm 1507).

⁹ Fiore dei Liberi, *Flower of Battle*, 1410 (Los Angeles, J. Paul Getty Museum, Ms Ludwig XV 13).

¹⁰ Jaquet, Daniel, Alice Bonnefoy Mazure, Stéphane Armand, Caecilia Charbonnier, Jean-Luc Ziltener, and Bengt Kayser, 'Range of Motion and Energy Cost of Locomotion of the Late Medieval Armoured Fighter: A Proof of Concept of Confronting the Medieval Technical Literature with Modern Movement Analysis', *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, 49 (2016), 169–86 <https://doi.org/10.1080/01615440.2015.1112753>.

Material culture

[Jaquet:]

At the end of the Middle Ages, armour production reached a peak of technological achievements.¹¹ It is the era of plate armour (or harness in the old texts). These outfits were complex technological exoskeletons encapsulating the whole body, made to measure. This example is the original harness, which we took as model for our replica. It is kept in the Hofjagd and Rüstammer in Vienna and belonged to Frederic the Victorious, a Palatine prince of the Holy Roman Empire in the mid 15th century.¹²

Figure 1. Comparison between the original suit of armour, the representation of its typology within the Fight Books corpus, and the replica worn for the experiments. Left panel: Suit of armour of Frederick I, steel and leather, several Milanese workshops, ca. 1450, ©Wien, Kunsthistorisches Museum, Hofjagd and Rüstammer, Inv.-Nr. A 2. Center panel: Representation of a pair of armoured fighters in Paulus Kal's Fight Book (1459–79), Paper, ©München, Bayerische Staatsbibliothek, Cgm 1507. Right panel: Replica, steel and leather, photo by E. Jaquet.

[Jaquet:]

This suit matches the representation found on various fight book of the period. Most of its technical characteristics also allowed us to consider this harness in the context of the application of gesture as codified on the fight book corpus, that is ritualised combat on foot with swords or axes, the famous *pas d'armes* or chivalric games of the 15th century. We studied this harness, took measurements and started the production process of the replica. We had to adapt the measurements to the experimenter, which was

¹¹ Williams, Alan R., *The Knight and the Blast Furnace: A History of the Metallurgy of Armour in the Middle Ages & [and] the Early Modern Period*, *History of Warfare*, vol. 12 (Leiden: Brill, 2003).

¹² Harness, various workshops (Milano), 1450 (Vienna, Hofjagd- und Rüstammer, A2).

surprisingly close to the anatomical measures of the original wearer. The details of the measurements are shown on the chart.

Original

Replica

[4:50]

[Jaquet:]

We described the choices that guided the process of the production of the replica in the same article from which the chart is taken. In short, we prioritised the replication of the mechanical behaviour of the object rather than its visual aspect. We also chose a raw material amenable to heat treatment that would replicate the surface hardness test performed on the original by Alan Williams.¹³ We decided to change a few pieces to allow us to experiment with an harness made to fight on foot. That is, the sabatons and the gauntlets, and we left the reinforcing plate on the elbow, originally made for fighting on horseback. The same for the long and pointy feet defences – the sabatons – which were designed for fighting on horseback, in order not to lose the stirrups when stricken. The most difficult thing to do, was actually to reproduce the arming garment worn underneath. For this we are still experimenting to find the best solution.¹⁴ Due to the lack of preserved material, we have to mainly rely on iconographical representation. However, we would like to point out, that this point is critical regarding the mobility in armour. We here rely on ongoing cycles of trial by error as experimental archaeologists are used to.

¹³ Jaquet, Daniel, Alice Bonnefoy Mazure, Stéphane Armand, Caecilia Charbonnier, Jean-Luc Ziltener, and Bengt Kayser, 'Range of Motion and Energy Cost of Locomotion of the Late Medieval Armoured Fighter: A Proof of Concept of Confronting the Medieval Technical Literature with Modern Movement Analysis', *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, 49 (2016), 169–86 <https://doi.org/10.1080/01615440.2015.1112753>.

¹⁴ Capwell, Tobias, 'A Depiction of an Italian Arming Doublet, c. 1435–45', *Waffen- Und Kostümkunde*, 44 (2002), 177–96.

[6:38]

Experience/experiment

[Jaquet:]

We lastly would like to make a methodological comment regarding the difference between experiencing and experimenting, and between the type of video material associated with it.¹⁵ Experimental archaeologists make a strong difference between experiencing and experimenting. The first type is to be considered a tryout, made for various purposes, not specifically in the framework of scientific research, even if it can be. The second type is a form of test, based on a method. The process is documented and would produce results that can be analysed and discussed, and maybe replicated by other researchers. In the framework of our research we did both and the viewer has to distinguish between them. The example shown is a short film produced in the early 20th century by the Metropolitan Museum of New York for educational purposes. It shows various sequences of what can be called experience of embodied knowledge that is similar to ours. The second video excerpt is a promotional video material in the frame of a public outreach event during a museum exhibition on tournaments in Schaffhausen in 2014.¹⁶ There as well can be observed reconstructed embodied knowledge similar to our approach. Moreover, the main character is actually an esteemed colleague and a scholar, Dr. Tobias Capwell, curator of the Wallace Collection, London. However, none of these video materials are to be considered as experimentation, contrary to what will shortly be showed in the second part of this video article.

[8:10]

¹⁵ Griffith, D. W., and Barrymore, John, *A Visit to the Armor Galleries* (New York: Metropolitan Museum, 1924).

¹⁶ Koets, Arne, *Jousting Events at the Museum zu Allerheiligen Schaffhausen* (Youtube, 2014).

2. Quantification of movement liberty and energy expenditure

Interdisciplinary approach

History

Archaeology

Sport Sciences

[Jaquet:]

Starting in 2011, we performed a series of tests with an interdisciplinary approach, mixing medieval history (inquiries based on documents), archaeology (inquiries based on objects), and sport sciences (analyses of the mechanical behaviour of the body). Our research question focused on the impact of wearing armour on the body. Although it is possible to find various examples of subjective remarks on the potential limitation of movement due to armour, no document is able to inform us objectively about the possible quantification of those limits. Therefore we proceeded, as a proof of concept, to the following series of tests, performed on a single subject knowledgeable in armour fighting techniques based on the study of fight books, and accustomed to the wearing of armour.

[08:59]

[Jaquet:]

The subject walked and ran on a motorised treadmill, once wearing shorts and running shoes and once in armour. Pulmonary gas exchange was measured according to routine technique on a breath-by-breath basis with indirect calorimetry. The subject started to walk at 2 km/h for 4 minutes set after which the speed was increased by increments of 1 km/h until 8 km/h. After 8 km/h, incremental steps of 2 km/h followed, until voluntary exhaustion at 14 km/h. Gas exchange was analysed for the last 30 sec of each set. We interpreted the maximum oxygen consumption attained, while

running in shorts and running shoes, as the subject's maximum aerobic capacity. The video shows the test of 10 km per hour. The method is similar to the one used in the study of Askew et al.,¹⁷ but our results are different, probably due to better armour and better trained subjects. We found an average increase in the energy cost of locomotion of 66 percent while the previous study measured between 110 and 130 percent.

66% increase in the energy cost while wearing armour.

[10:09]

[Jaquet:]

A three-dimensional movement analysis was performed during two separate sessions in order to measure, to quantify, and then to compare the range of motion of each body joint of the subject in and out of armour. The subject was first studied while walking – that is the gait analysis displayed, on the video – and then during more complex and maximal functional movements for each body joint – that is the functional movement test that will be shown later. The passive-reflective markers were then analysed with computer assistance to capture the full motion of the body. The results are interesting.

2.48% difference in and out of armour.

[Jaquet:]

For the gait analysis, only a 2.48 percent difference was measured in and out of armour. That means that, for natural movement such as walking or sitting, the limitation of movement while wearing armour is insignificant. When we go into more details, we can even see that the range of motion of several movements are actually increased by the wearing of armour. This is for example the case for the flexion of the ankle, due to the increased load of armour on the body. You can see on the chart that the lighter curve showing

¹⁷ Askew, Graham N., Frederico Formenti, and Alberto E. Minetti, 'Limitations Imposed by Wearing Armour on Medieval Soldier's Locomotor Performance', *Proceedings of the Royal Society: Biological Sciences (Proc.R.Soc.B)*, 279 (2012), 640–44.

range of motion while wearing armour is actually over the darker one on the two last panels.

[11:08]

Trunk Tilt

Pelvis Tilt

Hip Flexion-Extension

Knee Flexion-Extension

Ankle Dorsi-Plantarflexion

Right limbs

with and without armour

Left limbs

with and without armour

[11:21]

[Jaquet:]

The following test consisted of measuring the maximal range of motion of each body joint in the three directions, that is flexion/extension, adduction/abduction and internal/external rotation. For an overall difference of close to 20 percent, we could observe that some movements were significantly limited, while others were not. While analysing the results from a perspective informed by the study of medieval fight books, we came up with a working theory that those limitations were actually designed on purpose. Indeed, while fighting an opponent, an armoured fighter would rather not lift his arms up, since it would expose a weakness – that is the armpit – allowing the opponent to pierce through the lungs.¹⁸ A minimal range of motion for this movement is enough for natural and complex movements, including standing up or most basic wrestling movements.

¹⁸ Jorg Wilhalm, *Fight Book*, 1523 (Augsburg, Universitätsbibliothek, Cod.1.6.2°3, fol. 20r).

[12:10]

ROM and STD for trunk, arm, elbow, and wrist during specific maximal functional movement without and with armour. Flexion-Extension: Flex/Ext; Abduction/Adduction: Abd/Add; Internal and external rotation: RI/RE.

[Jaquet:]

However, a fighter would need a full range of motion for the adduction of the shoulder, if he would like to actually strike with his weapon. This specific movement was measured close to no limitation at all in our test. Further research is needed to turn this working theory into a postulate.

[12:28]

ROM and standard deviation (STD) of hip, knee, and ankle joints during specific maximal functional movement with and without armour. Difference (DIFF) between ROM in and out of armour are given in degrees. Flexion-Extension: Flex/Ext; Abduction/Adduction: Abd/Add; Internal and external rotation: RI/RE.

[Jaquet:]

Other tests were performed, but not included on the published article or in this video article. Among those were the shifts of body centre mass between the two conditions; the explosive strength developed while jumping up; or more complex capture of motion for selected technical movements.

[12:45]

3. Performance test (Obstacle Run in Armour)

[Jaquet:]

Now, something different from the tests in the controlled environment of the lab. We wanted to reach a wider audience with the results of our research,¹⁹

¹⁹ Jaquet, Daniel, *Moving in harness* (Morges, 2016).

and like the Head of the Armour's Department of the Metropolitan Museum in 1924 already, we also explored short movies for educational purposes. In the context of a temporary exhibition of arms and armour at the Castle of Morges in 2016, we made this short movie intended for display within the exhibition.²⁰

Obstacle run in full gear

[internal time code from the obstacle run]

[Jaquet:]

The goal was to show that the outfit of a modern firefighter, a modern soldier and of a medieval knight are actually similar when it comes to looking into the limitation of movement and energy expenditure during performance. The set of goals of this video aim more towards revising widespread misconceptions about arms and armour, than to present an experimentation for a scholarly audience. However, we would like here to outline a few of the choices and methods, which we set in place for this experience, even if we made it clear in the disclaimer at the end of the movie that the intention was not experimentation. We chose to perform a standardised obstacle course of the Swiss army, with a few differences on several obstacles in order to prevent injuries. We also wanted to have comparable subjects, we then chose not to invite professional soldier and firefighter, but a militiaman and a volunteering firefighter, since the subject in armour is not to be considered a late medieval knight.²¹ Indeed, he wears the armour only part time for research or leisure and his body, his diet and his way of life are those of a 21st century scholar.

²⁰ Jaquet, Daniel, *Obstacle run in armour* (Morges, 2016).

²¹ For a theoretical approach and critical point of views about experimentation and reconstruction, I invite the viewer to consult the bibliography at the end of the video, especially the cited works of Ben Spatz, Daniel Jaquet, and Eric Burkart.

The day of the run, we took a series of measurements and we were monitored as it will be outlined later. We then performed a first course without the armour, but with the clothing, which are worn underneath, for all subjects, since the undergarments do impede movement as well, sometimes even more than the armour itself.

Obstacle run in light gear

[Jaquet:]

On the day of the run, we performed a monitored run without armour, followed by another one in armour. The second run received additional attention and ruleset. For example, each subject received a helper who followed him in case of any technical malfunction due to the armour or any physical issue during the run. Both the soldier and the knight actually used the helper for a very brief period of time – time which has been withdrawn from the results of the race. Both interventions will be shortly commented later. We also had a lot of discussion about the protection worn on the head. We decided not to run with a closed face helmet, because the goal of the experience was not to observe breathing issues that could not be compared between the three outfits. The firefighter could have worn a facemask alimented by oxygen, whereas the modern soldier would have worn a protection mask with a filter against toxic environment. These would have caused more issue when compared, than actual relevance for the experience.

Lastly, I would like to outline a few of the choices made for prevention of injuries. The subject wearing armour ran with modern sport shoes, because the ground included rocky paths and the medieval footwear with soft sole shoe could not prevent possible injuries to the feet of the subject, which are not strengthened by daily wear. Some of the obstacles were not attempted according to routine technique made for unarmoured soldier. All subjects

were forced to observe defined rules to cross over each obstacle potentially dangerous with an overload of average 37% of the body mass of the subject. Let's now have a look at the different measurements taken and monitoring device used to gather data.

[16:18]

[Jaquet:]

We undertook three weighing operations. The first was without clothing, the second with the undergarment, and the third with the complete outfit. A plate armour is never worn without specific undergarment usually complex and most of the time also including protection, like the mail gussets, pretty heavy. But the most difficult idea to come over for those who never wore any kind of armour, is that it is usually made to measure or with a material which could not be adapted to one's body. The association of idea with familiar objects with similar weight is a bias. Indeed, most of the outfits are made to distribute the weight over the whole body in order to ease movement.

[table]

Light gear

6.6 kg

5.6 kg

4.4 kg

Full gear

28.5 kg (6.6+21.9)

29 kg (5.6 + 23.4)

31.2 kg (4.4 + 26.8)

Added load to bodyweight

→ +39.26%

→ +35.45%

→ +37.05%

[16:58]

[Jaquet:]

Another data monitored was the heartbeat, captured by professional devices similar to sport leisure watches. Heart rate is a type of objective data, however it is not relevant if not analysed in context and in comparison with a baseline. In our case, we did not do the whole protocol allowing to use this data scientifically. Nonetheless, by comparing the curves, we can see the effort level of the different subject during the different run.

[17:18]

Heart rate (bpm) – average

Knight +12.25 BPM in full gear (max 196)

Firefighter +25.05% BPM in full gear (max 198)

Soldier +0.2% BPM in full gear (max 192)

Run in light gear

Run in full gear

[17:23]

[Jaquet:]

Lactate level are another type of data used for sport science to observe effort. It consists of analysing the lactate and/or lactic acid in the blood in the context of a high energy expenditure, that is at 85 percent of maximum heart rate or 75 percent of maximal oxygen intake. Practically, it is done before and after the effort by puncturing blood according to routine sequence of puncture. Like the heart rate, the analysis of this data is only valid in context and according to established methodology, which was not followed during the experience. Nonetheless, it allows us to objectively appreciate the level of effort and the physiological resistance to energy expenditure.

[17:50]

Blood lactate level (mmol/L) – light gear

[17:57]

Comparison delta blood lactate level between light and full gear condition

[18:03]

[Jaquet:]

Time is data with intrinsic value, in other words, which does not need contextualisation to be appreciated, like the ratio between bodyweight and the added load. We chose these data as a final result, although the age difference is also a factor. Both the firefighter and the soldier are ten years younger than the subject in armour. The soldier actually won the run without armour, and he was the better trained subject. The firefighter won the run in armour. He was the most agile and the fastest. He also did not use his helper during the run. The knight stopped for 13 seconds because he was blinded by the undergarment which slipped before his eyes during ramping. The soldier stopped for 14 seconds because he was stuck in the last obstacle during ramping by his backpack. Both of these stops were withdrawn from the final time result.

Firefighter: 03:00

Knight: 03:10 (+13s)

Soldier: 03:35 (+14s)

[19:02]

Dr Daniel Jaquet

The results speak for themselves. The performance of the obstacle course in full gear is pretty close between a modern firefighter, a soldier, or the wearer of a replica of a late Medieval harness. This experience accords with our working hypothesis from the beginning, that late medieval harness is a complex technological outfit, made to measure and allowing great range of movements, as do the military or firefighting gear. This aimed for public outreach, in order to revise widespread misconceptions inherited from the late Victorian era, but still very vivid in popular culture, today notably to the movie industry.

But more importantly, this experience confirms the result of our scientific investigation including modern-day experiments with a replica. We have quantified the impact of wearing armour on both energy expenditure and range of motion. We found out that natural movement such as walking is not impacted by the wearing of armour, whereas several functional movements are and others are not. We postulate that this difference is due to the design of the harness, made on purpose to allow or to restrict movement for tactical reasons during fighting. We rely on the study of both the preserved harnesses of the period and the technical literature regarding personal fighting techniques – the fight books. Our experiment is to be considered a proof of concept, where further studies are needed to demonstrate the point. We notably encourage similar documented experiences or experiments to take place, to broaden the sample of experimenters and to rely on more data.

[21:09]

Credits

Text: Daniel Jaquet

Video production: Vincent Deluz

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Competing Interests

The authors have no competing interests to declare.

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