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Comparison of Traditional Physical Intervention Techniques vs. Operational Tactical Procedures and Techniques in the Use of Force during Police Arrests

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Abstract: (1) Background: A set of relevant police ergonomic parameters (PEP) have been used for the assessment and prevention of occupational risks involved in police physical interventions (PITs). Through this set of PEPs, a comparison has been made between two traditional PITs against two novel OTPs (operational tactical procedures). (2) Method: The data have been collected by means of a motion capture suit fitted with 19 inertial measurement units (IMUs). A specific and powerful software package specific for ergonomic analysis has been used to manage the large amount of data registered and to generate a series of three-dimensional plots. Traditional PITs and newer OTPs have been performed for their analysis. Specifically, the PEPs corresponding to the implementation of four PITs have been analyzed by collecting the measurements provided by a set of IMUs installed on a motion capture suit, and their occupational risk assessments have been compared against those corresponding to newer OTPs. (3) Results: For the four PITs, the PEPs have been analyzed with the measured values from the IMUs, throughout the duration of each technique. The two traditional intervention techniques have scored higher than the new OTPs in the REBA system, the asymmetry angle, L5-pelvis shear and joint contact forces, and the total muscle power measurements. (4) Conclusions: It has been confirmed that the new OTPs minimize the risk of injuries, since their PEPs reached lower values than those corresponding to the traditional PITs, which are still being taught at police academies.

Keywords: ergonomic; occupational risk prevention; police physical intervention; use of force; operational tactical procedure; motion capture technology

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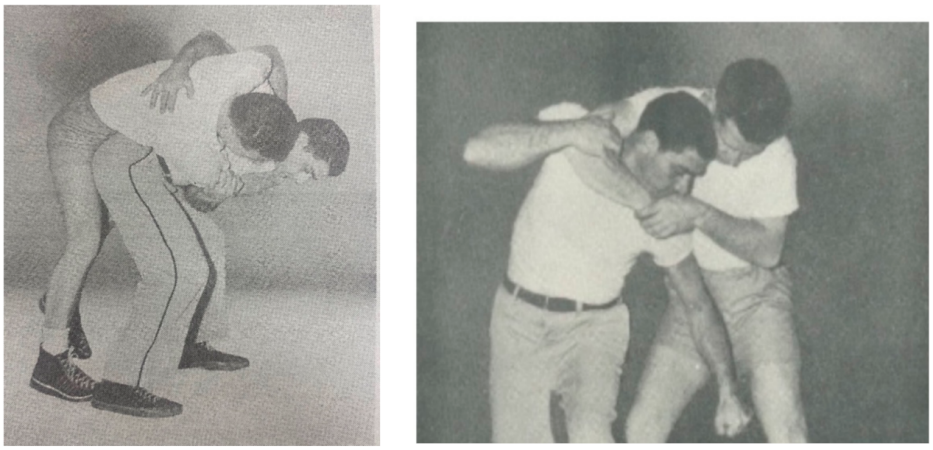
1. Introduction

The operational tactical procedures (OTPs) that have been analyzed have already been described by Vera-Jiménez [1], and they intend to achieve control of an adversary while minimizing the risk of any severe harm, which is in consonance with the use of proportional force and in contrast with other traditional intervention techniques that are still taught at most police training academies.

From the early 20th century, the traditional physical intervention techniques (PITs) used by the police and security force units have been based on techniques inherited from martial arts or combat sports and are intended to immobilize an opponent. Very clear examples can be found in the manual entitled "Destreza" by Gistau [2] from 1915, or the manual "Defensive Tactics", published in 1951 [3] (written by Hoover, the first Director of the United States Federal Bureau of Investigations (FBI)). "Complete Krav Maga", as published by Levine [4] and Guy Mor [5], has remained, until recently, the training manual for Israel's security forces. The "Basic manual of Police procedures and personal defense" (Benito [6]) has been a reference training book in Spain. The type of intervention techniques that are described in these books involve a high risk of injury both for the adversaries and for the police officers.

In the manual "Defensive Tactics" [3] in particular, some of the martial art techniques that are recommended to reduce an opponent are targeted at vital areas (liver, spleen, solar plexus, head). This manual presents a selection of simple and effective procedures extracted from certain ancient arts and sports such as judo, jujitsu, savate, boxing, wrestling or fencing. Among the PITs describe in this book, we have selected two of the most common ones as shown below: a throw (Figure 1a) and a choking (Figure 1b) technique.



(**a**) (**b**)

Figure 1. (**a**) Snapshot of a throwing technique. (**b**) Snapshot of a choke technique.

The throw techniques, commonly known as Koshi-Waza techniques in Judo (for example, Koshi Guruma in the Figure 1a), have the purpose of preparing the aggressor or adversary for handcuffing on the floor by making him fall onto the floor. This fall on a hard surface might cause trauma at head or spinal cord levels, besides the risk of hitting any of the likely hard elements around (curb, furniture, etc.) and suffering even more serious injuries.

The choking technique, Figure 1b, is known as rear naked choke (or Hadaka-jime). This technique may cause harm that goes from a light injury of the spine muscles to a more serious bone injury affecting the vertebrae themselves (fractures, crushing, etc.), or even severe spinal cord injuries (complete or partial shearing). Therefore, it goes without saying that both of these techniques have triggered some considerable controversy since they were first implemented.

Unfortunately, the current situation of police training has not substantially improved since then. In addition, a specific problem that could be characterized as procedural inertia has been identified, as reflected in a study by Williams J.J. et al. [7]. In this study, the use of force (UOF) by SWAT (special weapons and tactics) and non-SWAT police officers led to the conclusion that SWAT officers, who are taught to use force in normally dangerous situations, were more likely to use the same level of force in non-SWAT situations.

While certain technologies that are applicable to police interventions have changed substantially in the 2000s, the approach to police tactics has remained, with a few exceptions,

fairly unchanged since the 1980s. Naturally, this has resulted in some critical positions with respect to certain police training methods that have caused the implementation of certain legislative changes regarding the UOF. For instance, an article by Chappell et al. [8] states that even community or urban police forces remain highly militaristic and bureaucratic in their structure and culture.

On the other hand, from the late 1990s, police training has fostered a notable production of scientific literature. This appreciation occurs at a general level in all countries. For example, in the case of the US, in 1997 McEwen [9] analyzed the policies of 96 agencies with regard to the observance of the law in non-lethal UOF. It is worth mentioning that the article included a review of the definitions of lethal force and non-lethal force. It finally showed that most of the policies applied are deficient. More recently, in the year 2000, Garrett et al. [10] conducted a similar study on the policies related to the use of these two types of forces. According to the Bureau of Justice Statistics, it is estimated that over 93% of law enforcement agencies had policies governing the use of lethal force in place, while this percentage dropped to 87% when it came to the agencies that implemented policies concerning non-lethal force.

The controversy around the UOF is not only a matter of police training, since even more controversial scenarios are found in the training methods applied by private security companies (PSC). For example, in Spain, among other requirements, the trainers are required to hold a "level II" or a higher qualification in the disciplines of judo, karate, taekwondo, fighting or kickboxing, as stated in the Spanish Royal Decree 1363/2007, October 24th [11]. Similar cases are found in the legislation of other European countries, where the harmonization of the regulations for PSCs at European level is yet to be carried out. Consequently, the Geneva Center for the Democratic Control of the Armed Forces, after analyzing the existing regulations for PSCs in the different member states of the European Union (EU), makes an urgent recommendation to improve the current legal framework [12].

Luckily, in the early 21st century, a scientific evolution of tactics took place that resulted in the development of new policies and training methods to provide some guidance on the UOF by police officers, and a new approach to the role of police instructors and their training methods (Birzer [13]; Andersen et al. [14]; Renden et al. [15]; Di Nota, 2019 [16]; Mcneeley [17]; Bennell et al., [18]). Many other related pedagogical issues, that had so far received marginal attention, have also been more deeply investigated (Cushion [19]; Koerner [20]; Staller [21]).

McLean [22] analyzed the proliferation of those policies in USA that aimed at analyzing training programs and concluded that, although many promising ideas had arisen, practically no strategy had succeeded in achieving substantial changes with regard to a significant reduction in the use of lethal force. This fact represented a serious obstacle when it comes to selecting the new and effective policies that are so urgently needed.

Nevertheless, the appearance of this sequence of scientific studies on police training has made clear that strong policies on the use of force are of vital importance.

This controversy with regard to police training has moved into even harder terms when the areas of physical fitness, motivation and discipline have been contemplated. Koerner's study [23] gathers the expert opinions of eight police trainers on a number of pedagogical issues related to the actual training of police instructors themselves. When questioned on the different aspects of their training, the interviewed coaches reported certain learning deficiencies that could be classified into "social", "psychological" or "physical" factors. For instance, in this study, the authors focus on various issues criticized by coaches, such as the lack of discipline in young people in training and the motivation and concentration deficits during police training. However, the one that is considered most important is the physical deficiency, mainly in the lack of coordination and condition/aptitude in police recruits, which is also a source of injuries.

Moreover, the coaches' views with regard to female recruits revealed a pronounced gender bias. Koerner et al [23]. found that for several coaches the "Female Police officers are seen as "support members" in the context of Police deployment".

Another aspect that was strongly criticized with regard to the difficulty of implementing a particular police training method that would suit the needs of today's society lies on the insufficient provision of resources. This is reflected in a study on several police trainers from six European countries, developed by Kleygrewe et al. [24].

The use of force in European countries has also been analyzed because of the controversies unleashed by a number of events with extensive media coverage. These have caused concern among trainers/instructors, as reported in numerous publications. Staller et al. [25] suggested that police instructors need context-specific knowledge and support in order to develop knowledge structures—that is, a solid and systematically controlled knowledge base on the parameters involved in violent encounter scenarios is crucial.

Despite all of that said above, no bibliography has been found to describe a methodology for the training of tactics intended for these types of real-life situation. An initial approach was pointed out by Cushion et al. [26], who described in their paper an analysis on the use of scenario-based training (SBT) and its subsequent adaptation to the officers' personal security training (PST) based on existing police research in UOF training and SBT from the United Kingdom, Europe, North America and Australia. The idea is supporting a national initiative across 43 police forces in England and Wales to change the PST curriculum and the "train-the-trainer" training.

In this sense, OTPs should be considered as an innovation, as presented by Vera et al. [27]. Unlike the traditionally taught techniques, OTPs not only avoid hitting any vital areas and causing serious harm to opponents, but they also represent a lesser risk of injury for police officers themselves. In the present study, risk prevention has been addressed by comparing different types of PITs by means of ergonomic evaluations. For this purpose, a proper evaluation form that allows a precise identification of specific biometric parameters such as angles, forces or energy, among others, has been created. Furthermore, a set of inertial measurement units (IMUs) combined with 3D motion capture tools have been used and their level of accuracy for the measurement of the parameters of interest has been confirmed [28].

It should be noted that the four PITs that have been studied were executed under controlled conditions in the adequate sport facilities and after completing the essential physical warm-up required to avoid any additional risk of injuries [29].

2. Materials and Methods

2.1. Police Ergonomic Parameters

The selection of the most relevant occupational risk assessment parameters and methods was based on a previous work by Vera et al. [27] as follows:

1.1 Parameters of interest for the REBA method (Rapid Entire Body Assessment). Designed by Cuixart [30] and built into NTP 601 (Tech Notes on Prevention, as it is in Spanish abbreviations), the REBA method evaluates a set of geometrical parameters of relative positions of parts of the human body, such as flexion angles, torsion angles, positions of the extremities, trunk, head, etc. As the techniques of interest are being implemented, these parameters are awarded a series of scores at specific intervals and within a specific range of values.

1.2. Asymmetry angle. It is a parameter of interest in the NIOSH (Work Practices Guide for Manual Lifting, named after the acronym of the National Institute for Occupational Safety and Health) method, which has focused on the risks that may cause lower back pain or back discomfort. From this method based on the NIOSH lifting equation [31], we have considered the compression force (or joint contact force) at the junction of the pelvis, with the fifth lumbar vertebra, L5-pelvic junction and the angle of asymmetry as the most appropriate parameters.

The asymmetry angle (A) is an angle used to determine the asymmetry of movements with respect to the vertical plane of the human body (sagittal plane) when a worker is performing a lifting or loading task.

The greater the angle of asymmetry, the greater body effort must be made to achieve the same lifting work. For this reason, the NIOSH method advises against movements that involve flexing, bending and twisting the trunk. If A > 135°, no weight lifting would be recommended.

1.3. Compression force at the L5-pelvic junction, which is also called the lumbosacral joint or L5-S1 joint (the joint of the fifth lumbar vertebra with the first of the sacrum). The most important compression forces that appear when performing the techniques are body weight and the load of the lifting that take place. According to the NIOSH criteria [31], it has been reported that the cutoff for lower back pain risks arising at the L5-P=pelvic junction is 3400 N.

1.4. Shear force at the L5-pelvis junction. These forces have been defined as the forces that cause a slide or parallel displacement of a vertebra with respect to the one immediately below or above [28]. Therefore, they are perpendicular forces with respect to the compression force. Shear forces usually arise when the trunk of a human body performs pulling and/or pushing efforts. For the shear force, it has been established that 1000 N is the recommended limit [31].

1.5. Total muscle power. It is another of the police ergonomic parameters (PEP) that was mentioned as very important in a previous paper [27]. Muscle power, expressed in watts, has been calculated as the amount of energy per time used to complete a specific job.

The aim of this study is to evaluate the occupational risks associated with the physical intervention techniques (PITs) used by police officers. Our research has been specifically focused on the risk of injuries related to the UOF. For this purpose, a comparative analysis between the traditional PITs commonly used by police forces against new operational tactical procedures (OTPs) has been conducted.

2.2. Bob-Biomechanics

Shippen's biomechanical modeling software package, BoB (Biomechanics of Body), is a powerful tool for the analysis of human and ergonomic biomechanical factors. It has been used to calculate a set of biomechanical parameters such as the relative movements of the joints, as well as the trajectories, velocities, accelerations, forces, energies and powers of a part of the body or of the whole body.

Figure 2 shows several examples of the graphic output capabilities of biomechanical calculations that BoB can generate: 3D graphics and animations of an avatar that recreates the movement of a person, attached to a video synchronized with the animation, and the generation of plots of biomechanical parameters and risk assessment methods.

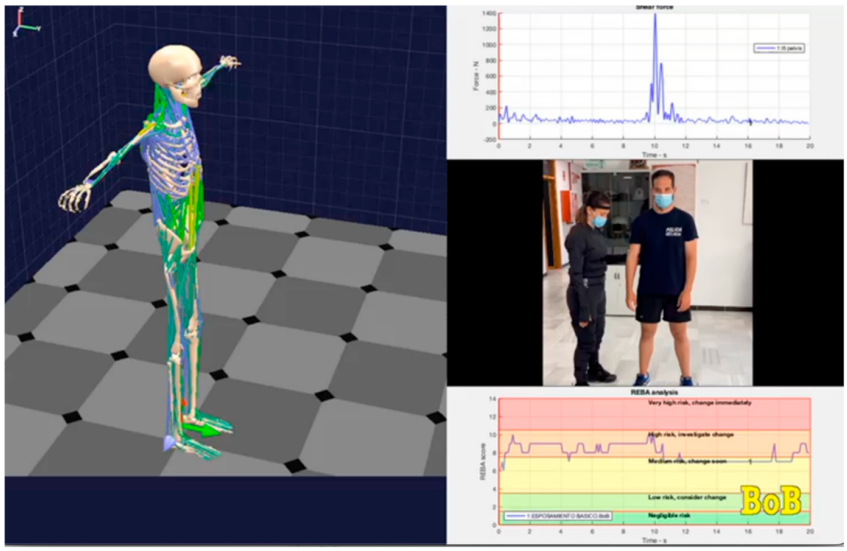


Figure 2. Graphs generated by means of BoB software package.

To obtain the values of the scores throughout the REBA analysis, in this software, there are four options of "**Grip Quality?"** (*Well-fitting handle and mid-range power grip; Acceptable but nto ideal hand hold; Hand hold not acceptable but possible; No handles, awkward and unsafe*), and others four options of **"Degree of activity?"** (*One or more body parts held static for over 1 min; More than 4 repeated small range actions per minute; Actions causing rapid change in posture; None of the above*). OTP procedures are designed in this way, and the options underlined are the most appropriate.

2.3. Rokoko Smartsuit Pro

The Rokoko Smartsuit Pro is a suit that fits a single person and has 19 IMUs incorporated. With these sensors, magnetic fields, positions, speeds and accelerations of anatomical parts of a human body are determined. It has a controller that connects to a computer via Wi-Fi. It incorporates a specific software application that allows the display of body positions as avatars on the screen (Figure 3). The controller allows the capturing of up to 100 data series per second.

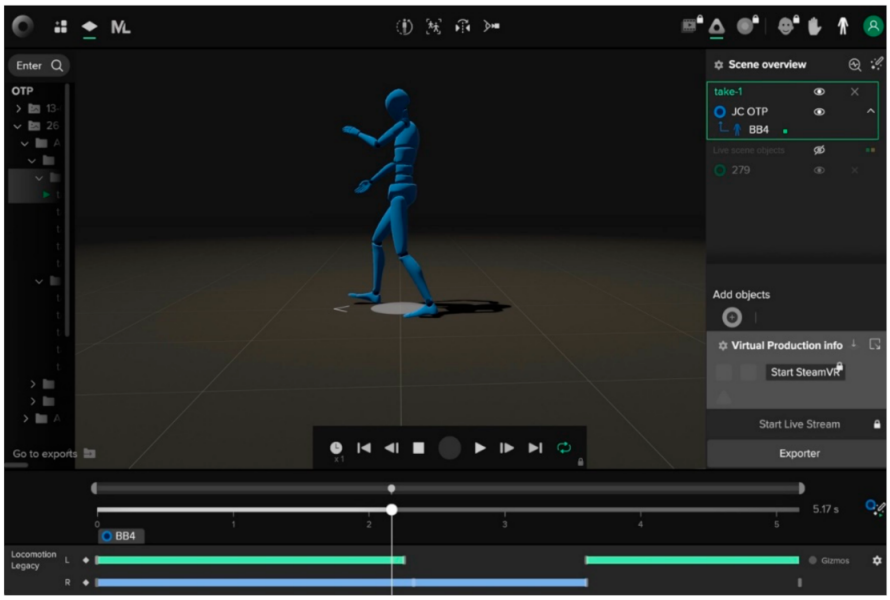


Figure 3. Avatar illustrating the posture of a human body while performing an intervention technique.

2.4. Police Physical Intervention Techniques

2.4.1. Operational Tactical Procedures (OTP)

Operational tactical procedures (OTP) are a group of physical intervention techniques (PIT) designed to avoid hitting vulnerable and vital areas of the human body [1].

The OTP techniques that have been evaluated in this study are the basic OTP 1 and 4. Both OTP techniques are those used in [27]. These procedures prevent serious damage not only to the opponent but also to the policeman.

The basic OTP 1 is also called OTP basic immobilization technique number 1, and can be described in four main steps (Figure 4):

a. Let us start in guard position;
b. Obliquely, we step forward with the leg closest to the place we go;
c. With our forearm, we seek his elbow;
d. We take it down to our hip, where he will be perfectly controlled.

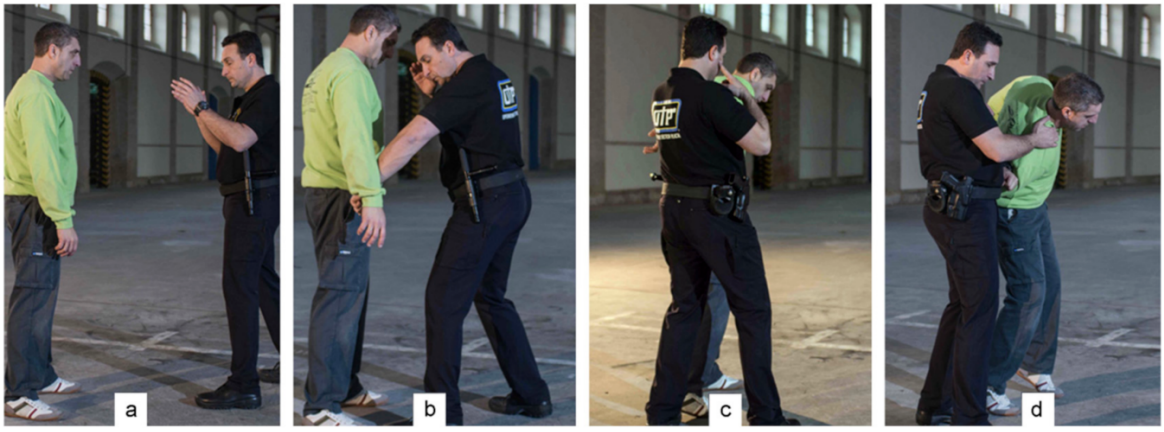


Figure 4. A sequence of snapshots corresponding with the four main steps of the basic OTP 1.

The basic OTP 4 is also called OTP basic immobilization technique number 4 (control on the floor), and can be described in five main steps (Figure 5):

a. Let us start in guard position;
b. Obliquely, we step forward with the leg closest to the place we go;
c. Continue with the padlock technique;
d. Strike with our rear leg on his thigh;
e. Take him to the floor in a controlled way.

Figure 5. A sequence of snapshots corresponding with the five main steps of the basic OTP 4.

2.4.2. Traditional Techniques

Among the traditional techniques found in Hoover's manual [3], and after being studied by high-performance athletes in martial arts, two traditional techniques considered

less harmful have been chosen for the present comparative study: Koshi Guruma (Figure 1a) and Hadaka-jime (Figure 1b).

Koshi Guruma means "rolls by the hip". This judo technique of the Koshi-Waza category belongs to the 40 original throwing techniques of Jigoro Kano. To perform Koshi Guruma, the police officer (or tori) wraps his arm around the opponent (uke), and simultaneously brings his hip together in front of the opponent to perform a hip and trunk rotation to complete the throw.

Hadaka-jime means naked (rear naked choke). It is the most intuitive choking technique and only the arms and hands are used, without the need to use the uniform for this purpose. This technique is used when the tori (police officer) is behind the uke (opponent) in a higher position than him. It is practiced by surrounding the uke's neck with the tori's forearm. Then, the other hand is interlocked and the uke is controlled and lowered to the ground.

2.5. Research Collaborators

The measurements of all the above PEPs were recorded when the entire process of each one of the PITs was carried out with two police officers wearing the suits with wireless IMU sensors.

The physical characteristics are a man of 1.83 m in height and 98 kg in weight for the officer who was playing police officer, and a man of 1.73 m in height and 68 kg in weight for the officer who was in opposition.

Both are high-performance athletes in martial arts and combat sports. The techniques were carried out in a prepared gym with prior warm-up.

3. Results and Discussion

The biomechanical analyses that have been performed using this novel wireless sensor-capturing technology and the BoB package allowed for the simultaneous analyses of a large set of biometric parameters.

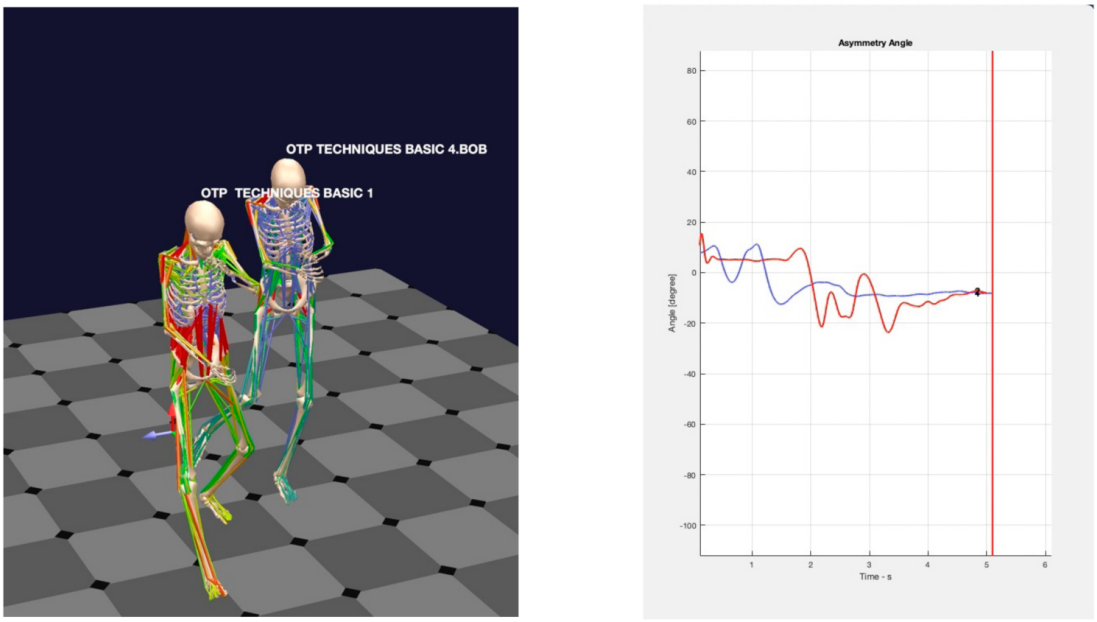
This study has considered the parameters that have been previously selected by Vera-Jimenez [27] and, as shown in their study, it allowed us to successfully determine the risk of suffering injuries.

3.1. Asymmetry Angles

The avatars of the individuals who implemented the techniques to carry out the measurements can be seen on the left side of Figure 6, both at a moment of performing each of the two basic OTPs (Figure 6a) as well as when performing the traditional choke and throw techniques (Figure 6b). Both figures have been captured from the videos that are incorporated as Supplementary Materials to this study. On the videos, you can see how the avatar executes each one of the techniques in real time. It is worth noting the graphical representation of the muscles in the form of ligatures, where they may display from light blue, green, yellow and up to red colors in order to denote the amount of tension exerted by the corresponding muscles at every moment.

The curves corresponding to the asymmetry angle values for each of the techniques are shown on the left of Figure 6b. As can be seen, the range of values of the asymmetry angles in OTPs is around 20° above the vertical line, while in the traditional techniques their values reached as much as 50°. It is, therefore, clear that according to NIOSH, the risk of injuries is considerably higher when using the traditional techniques.

(**a**)



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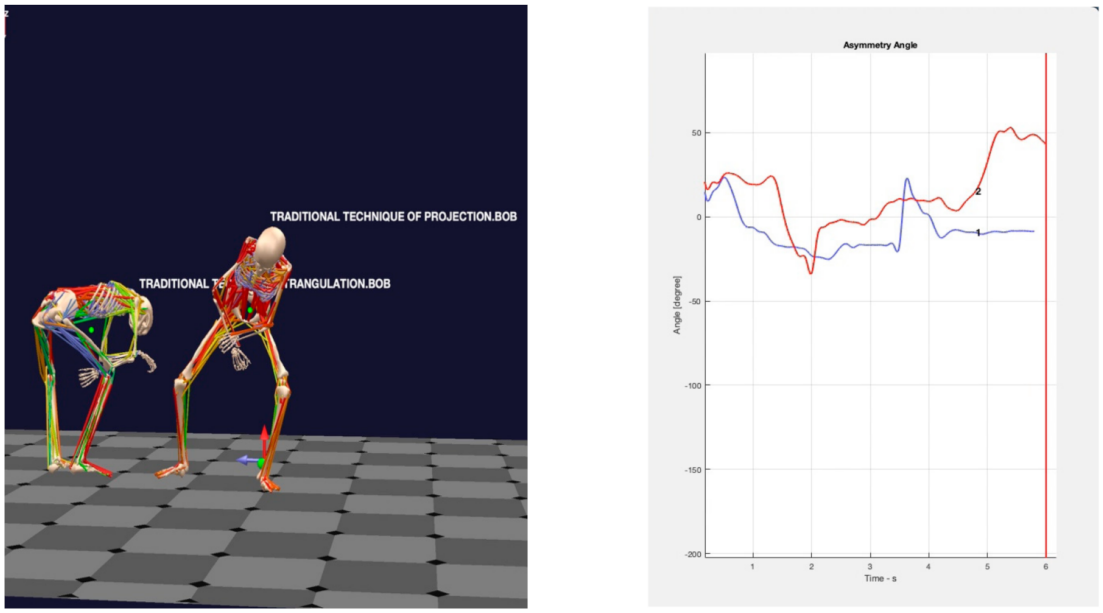
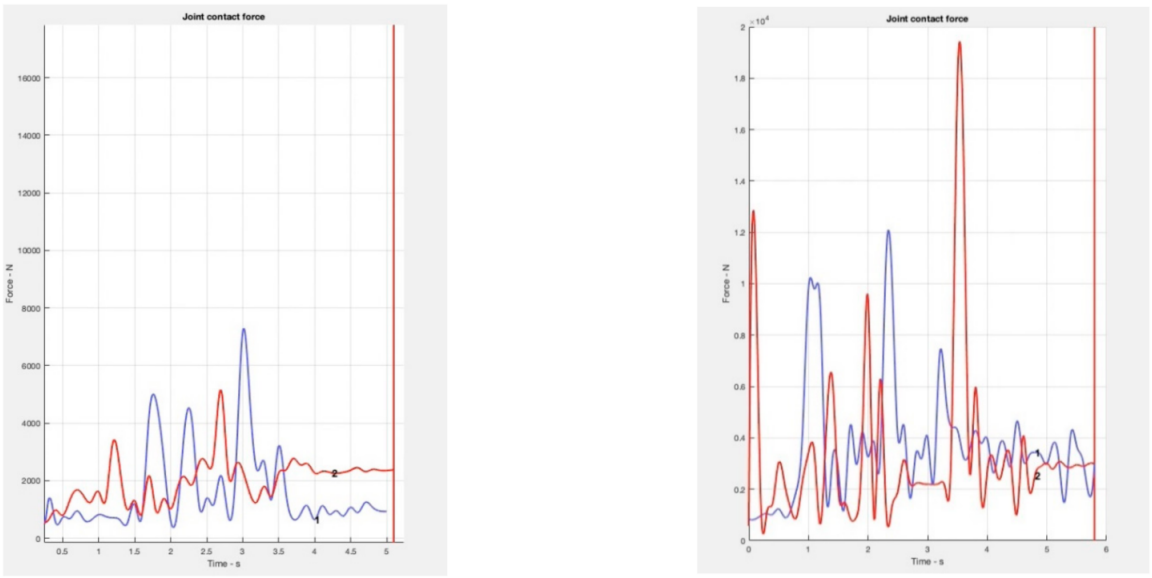


Figure 6. (**a**) The graph on the right shows the values of the asymmetry angles with respect to the sagittal plane of the body. The blue curve shows the values corresponding to the basic OTP 4 and the red curve represents the basic OTP 1; (**b**) shows the same values for the choke (red color) and throw (blue color) techniques.

3.2. Compression Force at the L5-Pelvis Junction

The compression force at the L5-pelvis junction changes very quickly, as can be seen in Figure 7 where greater values indicate a higher risk of injury.

NIOSH [31] establishes a limit value of 3400 N as the threshold value that should not be exceeded for a long time. In the cases of the OTPs, the curves representing this parameter rarely exceeded this limit, despite the fact that the highest value in this study is 7500 N. Something very different happens with the traditional techniques, where the threshold is exceeded most of the time while the technique is being implemented.

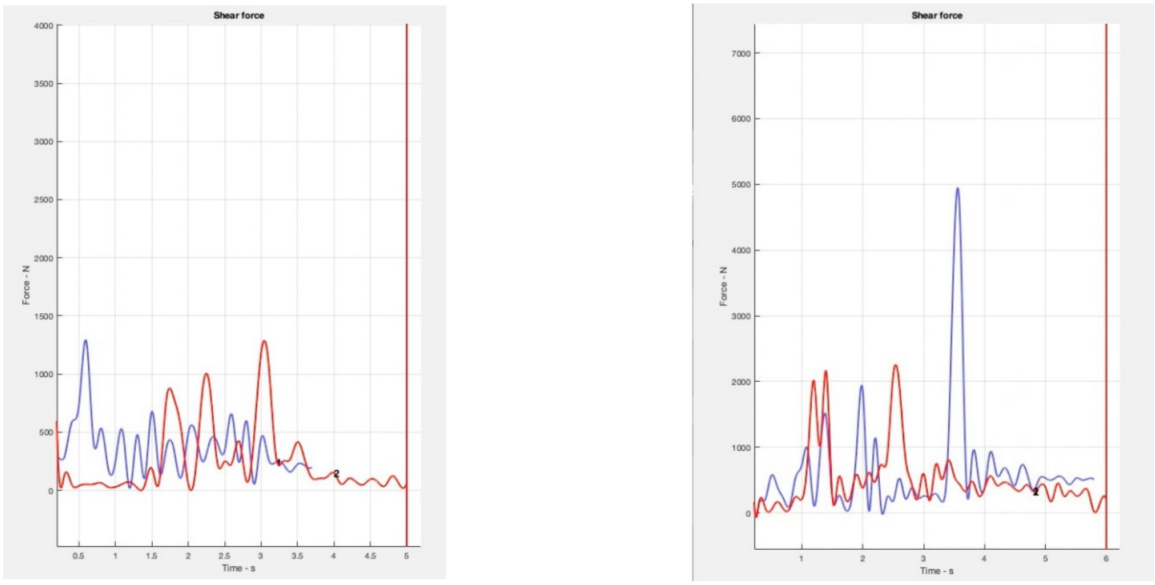


(**a**) (**b**)

Figure 7. (**a**) The graph on the right shows the compression force values at the L5-pelvis joint when performing the basic OTP 1 (red color) and OTP 4 (blue color). (**b**) The blue curve represents the values that this parameter reaches with the choke technique and the red curve corresponds to the throw technique.

3.3. Shear Force at the L5-Pelvis Junction

One of the parameters of special interest in this work is the shear force on the segment between the L5 vertebra and the pelvis. Figure 8a shows the values reached by this force in OTPs, which do not exceed 1400 N. In contrast, the values corresponding to traditional techniques frequently exceed the value of 2000 N and even went up to nearly 5000 N in the case of the throw technique (Figure 8b).

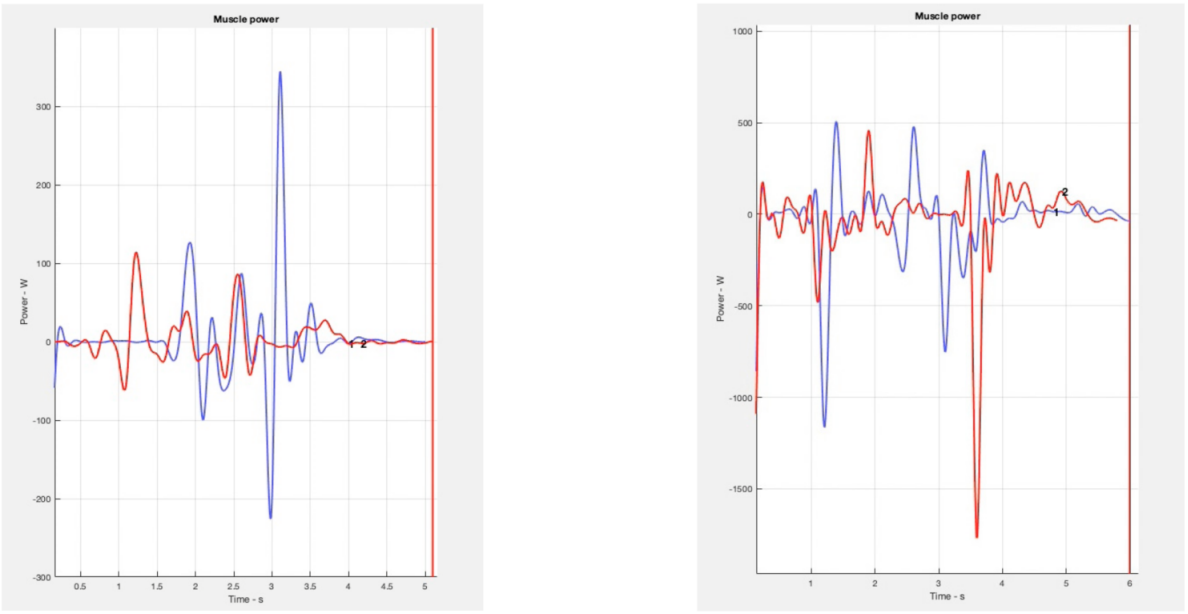


(**a**) (**b**)

Figure 8. (**a**) The plot on the right shows the values of the shear forces at the L5-pelvis joint when performing the basic OTP 1 (red color) and OTP 4 (blue color). (**b**) The blue curve represents the values that this parameter reaches with the choke technique and the red curve corresponds to the throw technique.

3.4. Muscle Power

The muscular power exerted by police officers is another parameter of substantial relevance from the point of view of occupational hazards. Figure 9 represents the total muscle power as positive or negative values, where positive values are assigned to the eccentric movements (i.e., muscle force is exerted in the opposite direction of the muscle movement). Accordingly, the concentric movements have been assigned negative values in the graph. When absolute power values have been considered (amount of energy consumed per unit of time), the highest muscle power consumption corresponding to the OTPs was around 340 W, while the traditional techniques exceeded 1000 W.



(**a**) (**b**)

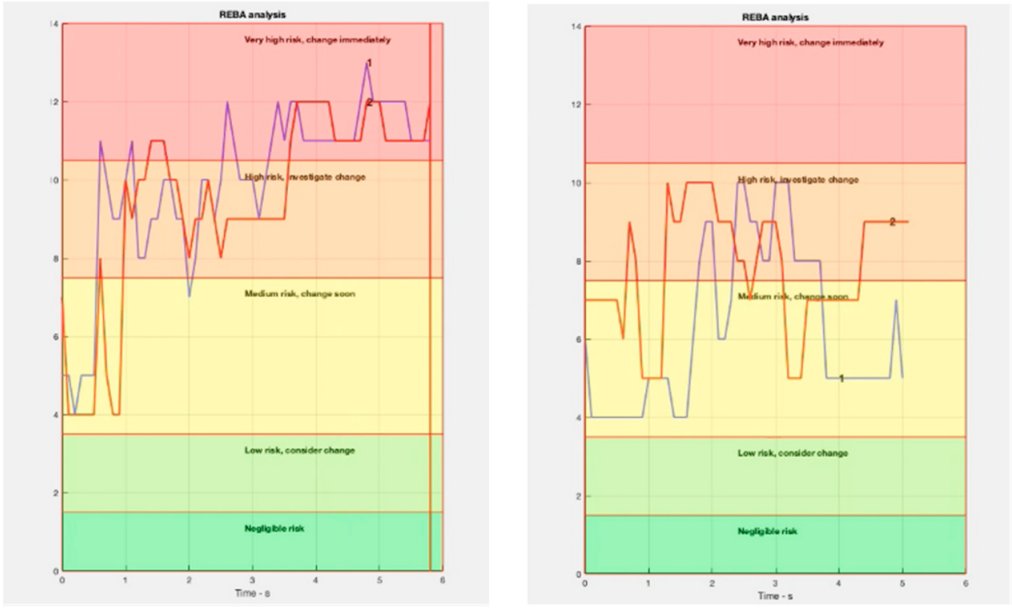
Figure 9. (**a**) The plot shows the muscle power values when performing the basic OTP 1 (blue color) and OTP 4 (red color). (**b**) The blue curve represents the values that this parameter reaches with the choke technique and the red curve corresponds to the throw technique.

3.5. REBA

This assessment method is based on the postures of the upper extremities, the lower extremities, the trunk and the neck and makes a distinction between the right and left side of the body. Thus, each part of the body is assigned a score that will be higher as its position is further away from its most relaxed posture. The biometric values of the extremities are instantly detected by the IMU sensors and the software transforms their signals into REBA scores.

The REBA method also takes into account the type of grip so that the more awkward the grip, the higher it will be scored.

Figure 10 shows the evolution of the REBA scores throughout the implementation of the OTPs and the traditional techniques. The top REBA score is 15, and it comprises five sets of values. A risk index and the recommendations or interventions correspond to each different risk level. The risk index can go from negligible to very high risk as follows: *negligible risk*, no action required; *low risk*, changes may be needed; *medium risk*, some changes are needed; *high risk*, changes are to be implemented as soon as possible; and *very high risk*, changes must be implemented immediately.



(**a**) (**b**)

Figure 10. (**a**) The left plot shows the REBA scores when performing the basic OTP 1 (blue color) and OTP 4 (red color). (**b**) The right plot is the same plot for the choke technique (blue color) and for the throw technique (red color).

It can be seen in Figure 10 that the basic OTPs do not exceed the set of values labeled as "High risk". However, traditional techniques scored above the "Very high risk" level for a considerable part of their implementation and were scored as high as 13 in their REBA.

4. Conclusions

Based on the results at a general level, with respect to the NIOSH criteria (greater value of asymmetry and compression force in traditional techniques than the OTP techniques considered here), the shear force in the L5-pelvis (in which traditional techniques exceed the 1400 N limit), muscle power (higher energy consumption in traditional techniques) and REBA risk levels (higher in traditional techniques), and through the performance of PITs—carried out by two male police officers with mesomorphic physical characteristics and of medium height—we can conclude that the traditional techniques are potentially more prone to risks of injuries for police officers performing them than the two OTPs that have been evaluated.

Therefore, training in operational tactical procedures for police intervention should be highly recommended.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/safety9020039/s1.

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Abbreviations

BoB	Biomechanics of Body
IMU	Inertial Measurement Units
L5-pelvic junction	Junction of the pelvis with the fifth lumbar vertebra
NIOSH	National Institute for Occupational Safety and Health
OTP	Operational Tactical Procedure
PEP	Police Ergonomic Parameters
PIT	Physical Intervention Techniques
PST	Personal Security Training
REBA	Rapid Entire Body Assessment
SBT	Scenario-based training
UOF	Use of Force

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