KICK FORCE ASSESSMENT OF DETAINEES INSIDE A POLICE PATROL VEHICLE RESTRAINT

FORÇA DOS CHUTES DE UM DETIDO DENTRO DA CELA DE CONTENÇÃO DE UM VEÍCULO DE PATRULHA POLICIAL

FUERZA DE LAS PATADAS DE UN DETENIDO DENTRO DE LA CELDA DE CONTENCIÓN DE UN VEHÍCULO DE PATRULLA POLICIAL

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ABSTRACT

Background: Detainees under the influence of drugs or psychotic episodes are likely to kick inside a restraint cage of a police patrol vehicle, causing damage. These vehicles, however, are essential to public safety and must be kept operable. Consequently, the components of the prisoner transport compartments need to be suitable for the impacts to which they may be subjected. The aim of this study was to compare the peak force of double leg kicks (bipedal kicks), single leg-kick (unipedal kicks) and isometric compression of double leg (isometric kick) of people locked inside a vehicle restraint cage. Methods: A total of 15 male Military Self Defense specialists were confined inside the vehicle and performed (dynamics) bipedal and unipedal kicks and isometric kicks on a force platform attached to the rail of a restraint cage. Results: A one-way ANOVA revealed that the peak isometric and dynamic bipedal kicks in the restraint cage were similar and greater than the peak of unipedal kicks (2324 ± 438 N vs 2149 ± 345 N vs 1638 ± 219 N, respectively). To prevent deformation or rupture of the restraint cabin, this study suggests materials and components with a resistance of 3614 N (average + 3 deviations from our sample). This would contribute to having fewer vehicles out of service for maintenance.

Palavras-chave: police cruiser; prisoner transport system; manufacturing; muscle power; security screens.

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RESUMO

Introdução: detidos sob a influência de drogas ou acometidos de episódios psicóticos são propensos a chutar dentro da gaiola de contenção de um veículo de patrulha policial, causando danos. Esses veículos, no entanto, são essenciais para a segurança pública e devem ser mantidos em funcionamento. Consequentemente, os componentes dos compartimentos de transporte de prisioneiros precisam ser adequados aos impactos a que poderão estar sujeitos. O objetivo deste estudo foi comparar o pico de força de chutes duplos (chutes bípedes), chutes unipodais e compressão isométrica de perna dupla (chutes isométricos) de pessoas trancadas dentro de uma gaiola de contenção de veículo. Métodos: Um total de 15 especialistas em Defesa Pessoal Militar do sexo masculino foram confinados dentro do veículo e realizaram (dinâmica) chutes bípedes, unipodais e chutes isométricos em uma plataforma de força fixada no trilho de uma gaiola de contenção. Resultados: Uma Anova unidirecional revelou que o pico de chutes bípedes isométricos e dinâmicos na gaiola de contenção foram semelhantes e maiores que o pico de chutes unipodais (2324 ± 438 N vs 2149 ± 345 N vs 1638 ± 219 N, respectivamente). Para evitar deformação ou ruptura da cabine de contenção, este estudo sugere materiais e componentes com resistência de 3614 N (média de 3 desvios da nossa amostra). Isso contribuiria para ter menos veículos fora de serviço para manutenção.

Keywords: viatura policial; sistema de transporte de prisioneiros; fabricação; força muscular; telas de segurança.

RESUMEN

Introducción: Las personas detenidas bajo la influencia de drogas o que sufren episodios psicóticos tienden a patear dentro de la jaula de contención de un vehículo de patrullaje policial, causando daños. Sin embargo, estos vehículos son esenciales para la seguridad pública y deben mantenerse en funcionamiento. Por lo tanto, los componentes de los compartimentos de transporte de prisioneros deben ser adecuados para los impactos a los que podrían estar expuestos. El objetivo de este estudio fue comparar el pico de fuerza de los golpes dobles (patadas bípedas), patadas unipodales y compresión isométrica de pierna doble (patadas isométricas) de personas confinadas dentro de una jaula de contención en un vehículo. Métodos: Un total de 15 especialistas en Defensa Personal Militar de sexo masculino fueron confinados dentro del vehículo y realizaron (dinámicas) patadas bípedas, unipodales y patadas isométricas en una plataforma de fuerza fijada al riel de una jaula de contención. Resultados: Un ANOVA unidireccional reveló que el pico de las patadas bípedas isométricas y dinámicas en la jaula de contención fue similar y mayor que el pico de las patadas unipodales (2324 ± 438 N vs 2149 ± 345 N vs 1638 ± 219 N, respectivamente). Para evitar la deformación o ruptura de la cabina de contención, este estudio sugiere materiales y componentes con una resistencia de 3614 N (promedio de 3 desviaciones de nuestra muestra). Esto contribuiría a reducir el número de vehículos fuera de servicio para mantenimiento.

Palabras clave: vehículo policial; sistema de transporte de prisioneros; fabricación; fuerza muscular; pantallas de seguridad.

1 INTRODUCTION

Brazil occupies third place in world's prison population with approximately 887 thousand incarcerated individuals (Azevedo *et al.*, 2018). During the first wave of the Covid pandemic, when violence indexes were smaller than before, the state of Rio de Janeiro registered an average of 47 on-the-spot arrests per day (Haber e Morosini, 2021). These on-the-spot-arrests require the detainee to be transported in the prisoner's partition of a police patrol vehicle (Sinhoretto e Lima, 2015). These partitions separate detainees from officers and are widely used in law enforcement detentions. There are reports that some detainees present violent reactions upon arrest, even after being in custody and placed in the vehicle's restraint partition. In some cases, they kick and damage the cage inside of the vehicle, especially when the detainees are under the effects of narcotic substances, alcohol, or psychotic crises.

According to the Brazilian law, damage to public property must be formally

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investigated. In the Military Police of Paraná State, formal inquiry procedures may take up to forty working days and impede vehicles from returning to regular use (PMPR, 2014). In addition to the unavailability of this police patrol resource, the costs and the bureaucracy involved are secondary effects (Hicks, 2006; Pelfrey, 2004). It has been estimated that in some cases, up to 52% of the fleet might be under repair (i.e., for general maintenance) (Ribeiro, 2018). In the state of Paraná, the official data of 2020 revealed that repairing restraint compartments of law enforcement vehicles cost approximately USD$18.000, causing difficulties in sustaining regular patrolling activities (Fernandes, 2019).

Therefore, understanding the way the restraining compartment is damaged – especially by kicking – may help engineers and others involved in designing safer and more resistant systems. The forces applied in a kick have already been investigated by other studies (Carvalho *et al.*, 2021; Cimadoro, Mahaffey e Babault, 2019; Doewes, Elumalai e Azmi, 2021a; Pozo, Bastien e Dierick, 2011a; Wąsik e Shan, 2015a; Wasik e Shan, 2015b), but the analysis of kicks to determine the resistance of some materials are few. Stodulka (2009) performed a study in which trained Tae Kwon Do and Military Self Defense individuals kicked windows and protective grids and bars; they concluded that the characteristics of the materials were insufficient to resist kicking. However, the kicks performed inside a restraint compartment cannot be compared to those analyzed by Stodulka (2009), since the dynamics of the kicks differs when performed in a seated posture and with back support. In addition, kicks performed inside the restraint compartment may be also performed with the soles of both feet and may be more powerful and damaging than when using just one foot. To the best knowledge of the authors, there have been no studies to assess the force applied against the restraint compartments of law enforcement vehicles.

This study was designed to determine the forces applied against the restraint compartment of police patrol cars using the soles of one or both feet from a seated position. In addition, the static forces applied to the restraining structure were analyzed. The correlation between the force applied during the kicks and the anthropometric characteristics of the volunteers were examined.

2 METHODS

2.1 PARTICIPANTS

Fifteen male Military Police Officers (MPOs) recruited from the Military Police Battalion of the state of Paraná volunteered to participate. The inclusion criteria were: ages between 18 to 55 years; not having sustained injuries or health-related problems that could compromise their physical activity performance; no ankle, knee or hip surgery history; experience in Military Self-Defense or Jiu-Jitsu. The procedures of the study were approved by the Ethics Committee of the Technological Federal University of Parana (number 4920187) and by their immediate Commander. The participants were informed of the procedures and signed an informed consent form.

2.2 ANTHROPOMETRY

The anthropometric characteristics of the participants are presented in Table 1.

Table 1 – Characteristics of Military Police Officers participants in the study

Measures	Mean ± SD
Age (years)	34.60 ± 6.67
Body mass (kg)	82.47 ± 9.54
Stature (m)	1.77 ± 0.10
Body Mass Index (kg.m^{-2})	26.4 ± 2.83
Trochanteric height (m)	0.93 ± 0.06
Foot length (m)	0.27 ± 0.01

Source: Prepared by the authors (2024).

Participants were assessed barefoot in a standing position. Stature was measured using a portable stadiometer (Sanny, São Paulo, Brazil), while body mass was recorded by an electronic digital scale (Garmin Scale, São Paulo, Brazil). The Body Mass Index (BMI) was calculated from body mass and height.

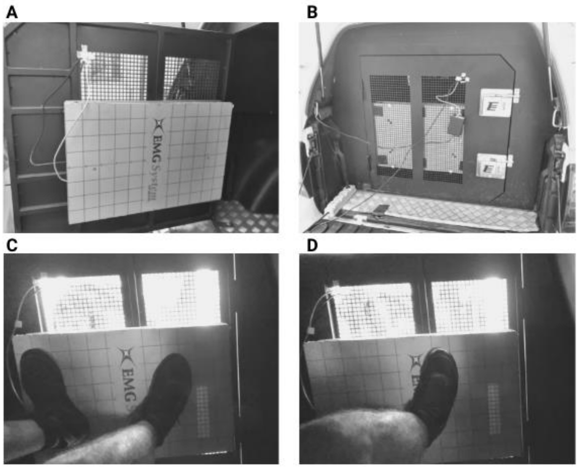
2.3 FORCE MEASUREMENTS

A force plate (EMG System, São José dos Campos, SP, Brazil) sampling at 500 Hz was mounted on the door of a standard restraint compartment (Figures 1A and 1B) fitted to a patrol vehicle (Renault model Oroch, year 2020). The restraint compartment was 1.20 m wide, 0.90 m long, 0.95 m high, and with a 0.82 m door. After a general, uncontrolled warmup, participants were instructed to assume a seated posture in the vehicle, with their back supported against the rear of the restraint compartment (i.e., facing the door). In this position, the angles of the ankle and knee joints ranged from 80º a 100º. In this position, the participants performed maximal isometric push-offs with both feet for 5 seconds (Figure 1C). Strong verbal incentive was provided during each of three trials and participants were requested to push-off as fast and as hard as they could. The highest isometric peak force was registered and used for analysis purposes. The rate of force development (RFD) was calculated by the force-time rate in the first 100 m of the test (Loturco *et al*., 2016).

In the tests of kicking with one (Figure 1C) or both feet (Figure 1D), the participants assumed the same position as in the isometric test and performed 3 maximal frontal kicks with their soles against the force platform. Participants wore their own regular sport shoes and were oriented to use their dominant leg for the unipedal kick. The peak and the RFD were also calculated.

The order of the tests was random, and a 30s interval was imposed between trials. The participants were allowed two trials to become familiar with the test protocol.

Figure 1 – The force platform fixed in the restraint compartment and the postures assumed during the test with both feet and the dominant foot



Source: Prepared by the authors (2024).

2.4 STATISTICS

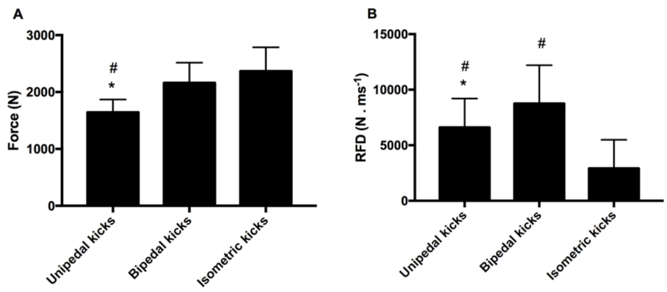
The Shapiro Wilk and the Levene's tests confirmed data normality and homogeneity, respectively. Standard descriptive statistics (mean and standard deviation) were applied. Peak force and RFD of the three tests were compared using a one-way ANOVA. The Bonferroni test was used to identify where differences occurred. The Pearson correlation coefficient was used to determine the relationship between anthropometrics and the force measurements (i.e., peak and rate for force development).

3 RESULTS

The results indicated that the kicking with one foot produced the lowest peak force, while no differences were found between the isometric and the bipedal kicks ($F = 19.7$; p <

0.001). The times to reach peak force after platform contact were: Unipedal kicks = 0.032 ± 0.005s < Bipedal kicks = 0.065 ± 0.061s < Isometric kicks = 3.394 ± 1.578s ($F = 70.541$ $p < 0.001$). On the other hand, the RFD showed differences between all tests ($F= 28.46$; $p < 0.001$), where the kicks performed by both feet (bipedal) showed the greatest RFD, the kicks performed with one foot (unipedal) and the isometric tests showed intermediate and lowest RFD, respectively. The peak and the RFD are reported in Figure 2, while the force-time representations are presented in Figure 3.

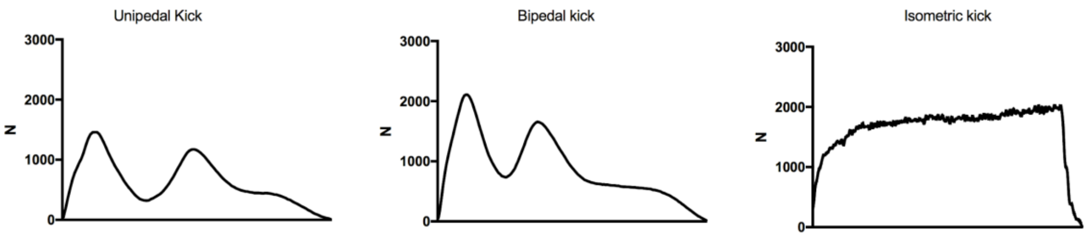
Figure 2 – Peak force (A) and the rate of force development (RFD); (B) across the kicks performed with one foot (unipedal), with both feet (bipedal) and the isometrically with both feet.



Legend: * Different Bipedal kicks ($p < 0.05$); # Different Isometric kicks ($p < 0.05$)

Source: Prepared by the authors (2024).

Figure 3 – Force-time curves of the tests performed unipedal (A), bipedal (B) and isometrically with kicks using both feet (C).



Source: Prepared by the authors (2024).

A positive correlation was found between foot length and the isometric result with kicks using both feet ($p < 0.05$). The other anthropometric variables were not significantly associated with peak strength in the other tests. A positive correlation was found between the body mass index and RDF Unipedal kick. The other anthropometric variables were also not significantly associated to the RDF of the other tests.

Table 2 – Correlation Coefficients between anthropometric measurements, strength and rate of force development (RDF) in the tests involving kicking with one leg, both legs and isometric with both legs.

	Peak Unipedal kick	Peak Bipedal kick	Peak Isometric kick	RFD Unipedal kick	RFD Bipedal kick	RFD Isometric kick
Peak Unipedal kick	1.00					
Peak Bipedal kick	0.07	1.00				
Peak Isometric kick	0.06	0.31	1.00			
RFD Unipedal kick	0.19	0.00	0.31	1.00		
RFD Bipedal kick	-0.01	-0.17	0.31	**0.65**†	1.00	
RFD Isometric kick	0.48	-0.27	-0.30	0.40	0.35	1.00
Stature	-0.03	0.30	0.19	-0.46	-0.36	-0.30
Weight	0.35	0.11	0.38	0.05	0.11	0.02
Body mass index	0.45	-0.20	0.22	**0.56**†	0.49	0.02
Trochanteric height	0.02	0.13	0.08	-0.49	-0.37	-0.32
Foot length	0.25	0.23	**0.60**†	0.29	0.18	-0.11

† $p < 0.05$

Source: Prepared by the authors (2024).

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4 DISCUSSION

This is the first study to report impact forces applied within the restraint cage of a police patrol vehicle. The peak forces applied to the cage by a single limb (unipedal kicks) were lower than those applied dynamically or isometrically using both feet (bipedal kicks). Additionally, the rate of force development (RFD) was higher in kicks performed dynamically (both unipedal and bipedal) than in those executed isometrically. In general, vehicle procurement processes lack sufficiently rigorous guidelines to eliminate substandard materials. Discussions on the specification of resistance parameters may contribute to the proper design and construction of restraint cages.

Dynamic kicks were characterized by two distinct force peaks, occurring at 32 ms for unipedal and 65 ms for bipedal kicks after contact. The first and largest peak corresponds to heel contact, while the second represents forefoot impact. Notably, peak forces generated using one leg were approximately 20–25% lower than those produced using both legs. The bipedal kicks performed in the restraint cage were comparable to those reported in Taekwondo (2160 N vs. 2089 N, respectively) (Falco et al., 2009). Conversely, isometric forces were nearly 30% higher than those produced by a single limb during dynamic kicks. This may be due to the backrest providing additional leverage, allowing participants to generate greater force. The nature of the kicks inside the restraint cage, where the sole is pushed against the grid under spatial and postural constraints, renders these movements unique compared to previously studied kicking variations (Doewes, Elumalai, & Azmi, 2021b; Pozo, Bastien, & Dierick, 2011b).

The lower RFD observed in isometric kicks compared to dynamic kicks can be explained by their execution technique. In isometric trials, participants begin exerting force with their feet already in contact with the platform, unlike in dynamic kicks where the force results from impact. Furthermore, the increased velocity of the foot in dynamic kicks enhances leverage and moment of inertia. Consequently, isometric kicks are less likely to cause structural damage. However, when suspects were allowed five seconds to apply isometric force, peak values were 8% higher than those recorded during dynamic bipedal kicks.

Among the anthropometric variables analyzed, only foot length was significantly associated with peak isometric force, while BMI correlated with RFD in unipedal kicks. During the pilot phase, it was observed that taller individuals had more difficulty maintaining posture and generating lower limb movement inside the cage. Thus, it was hypothesized that height would be inversely proportional to kicking power. However, no significant negative associations were found, despite marginal p-values between height and RFD in unipedal kicks (r = -0.46; p = 0.08) and between trochanteric height and unipedal RFD (r = -0.49; p = 0.06). BMI was significantly associated with unipedal RFD (r = 0.56; p < 0.05), and showed a marginal association with bipedal RFD (r = 0.49; p = 0.06). Weight alone did not show significant correlation with any of the kicking tests.

Participants in our sample had a relatively homogeneous height (1.77 ± 0.10 m), which may partially explain the lack of significant correlation between height and kick power. Future studies using more heterogeneous samples may yield different results. For instance, in the United States, approximately 75% of police vehicles are the Ford Crown Victoria Police Interceptor, with the restraint cage positioned behind the driver (McKinnon et al., 2014). In contrast, in Brazil, most restraint cages are located in the trunk area. Generally, these cages are constructed from tubular SAE 1020 steel or similar materials, using 20 mm square tubes with a 1.2 mm wall thickness, and feature a rear door with a horizontal opening, stainless steel hinges, and a lock with bolts (Ministério da Justiça e Segurança Pública, 2019). Therefore, different cage configurations may influence the peak forces recorded in our study.

This study did not assess the physical or psychological integrity of participants, as it was not possible to simulate scenarios involving detainees under the influence of drugs or experiencing psychotic episodes—conditions that may increase vulnerability. When reviewing design parameters and materials used in restraint cages, it is essential to ensure the dignity and safety of detainees during transport (Barroso Pinto & Franco Leão, 2023). Future research should also consider detainee integrity and human rights, including appropriate space, ventilation, lighting, and other conditions that ensure physical and mental well-being.

In the United States, approximately 23% of jails report using force to place a suspect in a restraint cage (Smith & Petrocelli, 2002). Inside patrol vehicles, kicking is the most common resistance technique used by apprehended suspects (Ferguson, 2015; Robinson, 2016). It is known that acceleration and extension of the knee and hip are key to generating powerful kicks (Miziara et al., 2019). The greater the angular velocity and moment of inertia, the more kinetic energy is transferred on impact (Doewes, Elumalai, & Azmi, 2021b).

Although there are various vehicle types and restraint cage configurations, our results contribute to estimating manufacturing and testing parameters for transport compartments. To prevent deformation or failure of the cage, and assuming a normal distribution covering 99.7% of the population, we recommend that the average of the highest peak force (~2300 N), plus three times the standard deviation (~438 N), be used as a benchmark. Thus, a testing parameter of approximately 3600 N is proposed for evaluating restraint cage components.

It is also important to consider the contact area of the foot (heel or entire sole) during impact. As noted, foot length was significantly associated only with isometric peak force. If dynamic impact forces exceeded isometric values, it would be necessary to calculate the kinetic energy transferred by the kick to define additional manufacturing parameters. However, since dynamic peak forces were lower, this calculation was deemed unnecessary in this context.

Finally, our study did not include measurements of lower limb muscle mass or perform kinematic analysis. Including such variables would allow for additional assessments, such as estimation of kinetic energy and movement characteristics. Similarly, we did not analyze peak punching force, upper limb isometric strength, or barefoot kicking. It is well known that the human leg is heavier than the arm and therefore capable of transferring more energy upon impact (Poortmans et al., 2005).

5 CONCLUSION

The dynamic bipedal and isometric kicks reached similar peak force values in the restraint cage. However, the rate of force development (RFD) was higher in the dynamic kick tests (both unipedal and bipedal) compared to the isometric kicks. Foot length was positively associated with peak force in the isometric kicks. These results contribute to establishing manufacturing and testing parameters for the resistance of the restraint compartment used in detainee transport. Materials and components designed to withstand forces of up to 3600 N would likely be sufficient to resist the kicks delivered by detainees. This could lead to fewer vehicles being taken out of service for repairs to the restraint area. However, it is crucial that any reformulation of parameters or materials used in constructing vehicle cages also considers the physical and psychological integrity of detainees, who may be under the influence of psychoactive substances. In this context, it is necessary to assess whether the proposed materials and structures can ensure not only the security of the vehicle’s structure but also the well-being of the detainees, who may be in more vulnerable conditions. This reflection is essential to ensure that the development of new technologies does not compromise the rights and health of detainees, thereby expanding the discussion on the human implications of these improvements.

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