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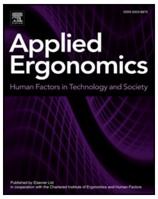

Police Officer performance and perception using light, medium and heavy weight tactical batons

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ABSTRACT

Objective: Compare the effectiveness of light, medium and heavy weight Police expandable batons from a performance and a user perception perspective.
Rationale: Police Officers are required to control combative individuals using less lethal tactics in proportion to the threat they face. Officers need to deliver sufficient force quickly and accurately. As such, it is important to select batons that are optimal for both performance and user experience.
Methods: Eleven active-duty New York Police Department Officers completed static and dynamic strike testing followed by a questionnaire. Six baton types were tested using different weights and lengths.
Results: Peak force, dynamic task speed and accuracy were similar between baton types. Peak impulse, forearm muscle activity, and discomfort were higher with the heaviest baton.
Conclusions: Lighter batons can deliver sufficient force to control assailants while imposing lower ergonomic costs and being preferable to the user with no impact on speed or accuracy.

1. Introduction

While violence experienced by front-line Police Officers has continually been reduced in recent decades, assaults against Officers remain the largest reported cause of Officer death and injury (Houser et al., 2004). At the same time, law enforcement agencies implement policies to guide Officers towards less lethal use-of-force tactics. These tactics are supposed to allow Officers to respond proportionally to the threat while acknowledging that the Officer needs to adjust their response from a low to a high threat or vice versa in fractions of a second (Terrill and Paoline, 2013). In a review of the state of less lethal weapons (Downs, 2007), the author advocates that the tools Officers use need to be safe, effective (as related to the ability to control an assailant as required), and able to vary proportionally to the threat (Downs, 2007; Jussila, 2007). Batons are a core component of the toolkit Officers require when using less lethal use-of-force tactics.

The role of a baton is to assist Officers in assailant control by creating the opportunity for: a) the placement of restraints; and/or b) tactical repositions and assessments (Vancouver Police Department, 2008). As such, an expandable Police baton must be quickly accessible, easy to manipulate and facilitate sufficient control over an assailant. In line with use-of-force policies, batons offer proportionality when controlling assailants by causing pain or injury of varying degrees through the application of blunt force. This can be an abrasion, contusion, laceration, fracture or any combination thereof (Davis, 1998; Johnson, 2003). The extent of the injury depends on the characteristics of the striking object, the amount of force inflicted on the body, the time over which the force is delivered (impulse), the part of the body struck, and the surface area of contact between the baton and body area (Davis, 1998; Johnson, 2003).

Apart from the immediate use of a baton in threatening situations, Officers are required to carry this and other tools constantly throughout their career. Police policymakers aim to minimize the weight and optimize the size and distribution of tools worn by Officers. They also aim to reduce discomfort and awkward postures. It has been shown that reducing the overall weight carried by Officers, at the waist level or otherwise, decreased both injury rate and injury claim amounts (New South Wales Police Force, 2011; Police Association of New South Wales, 2012). At the same time, Officers need to move with speed, coordination, and agility while manipulating the baton to control an assailant. The ability to use the baton with appropriate force while still effectively controlling an assailant depends on factors including Officer and assailant age, gender, size, fitness and skill. Characteristics of the baton such as the length, overall weight and weight distribution may also influence how easily an Officer can retrieve and manipulate the baton. A baton that is easier to manipulate without sacrificing its striking

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Abbreviations

NYPD	New York Police Department
EMG	Electromyographic
FCR	Flexor carpi radialis
ED	Extensor digitorum
MVE	Maximal voluntary exertion
CFC	Channel frequency class
CAD	Computer aided drawings
RM ANOVA	Repeated measures analysis of variance

capability would benefit the policing community.

Most research conducted to improve Police batons focus solely on strike capacity. A pilot study by Collie et al. considered baton weight and swing speed as primary factors affecting striking. This study ignored differences in mass distribution and user-comfort (Collie et al., 2009). Roberts et al. compared a modern steel expandable baton to a wooden baton. Impact forces were found to be within 9.6% of each other (Roberts et al., 1994). They also found that the modern expandable baton had greater potential to cause injury as it presented roughly half the cross-sectional area on target, doubling its pressure at impact. Strike capacity is not the only determinant required to control an assailant or evaluate the global effectiveness of a baton.

This study aims to evaluate six types of commonly used Police expandable batons. To provide a comprehensive evaluation, a practical definition of baton effectiveness was followed to address performance-based measures, physical demand on the Officer and user perceptions.

2. Material and methods

Twelve active-duty New York Police Department (NYPD) Police Officers were recruited to participate in the study. All participants were blinded to conditions, signed informed consent forms and the NYPD Union Office approved the study protocol. During the static program, participants tested batons of two lengths (21 and 26 inches) with light, medium and heavy weights (six batons in total) fitted with standard tips. During the dynamic program participants selected the baton length they felt would provide the greatest comfort and control. A post-program questionnaire addressed participants' perceptions related to comfort, exertion, and utility of each baton type. Baton order was randomized for both static and dynamic programs and users were blinded to the baton brand. Sample video footage of the programs can be found in supplementary material.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.apergo.2018.10.004.

Despite the importance of proportional response in baton use, all testing was performed at maximum effort due to it being more repeatable than scaled effort. Also, it was believed that scaling the strike force was an ability shared by all batons regardless of weight or length.

2.1. Static program

The static program evaluated the peak impact force and impulse participants exerted with each baton. Participants stood over a horizontal striking pad and performed five maximal exertion strikes with each randomly assigned baton, with appropriate rest between each trial. The striking method was left to the discretion of the Officers given their training in the use of batons. Beneath the striking pad were three load cells (PCB, #208C05, Depew, NY). Participants were instrumented with two surface electrodes to record electromyographic (EMG) activity from the flexor (flexor carpi radialis (FCR)) and extensor (extensor digitorum (ED)) muscles of the forearm (Delsys, Bagnoli, Natick, MA). Placement was identified through manual palpation and resistance testing. Each participant performed a maximal grip test to obtain their maximal voluntary exertion (MVE) which was used to normalize muscle activity during striking. The data acquisition system consisted of a CompaqDAQ chassis and two by four channel modules (National Instruments, 2x #NI9215 modules, Austin, TX) sampling data from each channel at 10 kHz. Custom data collection software utilizing MATLAB 2015a (MathWorks, Matlab, Massachusetts) with the Data Acquisition Toolbox was used (see Fig. 1).

2.2. Dynamic program

The dynamic program required participants to complete coordinated, high-impact, and accurate movements in the minimum amount of time possible. Participants selected their preferred baton length and completed the dynamic program three times, once for each light, medium and heavy weight baton types. Tasks included: a) an initial six-point zig-zag pattern strike shield course where participants were required to strike each shield two times prior to moving to the next one; b) then immediately strike a 18 kg heavy bag with a visible target and force measurement capability; c) complete an agility T-test

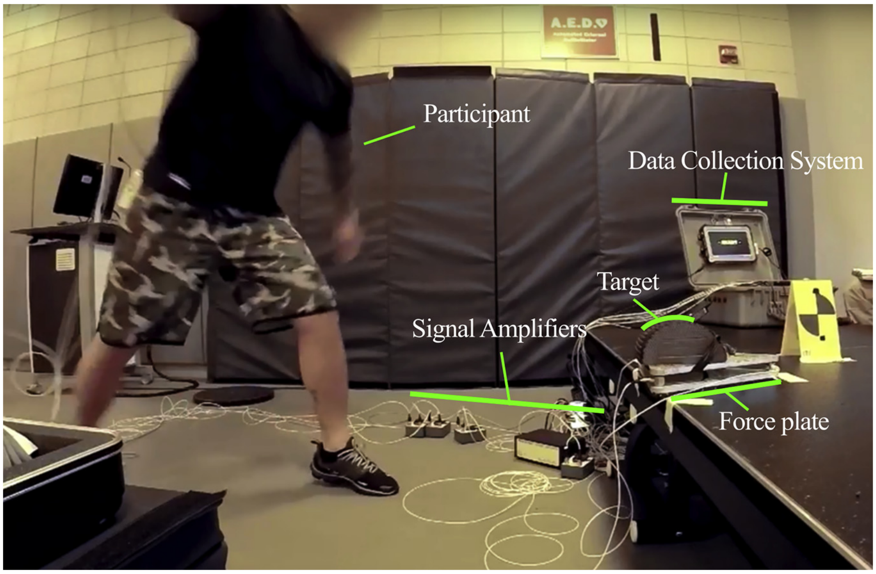

Fig. 1. Static program test setup.

to assess officer mobility with the different batons, d) finishing in a cone-tapping test to assess coordination (see Fig. 2). The initial zig-zag striking task was included in order to simulate a more realistic situation where fatigue would play a part in the performance of the officers.

Participants were timed during each component of the dynamic program. A three-axial accelerometer (described above) was secured inside the heavy bag at its center of mass to approximate dynamic impact forces of the initial strike. After each trial, participants responded to 10 questions assessing: comfort, exertion, perceived utility and baton weight. Participants completed a 5-point Likert Scale for each question and provided a written comment related to how successful they felt with each baton.

2.3. Data processing

All data were processed using MATLAB (MathWorks, Matlab, Massachusetts). EMG data from the static program were smoothed with a bi-directional high-pass Butterworth filter (1st order, fc = 410 Hz), de-biased, full-wave rectified, then low-pass filtered using a dual pass Butterworth filter (4th order, fc = 2 Hz), and normalized to maximal voluntary exertion (Buchanan et al., 2004; McDonald et al., 2013; Potvin and Brown, 2004). Peak resultant forces, peak impulse, and muscle activity (%MVE) were averaged across trials for each baton.

Dynamic program accelerometer data was filtered (channel frequency class (CFC) 1000 parameters) in MATLAB (SAE International, 2014). To obtain relative measures between batons, the peak resultant acceleration recorded during the initial strike of the heavy bag was multiplied by the mass of the bag and then normalized to the user's highest force strike recorded during the static trials in order to obtain relative measures between batons. Time to completion and heavy bag strike accuracy (distance from the center of the target, found by video recording) were also captured during each dynamic trial.

Properties of each baton including center of mass and moment of inertia were calculated from reconstructed computer aided drawings (CAD) using the known mass, length, and material densities. The axis of rotation while striking was determined through video footage and estimated to be at 90% the length of the baton.

2.4. Outcome measures and statistics

In order to properly qualify and quantify baton effectiveness, a combination of factors was investigated to compare the suitability of light, medium and heavy weight batons. The definition of baton effectiveness used includes:

1. Performance metrics:
   a. Ability to produce strikes beyond injury threshold levels of force and impulse during static striking.
   b. Speed of task completion during dynamic program environmental task simulation.
   c. Strike accuracy during dynamic program environmental task simulation.
2. User perception and interaction
   a. Minimizing user demand while performing strikes (as measured by forearm muscle activity).
   b. User perception of baton utility during the dynamic program.

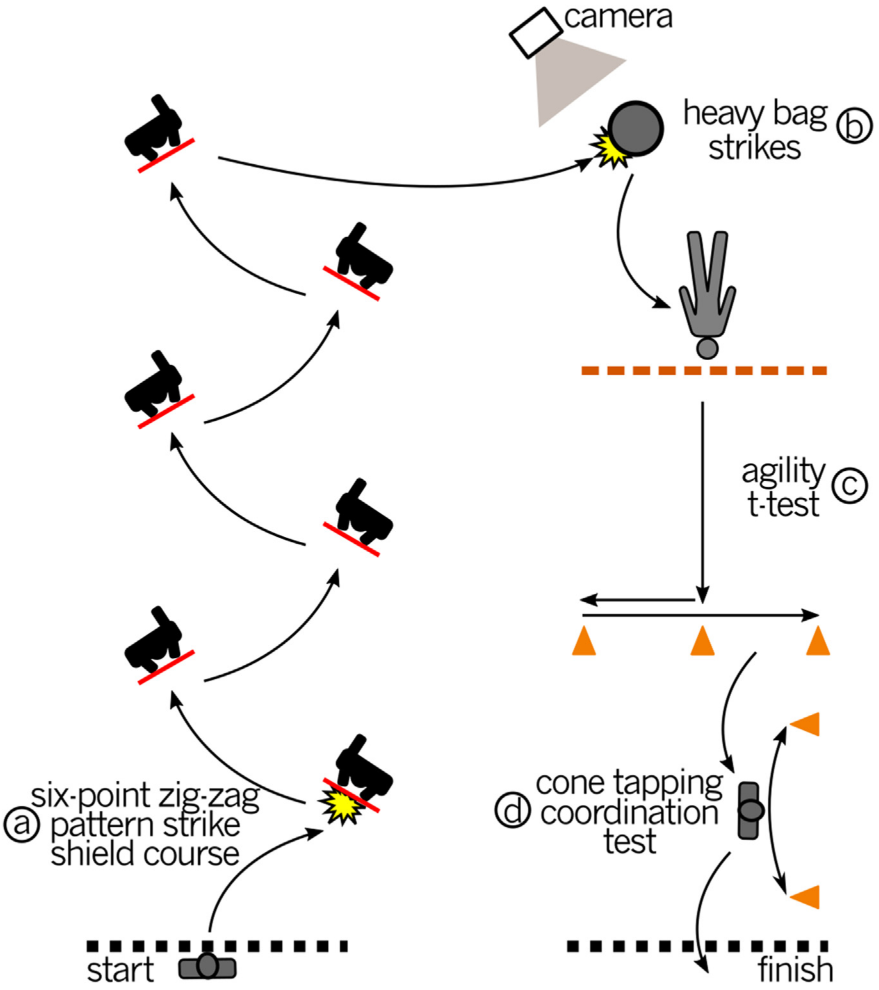

Fig. 2. Dynamic program tasks.

c. User perception of baton comfort during the dynamic program.

Descriptive measures of the mechanical properties were calculated for each baton. In the static program, absolute peak force, impulse, and forearm flexor and extensor muscle activity were compared between batons using a repeated measures analysis of variance (RM ANOVA) with six baton types (light, medium, heavy at 21 or 26 inches) as the within-subject factor with Bonferroni post-hoc testing for all significant main effects. Results for each component of the dynamic program were evaluated using a RM ANOVA with Bonferroni adjusted post-hoc testing for all significant main effects. The independent variable was baton type (light, medium, heavy as participants chose their preferred length) and the dependent variables were: normalized heavy bag strike force, distance from heavy bag target center, time to completion on coordination and agility courses. Post-program Likert scale questionnaire data were evaluated using Friedman tests and Wilcoxon Signed Ranked post-hoc testing. Finally, a Kruskal-Wallis Chi-square test was used to determine if batons perceived to be heavier were also perceived to be more effective as determined through questionnaire results.

3. Results

3.1. Descriptive characteristics of participants and batons

Participants were eleven males (Mean (SD): height = 177.3 (5.6) cm; weight = 86.5 (5.9) kg; age = 37.6 (4.8) years). One female was recruited for the study but could not participate due to prior injury. Baton physical properties can be found in Table 1. Baton mass ranged from 250 to 735 g. The position of center of mass, relative to the base of the baton ranged between 42 and 52% of the length of the baton.

3.2. Static program

The complete static program results summary can be found in Table 2, with all significant post-hoc difference between batons identified. Overall, peak impact force averaged at 4186 N across all batons ranging from 2281 N with Light-21″ to 6801 N Heavy-26″. Peak impulse averaged at 97.7×10^3 Ns across all batons ranging 67.1×10^3 Ns with Light-21″ to 147.4×10^3 Ns for Heavy-26″. The RM ANOVA showed no significant differences in absolute peak force between batons ($F_{1.6,11.44} = 1.51$, $p = 0.26$, $\eta_p^2 = 0.18$). Grouping peak force by baton weight also showed no differences ($F_{2,16} = 2.55$, $p = 0.11$, $\eta_p^2 = 0.24$). There were overall differences in peak impulse ($F_{5,35} = 4.85$, $p = 0.002$, $\eta_p^2 = 0.41$). When grouping by baton weight, impulse was higher with heavy compared to light and medium weight batons ($F_{2,16} = 10.88$, $p < 0.001$, $\eta_p^2 = 0.58$). Peak forearm muscle activity while striking averaged at 29% MVE at impact across batons. Extensor muscle activity had the widest range, from 21% MVE while using Medium-21″ to 45% MVE while using Heavy-26”. There were differences across batons for flexor ($F_{5,35} = 3.28$, $p = 0.01$, $\eta_p^2 = 0.32$) and extensor ($F_{5,35} = 1.51$, $p = 0.01$, $\eta_p^2 = 0.36$) activity. Pairwise post-hoc analyses with Bonferroni adjustments showed no significant differences between batons. When grouping by baton weight, flexor activity was similar ($F_{2,16} = 277$, $p = 0.93$, $\eta_p^2 = 0.26$) and extensor activity was higher with heavy compared to light and medium weight batons ($F_{2,16} = 13.38$, $p < 0.001$, $\eta_p^2 = 0.63$).

3.3. Dynamic program

Complete dynamic program results summary can be found in Table 3. Peak forces for the heavy batons were on average 3.2 ± 3.3 times that of light batons and 3.5 ± 3.6 times that of medium batons. However, peak heavy bag forces were statistically similar between baton weights ($F_{1.08,7.57} = 3.79$, $p = 0.088$, $\eta_p^2 = 0.09$ after Huynh-Feldt correction for sphericity). There were no differences in heavy bag strike accuracy between baton types ($F_{2,14} = 1.29$, $p = 0.312$, $\eta_p^2 = 0.18$). Time to complete cone-tapping and agility tests averaged at 23.8 ± 3.9 s and 15.4 ± 1.5 s respectively. Time to complete were similar between baton types (Coordination cone-tapping test: $F_{2,14} = 0.49$, $p = 0.62$, $\eta_p^2 = 0.07$; Agility T-Test: $F_{1.16,8.13} = 0.64$, $p = 0.47$, $\eta_p^2 = 0.08$).

3.4. Post-program questionnaire

Questionnaire results are summarized in Table 4. In 21 of 24 trials participants indicated they highly exerted themselves during the dynamic program. Participants indicated all batons were usable (mean score = 3.9, χ^2 (2) = 1.9, $p = 0.39$) and baton types perceived as being lighter were ranked equally as effective as heavier batons (χ^2 (4) = 4.0, $p = 0.41$). Questions addressing if the baton type contributed to discomfort revealed that users perceived differences between batons (χ^2 (2) = 12.0, $p = 0.002$). Heavy batons were perceived to cause greater discomfort compared to both the medium $p = 0.03$ and light $p = 0.003$ batons.

4. Discussion

This study aims to evaluate baton use with a practical definition of effectiveness that addresses environmental factors such as speed, accuracy and required force while considering ergonomic factors (i.e. physical demand and perceived comfort with the tool). It was observed that Officers could produce sufficient force while striking with modern expandable batons of all lengths and weights tested. There were no meaningful differences in speed or accuracy during the dynamic program. However, during the dynamic program users did perceive lighter batons to be more comfortable to use while being equally effective. This agrees with findings in the static program where the highest flexor and extensor forearm muscle activity was observed when using the heavy batons.

4.1. Performance with the baton

In line with current use-of-force policies, an Officer is required to control the assailant in a manner proportional to the threat. For a baton to be an effective instrument in accomplishing this goal, the force produced by a baton should be variable. In the current study, under static idealized force production conditions, average peak forces were observed between 2281 and 6801 N. Within the spectrum of proportional use-of-force a baton may be used to cause contusions, lacerations, fractures and finally skull fractures as a worst-case scenario. The forces likely to be associated with these events range from 601 N for bruising (Desmoulin and Anderson, 2011) to fractures in long bones of the upper extremity ranging from 1200 to 2940 N (Nahum and Melvin, 2010). Allsop et al. (1991) discussed blunt impact trauma causing skull fracture with a concentrated surface area such as a small circular plate 0.77 inch^2 occurred on average at approximately 5200 N (Allsop et al., 1991). Although, the soft tissue covering these bones will act to decrease pressure and distribute the impending load to other tissues.

Table 1
Baton properties.

Baton type		Light		Medium		Heavy	
Baton Designation Length	in	21	26	21	26	21	26
Baton Mass	g	250	313	463	572	617	735
Baton Actual Length	mm	509	652	503	643	533	665
Baton COM Distance From End of Handle	mm	265	338	213	274	274	338
Moment of Inertia about CoM	kg*cm^2	71.6	139	101	198	169	312
Moment of Inertia about Axis of Rotation	kg*cm^2	88.5	177	105	211	207	379

Table 2

Static program results (mean and standard deviation).

Baton type	Units	Light		Medium		Heavy	
Baton Length	in	21	26	21	26	21	26
Average Peak Load	N	2281 (1662)	3468 (1676)	2396 (1512)	5476 (7592)	4694 (2581)	6801 (5725)
Average Impulse[a]	Ns	67 (27)	93 (35)	73 (36)	82 (62)	124 (31)	147 (46)
Forearm Flexor	% of MVE	30.8 (17.5)	23.6 (16.6)	21.5 (9.94)	29.6 (12.9)	25.6 (11.0)	42.5 (21.3)
Forearm Extensor[b]	% of MVE	23.0 (8.63)	24.9 (10.1)	21.3 (5.91)	26.8 (8.63)	33.9 (14.3)	45.1 (17.3)

[a] Heavy-21″ showed higher impulse than Light-21” ($p = 0.03$), Medium-21” ($p = 0.01$) after applying Bonferroni adjustments.

[b] Extensor activity was higher with heavy compared to light ($p = 0.01$) and medium ($p = 0.01$) weight batons.

Table 3

Dynamic program results (mean and standard deviation).

	Units	Light Weight	Medium Weight	Heavy Weight
Normalized Initial Strike Force	none	0.59 (0.57)	0.56 (0.4)	1 (n/a)
Distance from Target Center	in	2.59 (1.11)	2.32 (1.25)	2.93 (0.6)
Coordination Course Time	s	24.2 (4.92)	24.4 (3.78)	22.85 (2.38)
Agility Course Time	s	15.12 (1.36)	15.51 (1.4)	15.43 (1.69)

*No post-hoc differences observed between baton types on performance metrics during dynamic environmental task.

Table 4

Median questionnaire score by baton type (1 as strongly negative to 5 as strongly positive).

Question	Light Weight	Medium Weight	Heavy Weight
Did the assigned baton contribute to your discomfort?[a]	1	1	2.5
How fully did you exert yourself during the program?	5	5	5
How effective was the baton you used?	5	4.5	5
Would your discomfort be reduced if you could choose a different baton?[a]	1	3	5
How usable was the assigned baton?	4.5	5	3.5
How did you perceive the overall weight of the baton you used?	1.5	2.5	5

[a] Significant difference between heavy weight and other batons on median discomfort scores, $p < 0.05$.

These tolerances are within the range observed in this study. It would be possible that all batons studied could cause fractures of these bones although at varying probabilities.

Officers performed the dynamic program with similar speeds and accuracy regardless of the baton weight. Participants chose the baton length they were most comfortable with. All participants, except one, used the 21 inch batons, the length of baton currently issued to these Officers. Lighter batons were considered as effective as heavier batons even though normalized strike force on the heavy bag was on average approximately 58% that of heavy batons, although these forces did vary between individuals and across baton types. Overall, modern batons of all weight classes perform similarly in the sense that injury threshold levels of force are met and they can all be used with similar levels of speed and accuracy during dynamic tasks. This similarity in performance highlights the importance of considering the user.

4.2. *User experience and perception*

From the post-program Likert scale questionnaire data, heavier batons were found to be associated with higher discomfort during the dynamic task. There was an immediate difference noticed by participants and their comments towards the heavy baton reflected this (participant 7: “More weight increased impact. Also, caused the hand to fatigue faster” and participant 10: “Most likely it would be too heavy and cumbersome for a practical patrol baton”). Quantitatively, forearm muscle activity was (~30%) higher when using the heavy batons. In contrast, lighter batons had a reduced absolute ergonomic cost, and were still found to be effective in terms of user preference and absolute strike capacity. Provided strike capacity is sufficient, a baton with a lower weight and required exertion is preferred and can facilitate completing Officer objectives while lowering risk of injury and the cost of those injuries over the course of a career (New South Wales Police Force, 2011; Police Association of New South Wales, 2012).

4.3. *Baton design*

While overall weight is used to distinguish between batons in this study, the design of the baton, particularly the moment of inertia about the axis of rotation (within the hand) plays an important role in optimizing and maintaining impact capability. The light and medium weight batons in this study both have lower moments of inertia about this axis than the heavier batons. This design supports the findings of higher user preference and lower physical demand. These batons strike capacity may be increased while keeping overall weight low by optimizing weight distribution to minimize weight but increase the moment of inertia about the hand. This design modification may be critical to both maintaining baton effectiveness while simultaneously reducing overall weight carried by Officers which decreases both injury rate and injury claim amounts (New South Wales Police Force, 2011; Police Association of New South Wales, 2012).

4.4. *Limitations*

Results from the static program demonstrate the importance of mechanical properties and ergonomic effects of the baton-user interaction. However, it should be noted that only forearm muscle activity was measured to approximate required demand. While two EMG placement sites on the forearm have been used to estimate demand during gripping tasks (Bao and Silverstein, 2005), baton striking requires coordination from the legs, torso, and arms. Total body technique would influence strike performance, and this was not evaluated in the current study.

Due to available time and participant fatigue only 3 dynamic trials were completed per subject, once at each baton weight with their preferred length. Randomizing the baton type helped counteract between subject variability, however, multiple trials with all batons would have provided stronger evidence for the observations in this study. Additionally, peak forces on the heavy bag were difficult to measure directly as load cells could not be rigidly attached to the heavy bag. Accordingly, a normalized measure of force was used to provide the relative effect of the same Officer using different batons on the heavy bag.

5. Conclusion

This analysis demonstrates the importance of evaluating baton effectiveness not only from performance-based metrics (i.e. strike capacity, speed and accuracy) but also from a user perception and experience perspective (perceived comfort, utility, physical demand). When the absolute peak force or impulse is sufficient to control an assailant, as demonstrated by all the batons assessed, usability and perceived comfort become of greater concern. It was shown that lighter batons can deliver sufficient force while imposing lower ergonomic costs and being preferable to the user with no impact on speed or accuracy. The baton design, particularly moment of inertia about the axis of rotation can help retain sufficient strike capacity while optimizing user experience. When Officers are comfortable with their equipment and confident in its utility, they are in a better position to apply use-of-force tactics proportional to the threat and successfully control their assailant. This comprehensive evaluation of baton effectiveness helps achieve this objective.

Declaration of interests

The authors of this manuscript have no conflict of interest in relation with this research. Although work was funded by baton manufacturer ASP Inc., authors had no interests past payment for services. Authors also did not have and continue not to have any holdings/ownership/bonus associated with the work performed.

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