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TR-10-94
The Tactical Baton

Pierre Gervais, Ph.D., Director
Pierre Baudin, Ph.D., Research Assistant
The Sports Biomechanics Lab
Department of Physical Education and Sport Studies
University of Alberta

TECHNICAL REPORT

June, 1994

NOTE: Further information about this report can be obtained by calling the CPRC information number (613) 998-6343

EXECUTIVE SUMMARY

The primary purpose of this project was to conduct a biomechanical comparison between various sizes of expandable tactical batons and the standard issue PVC duty baton. Comparison was made on those quantifiable mechanical variables that were deemed significant with respect to trauma and the intended use of the baton as an intermediate weapon. The study proceeded under the assumption that the baton, if used as intended, will be an impact device that can effectively control an assailant.

The three ASP expandable batons, the side handle baton and wood duty baton all produced smaller impact forces when compared to what was achieved with the PVC duty baton. In a theoretical model of impact pressure, the expandable batons produced, on average, higher impact peak pressures than those produced with the PVC baton.

A large number of interdependent factors which relate to the effective and appropriate use of these intermediate weapons must be considered in their evaluation. No single factor can conclusively dictate a baton's superiority over another with respect to the inherent risks to an officer, or assailant.

RÉSUMÉ

L'objectif principal de ce projet était d'effectuer une comparaison biomécanique des bâtons tactiques télescopiques de différentes tailles et des bâtons standard en PVC. On a comparé les variables mécaniques quantifiables jugées importantes en matière de traumatisme et d'utilisation du bâton comme arme à portée moyenne. Aux fins de l'étude, nous avons supposé que le bâton, lorsqu'utilisé comme prévu, permettait de maîtriser efficacement un agresseur.

La force de l'impact généré par les trois bâtons télescopiques ASP, le bâton à poignée latérale et le bâton de bois est inférieure à celle générée par le bâton en PVC. Selon le modèle théorique de pression d'impact, les bâtons télescopiques produiraient, en moyenne, des crêtes de pression plus élevées que le bâton en PVC.

Il faut tenir compte, pour l'évaluation, d'un grand nombre de facteurs interdépendants liés à l'utilisation efficace et pertinente de ces armes à portée moyenne. Aucun facteur ne peut à lui seul déterminer de la supériorité d'un bâton par rapport à un autre, en termes de risques pour l'agent ou pour l'agresseur.

INTRODUCTION

It has been proposed that the **Tactical Baton** could be an attractive functional alternative to the duty baton that is currently being used by members of the Edmonton Police Service and The University of Alberta's Campus Security. A primary justification for the adoption of the Tactical Baton is that this less conspicuous intermediate weapon will be carried more frequently by the law enforcement professions thus providing greater protection to the professional and potentially less risk to the law breaking individual(s) and public by reducing the potential use of a firearm. It has also been suggested by the manufactures and members of the local law enforcement agencies that the Tactical Baton being lighter and better balanced than traditional batons is a more manageable device to yield thus making it more suitable perhaps to smaller, less physically robust officers which again would provided for the benefits previously stated. The Tactical Baton is also less conspicuous than the traditional baton, a requirement of certain environments such as the university campus.

The manufacturers of the expandable batons (Tactical Batons) describe the baton as an effective impact instrument. A concern that has been expressed about the expandable baton is that due to it being made of a metal alloy (as opposed to a PVC compound or wood as in the traditional duty baton) it may potentially cause greater harm to an assailant than the traditional baton upon impact. In considering the consequences of impact with an expandable baton or PVC baton a number of mechanical factors must be considered.

A considerable amount of research on soft tissue injuries have focused on restraint systems and risk of injury given a high or low mass with a high or low velocity of impact. Viano and Lau (1988) confirmed that the velocity of compression brought about by the impacting device was a determining factor in soft tissue injuries. They also warned that the compression forces which deforms the soft tissue can cause fractures when the force level exceeds the tolerance of the underlying skeletal structure. To effectively control or stop an assailant's hostilities the impacting device, the baton, must be swung to strike with a large force achieved through a fast delivery. Woo and Chapman (1991) assert that in sporting activities where the objective is to generate high end point velocities such as seen in kicking or striking, a proximal to distal pattern of segmental sequencing is usually observed.

In the evaluation of the cushioning properties of shoes, the shoe manufacturer will assess the peak deceleration recorded after an impact (Nike, 1988). Here the lower the shock peak (peak force) the better the cushioning system. In contrast the greater the peak force the greater the shock felt by the impacted system. Arnheim (1989), in his discussion of bruises (skin) and contusion (muscle and tendons) in athletic activities, submitted that these soft tissue injuries were the result of compression forces or pressure with enough energy to crush tissue. Although soft tissue can withstand and absorb compression forces, bruises do occur when these forces are excessive. With respect to sport, the extent to which an athlete maybe hampered by a blow is dependent on the location of the bruise and the force of the blow. A sudden traumatic blow can cause pain and transitory paralysis caused by pressure on and shock to the motor and sensory nerves (p. 199). **A**rmament **S**ystems and **P**rocedures, Inc's. (**ASP**) state in their operating instructions that a strike should be made to the appropriate muscle group or nerve centers to affect control. Therefore in addition to consideration of peak force where the blow is delivered is a critical factor in an officer's successful defence against an attacker.

In Karate, Walker (1975) proposed that the objective of a strike was to maximize the deformation damage at the area of contact. Mechanically this relates to 1) the amount of energy lost to deformation (or the work done) during the impact, and to 2) the impact forces and stresses imposed. As described by Walker, the work done during the impact is equal to the change in energy or energy dissipated during impact and is given by:

$$\Delta E = \frac{(1 - e^2)}{2} \frac{M_1 M_2}{M_1 + M_2} v^2$$

where:

e = coefficient of restitution[1]
$M_1 M_2$ = the mass of the colliding objects
υ = velocity of the colliding objects

To evaluate the effectiveness of a baton to control or subdue an attacker where the assailant is hit determines the magnitude of the coefficient of restitution (*e*). Soft tissue and fat have a higher *e* (i.e. more elasticity) than bone covered by a thin layer of skin but a smaller *e* than would be found if the same strike were made on a large muscle group that was maximally contracted in anticipation on the blow. As is pointed out by Walker (1975) even though contact on say the forearm just above the wrist may produce a greater impact deformation, due to the small *e*, a strike to a higher *e* area such as the proximal end of the forearm "may result in more pain to the opponent" (p. 845). In looking at the above equation it is apparent that the speed of the blow is a critical factor. To maximize the effectiveness of a strike, holding the other factors constant, the strike should occur at maximum velocity in the swing of the baton. In a karate punch, Walker found that maximum velocity occurs at 70-75% of the fully extended arm. Therefore the punch is taught to be stopped within the opponent. Velocity can be complemented by stepping towards the attacker during the striking swing and/or striking when the opponent lunges towards the striker.

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[1]a constant determined by the nature of the bodies involved in the impact which serves as an index of the elasticity. $e = 1$ indicates a perfectly elastic impact whereas $e = 0$ describes an inelastic impact.

A final mechanical consideration on risk of injury as a result of a collision is that of the peak pressure. In considering the effectiveness of shoe cushioning, the designer may look at whether the design produces any high pressure areas that over an extended period of time will produce musculo-skeletal stresses. In judo force attenuation is achieved by spreading the force of impact over as great an area as possible therefore reducing the peak pressure on anyone body part alone (Hay, 1993). In contrast were the objective is to disable an attacker, to increase the effectiveness of a strike with a baton, increasing the impact pressure is highly desirable. In boxing a blow is spread over a rather large glove yet in the karate punch impact is primarily with 2 knuckles and the force is applied at a single point (Walker, 1975). To effect the same consequences of the blow the boxer may have to strike harder or with greater frequency to get the same impact result as achieved by the karate fighter.

In summary, from the perceived objective of successful defense against and disabling an attacker, how the baton is swung, (speed), where an individual is struck (*e*) and with how much force and pressure will determine the overall effectiveness of a strike or series of strikes with a baton. Since it is ethically impossible to directly ascertain the consequences of an impact with the baton on living biological tissue, evaluation must be inferred through those variables that are quantifiable and that are relevant mechanical determinant.

Given that the traditional duty baton is an accepted impact weapon used by the members of the Edmonton Police Service and the University of Alberta Campus Security, assessment of the efficacy of the **Tactical Batons** (expandable batons) can only be conducted as a comparative analysis to the current issue traditional duty baton. It was not the intent of this research assessment to measure the risks or make recommendations on the injury risks associated with the use of these batons whether it was the traditional baton or expandable type. Since the actual dimensions of the Tactical Batons are quite a bit different from the traditional duty baton, their use may alter their effectiveness if there is a significant change in the movement pattern employed during a strike. Therefore, a comparison between the movement patterns during a strike with the Tactical batons and the standard issue duty baton was also conducted.

METHODS

The objective of this research investigation was to compare the strike and movement pattern performed by skilled law enforcement professionals with the traditional duty baton and the expandable tactical batons. For the purposes of this project the following batons were used:

BATON	LENGTH	CONTACTING END CIRCUMFERENCE	MATERIAL
Standard issue Traditional Duty (PVC)	26 inches	3.1 cm	PVC
Traditional Duty (WOOD)	26 inches	3.1 cm	Wood
Side Handle	24 inches	3.1 cm	Aluminum
ASP 16" Tactical	16 inches	1.1 cm	aerospace grade steel alloy
ASP 21" Tactical	21 inches	1.1 cm	aerospace grade steel alloy
ASP 26" Tactical	26 inches	1.1 cm	aerospace grade steel alloy

A total of four skilled subjects from the Edmonton Police Service and University of Alberta's Campus Security volunteered to participate in this study.

SUBJECT	GENDER	WEIGHT	HEIGHT
1	male	229 lbs	5′ 10″
2	female	143 lbs	5′ 7″
3	male	171 lbs	5′ 9″
4	female	122 lbs	5′ 4″

All subject were given a written explanation of the study and all signed a consent form (copies of which can be found in the Appendix). Data was collected for two sperate tasks using the different batons:

THE IMPACT SWING

Subjects were fitted with Penny & Gilles flexible strain gauge Electrogoniometers over the wrist and elbow joints of their swing arm. These electrogoniometers monitored joint angle changes during the course of a swing with the baton. Although the subjects were fitted with an electrogoniometer to monitor wrist flexion and wrist adduction/abduction this data did not provided any additional insights into the movement and are therefore not reported here. Subjects were asked to swing and strike a force measuring device that was mounted on a concrete wall. The device could be adjusted for height. Figure 1 provides an illustration of the experimental set up. The impact device consisted of a metal rod which moved freely within a cylinder. At the base of the cylinder the rod made contact with a piezoelectric dynamic force transducer. At the contact site, at the other end of the rod, there was a 4" X 6" X 2" rounded piece of wood which was bolted to a small steel plate that was welded to the rod. In order to protect the subjects, the measuring device and the batons the contact site was heavily padded with dense foam material[2]. Subjects were allowed a warm up to acclimatize to the experimental protocol. A sufficient rest period was provided between trials. The subjects were instructed to first attempt a strike at a self determined magnitude of 70% of their maximum. Following this, subjects were asked to perform two maximum effort impact swings making contact on the center of the impact measuring device. The force data from the transducer and the joint angle data were collected via an analogue to digital board connected to an i386 lab computer. Data were sampled at 5000 samples per second (5000 Hz). Subjects repeated the 3 test trials with all the batons for a total of 18 trials each.

THE FOREHAND AND FOREHAND/BACKHAND SWINGS

Two classical practice/training movement sequences were also analyzed in this study. Since the batons were of varying dimensions, these batons could effect how the subjects perform. Subjects were fitted with retro-reflective markers over the joints of the swinging limb, shoulders, hips, knees and ankles. The batons were also marked with the retro-reflective tape to facilitate tracking end point trajectories. Subjects were video taped by 2 SVHS recorders positioned such that their optical axes intersected at approximately 90°. This provided 2 oblique views of the subjects trials. With each baton, excluding the side handle baton, the subjects were asked to perform a series of forehand striking swings and forehand/backhand striking swings while being video taped. To facilitate subsequent data reduction the lab lights were subdued and photographic lights were directed onto the subject from the two camera stations. Synchronization between the two camera views was achieved by turning on a LED, which was visible to both camera views, during the course of each movement pattern taping. Video data were subsequently digitized and the 3 dimensional spatial locations of each joint center and of the baton were reconstructed from

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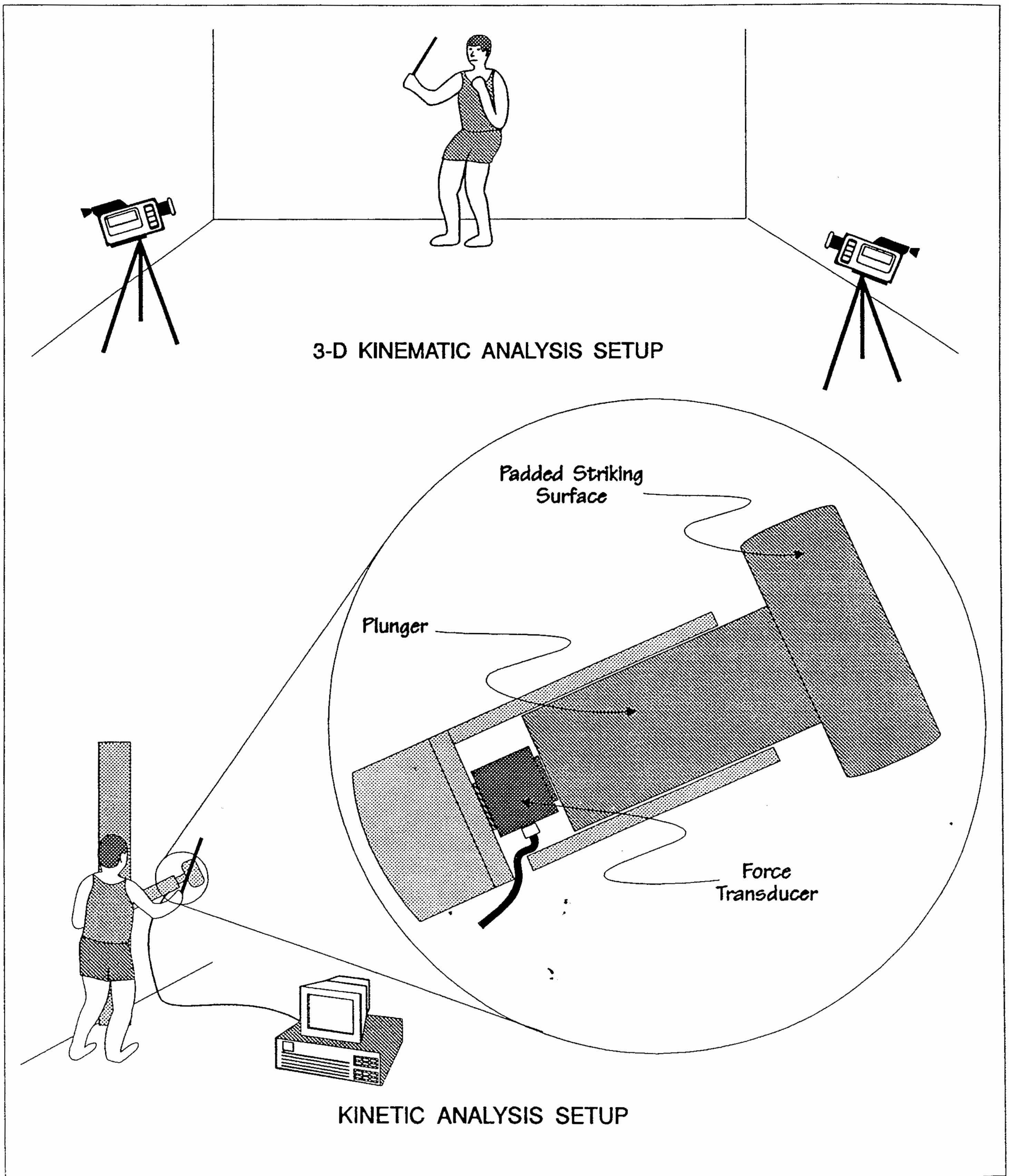
[2]the foam used was a gymnastics mat material.

Figure 1
EXPERIMENTAL SETUP



the two 2D views using the Direct Linear Transformation (DLT) method of Abdel-Aziz and Karara (1971). The video tape data were sampled at 60 Hz. Data were smoothed using a quintic spline. Temporal data as well as joint angle displacement and baton linear displacement data were determined. Data reduction and analysis was conducted using the Ariel Performance Analysis System.

RESULTS AND DISCUSSION

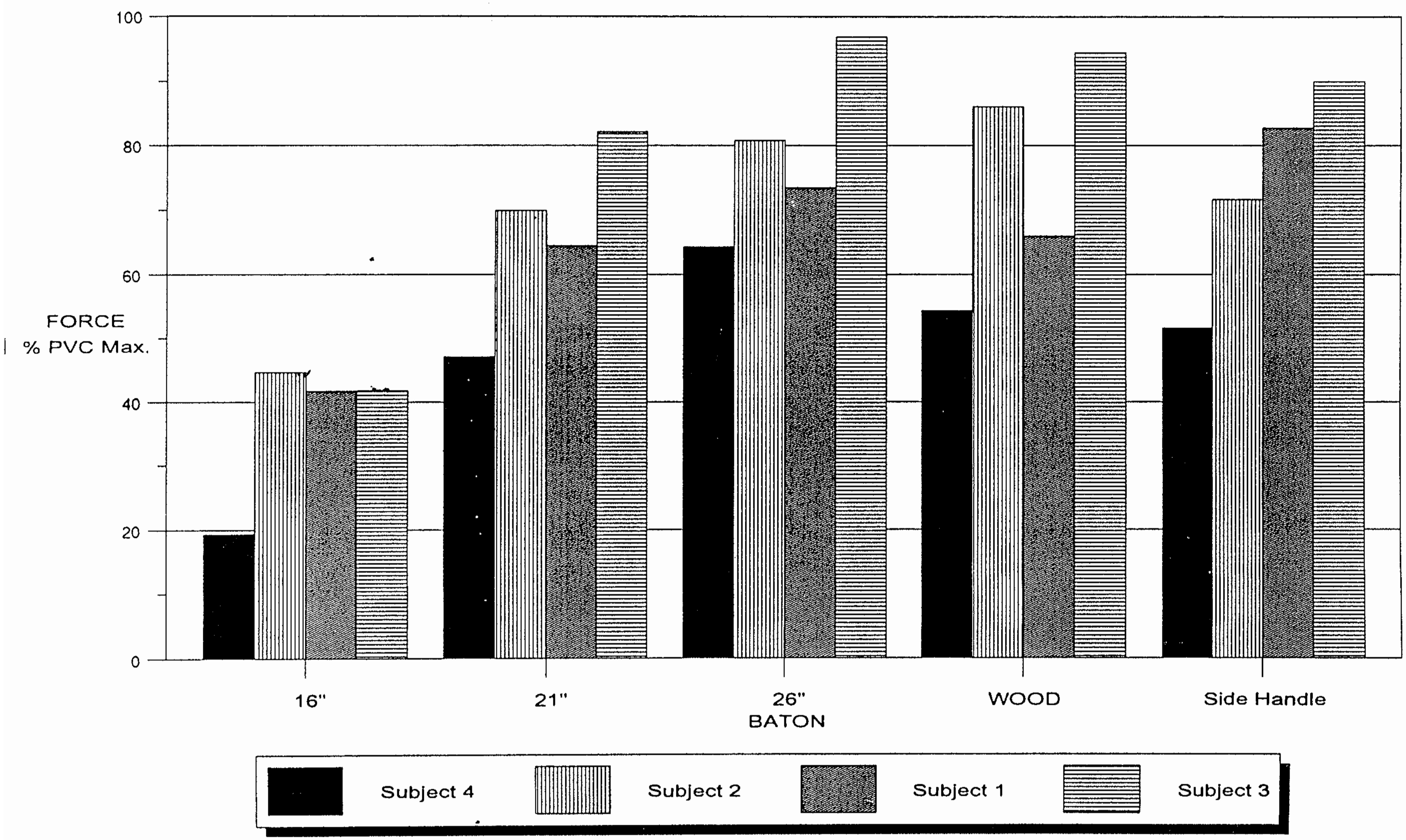
The purpose of this study was to investigate the relative mechanical differences between the standard issue duty baton (PVC) and the tactical (expandable) batons. The measurable mechanical determinants related to the effective use of the baton as an intermediate weapon are associated with the speed of the baton, the force applied in a strike and the impact pressure during a strike to an assailant.

Impact Force and Pressure

Impact force was measured using a force transducer in a custom built impact device. Since the PVC duty baton is currently the accepted impact weapon used by the Edmonton Police Service and Campus Security of the University of Alberta, comparison is made to it on the mechanical variables measured. Also, with respect to the objective of controlling an attacker's hostilities the efficacy of the other batons relative to a proven and accepted baton appears warranted. In the following reporting of the results, relative measures are given unless explicitly stated otherwise. The impact measuring device had to be padded. The extent to which this padding attenuated the impact forces would have required study well beyond the confines of this present project. In addition knowledge of absolute impact force magnitudes would not necessarily contribute to assessment of injury potential since there appears to be little or no normative data on human tolerances to these types of blows.

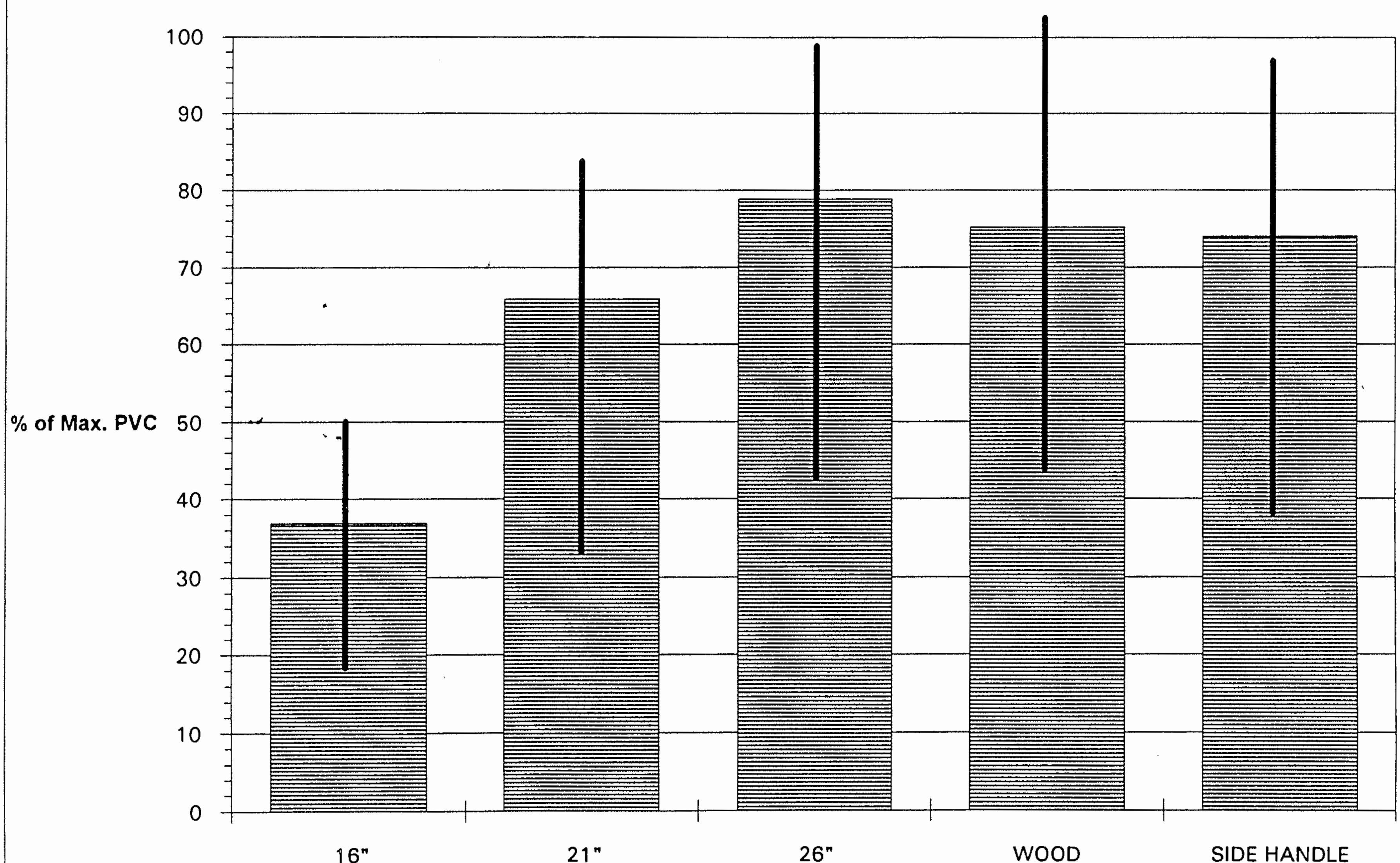
Subjects performed three trials with each baton for the impact force tests. The first trial with each baton, which was 70% of the subject's maximum, was used primarily as acclimatization for the subject and was not used in subsequent analysis. Unless otherwise stated, the results refer to the averages of the other 2 trials for each baton. All subjects produced less impact force with the other batons when compared to the peak impact force produced with the traditional duty baton (Figure 2). The 26" tactical baton, followed closely by the wooden and side handle batons, produced the greatest relative impact forces (Figure 2 and 3). The 16" tactical baton accounted for the least impact peak force. These results support the concept that to effect a greater deformation (ΔE) that the impacting mass can be influential, the greater the mass the greater the impact force. This would also imply that the smaller batons must be swung faster to get similar impact forces. The object of speed is partially met in the design of the expandable baton which has a reduced resistance to rotation (moment of inertia) due to reductions in either mass or length/mass distribution or both.

Figure 2
Average Peak Impact Forces



Values expressed as a percent of the subject's maximum impact force with the PVC baton.

Figure 3
BATON PEAK IMPACT FORCES



Combined average values of all subjects and trials (n=8). Vertical bars indicate the ranges.

Pressure is the force per unit area. For the purposes of illustration and comparison we modelled the impact pressure by suggesting a contact area in which the baton could compress soft tissue to ½ it's diameter (Figure 4) over a contact length of 6 cm. This would result in the following expression for pressure:

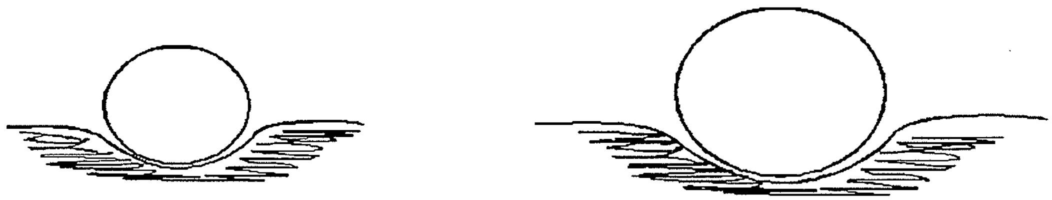


Figure 4 Baton contact with soft tissue tactical (left) vs PVC (right)

Peak Pressure = Peak Impact Force X Contact Area

where: Contact Area = 6 cm x ½ ($2\pi r$)
r = radius of that part of the baton which makes contact in the impact blow

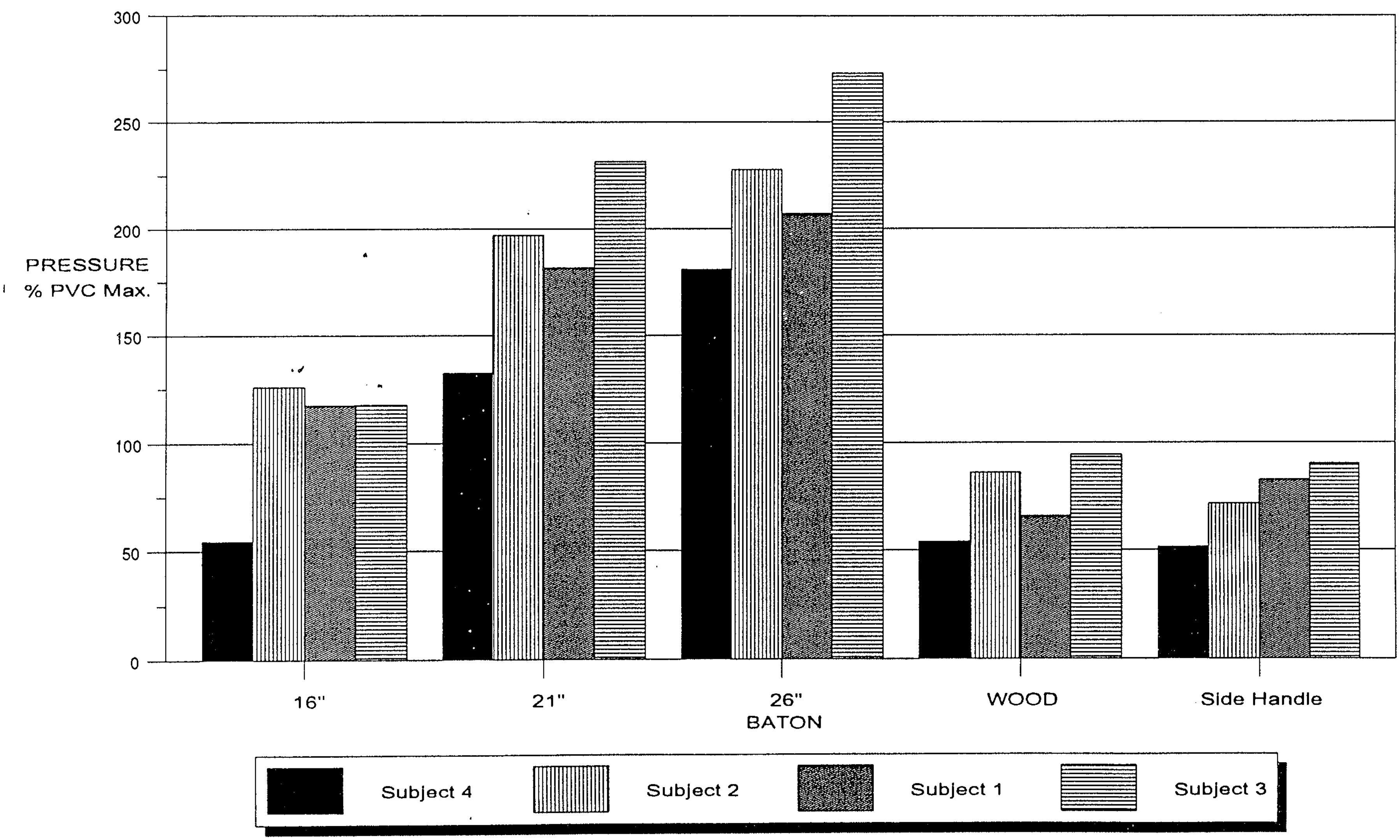
Force values were those measured in the impact test trials.

When compared to the peak pressure produced by the PVC baton during an impact, the 26" baton was greater for all subjects followed by the 21" and 16" batons (Figure 5). Averaging all trials (Figure 6) it was apparent that all three expandable batons were capable of producing higher impact pressures with the 26" reaching a maximum of approximately 2.75 times greater than the PVC. The 21" had a range from about 1.1 to 2.35 times the peak impact pressure seen in the PVC. Although the tactical batons had proportionally smaller peak impact forces, their smaller diameters of approximately one-third over the striking section of the baton, accounts for this relative pressure difference between the duty baton and these three expandable batons. The wooden and side handle batons both produced smaller peak impact forces and each has the same contact dimensions as that of the PVC. It is clear that these baton would produce comparatively less peak impact pressures relative to the other batons tested.

KINEMATICS

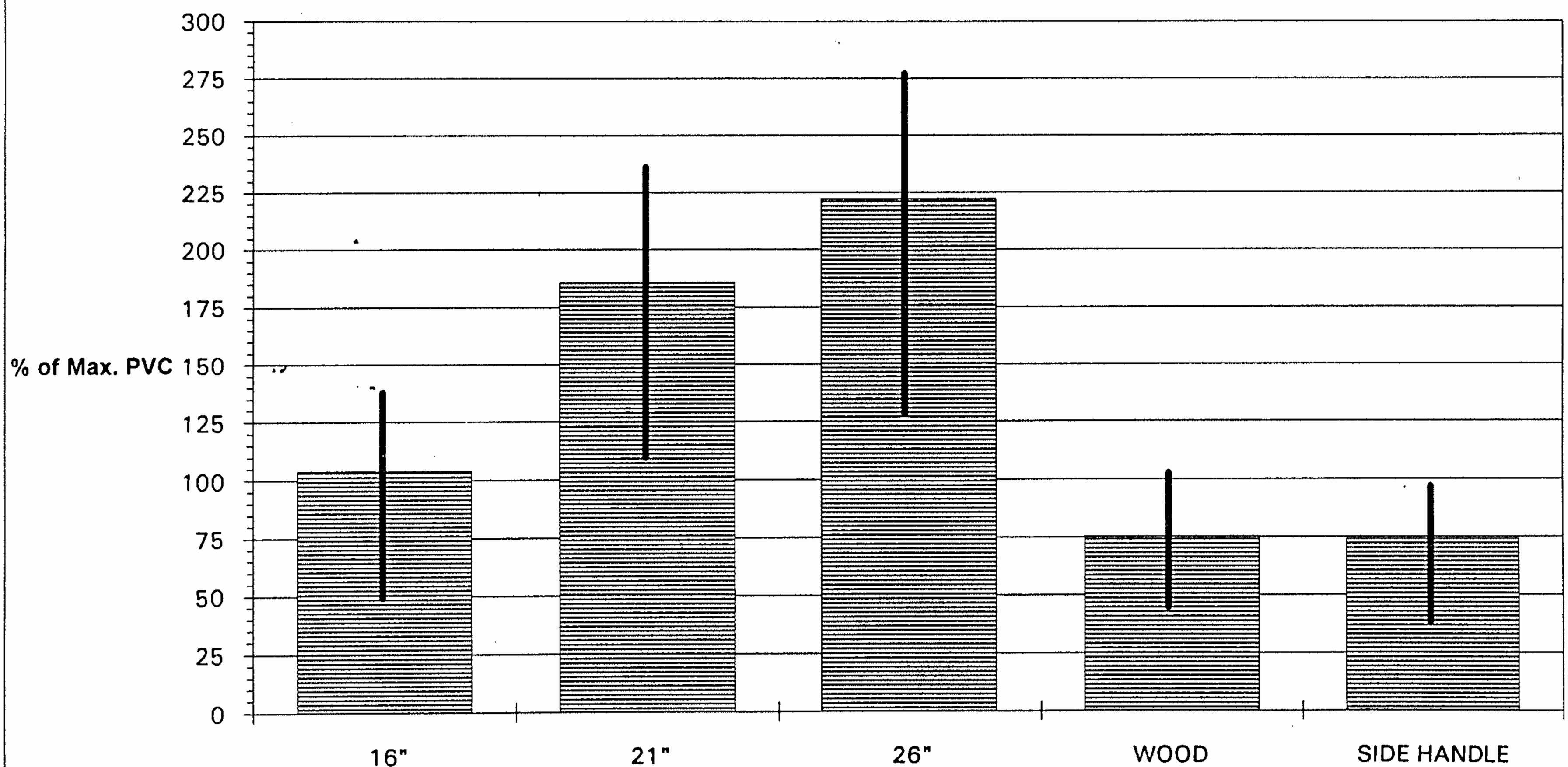
To disable or subdue an attacker the officer using the tactical baton can strike with maximum impact causing pain or temporary disability. Alternatively, the officer can disable the attacker with a series of rapid submaximal blows. Considering these factors, maximum force will be achieved at or near maximum arm extension speed (with the exception of the side handle baton because of the different swing technique). This has been found to occur at approximately 70-75% of arm extension in the karate punch (Walker, 1975). Timing the contact and maximizing speed could assure that the law enforcement professional is not already slowing the baton when contact is made with the assailant which would reduce the effectiveness of the device.

Figure 5
Average Peak Impact Pressure



Values expressed as a percent of the subject's maximum impact pressure with the PVC baton.

Figure 6
BATON PEAK STRIKING PRESSURE



Combined average values of all subjects and trials (n=8). Vertical bars indicate the ranges.

In Table 1 it can be seen that the subjects made contact when the arm was not fully

TABLE 1
MEAN ELBOW EXTENSION ANGLE AT CONTACT IN THE IMPACT SWING

	PVC	16 inch	21 inch	26 inch	Wood
SUBJECT 1	124.5°	129.5°	141.4°	133.7°	131.8°
SUBJECT 2	125.9°	122.7°	129.4°	140.9°	135.9°
SUBJECT 3	129.1°	129.7°	131.1°	135.8°	132.6°
SUBJECT 4	141.9°	152.7°	147.5°	135.5°	148.7°
AVERAGE	**130.4°**	**133.7°**	**137.4°**	**136.5°**	**134.8°**
SNAP	*125.9°*	*121.2°*	*128.7°*	*131.6°*	*130.0°*

extended. There was slightly more extension observed for the 21" and 26" tactical batons. Figures 7, 8, 9, and 10 graphically illustrate elbow extension along with when contact is made in the impact swing trials. On the basis of elbow range of motion data presented in Tables 2 and 3, contact and peak force were made earliest, on average, with the PVC baton and latest with the 26" tactical baton.

TABLE 2
TEMPORAL SEQUENCING
CONTACT AS % OF FULL IMPACT SWING

	PVC	16 inch	21 inch	26 inch	Wood
SUBJECT 1	68.74%	80.20%	47.15%	60.55%	70.19%
SUBJECT 2	58.29%	57.99%	69.27%	77.11%	68.97%
SUBJECT 3	71.6%	59.1%	85.63%	88.08%	72.01%
SUBJECT 4	63.47%	73.24%	65.77%	67.92%	67.68%
AVERAGE	**65.53%**	**67.63%**	**66.96%**	**73.42%**	**69.71%**
SNAP	*78.05%*	*68.71%*	*77.40%*	*78.19%*	*78.05%*

Figure 7
ARM EXTENSION DURING THE IMPACT SWING
Subject 1

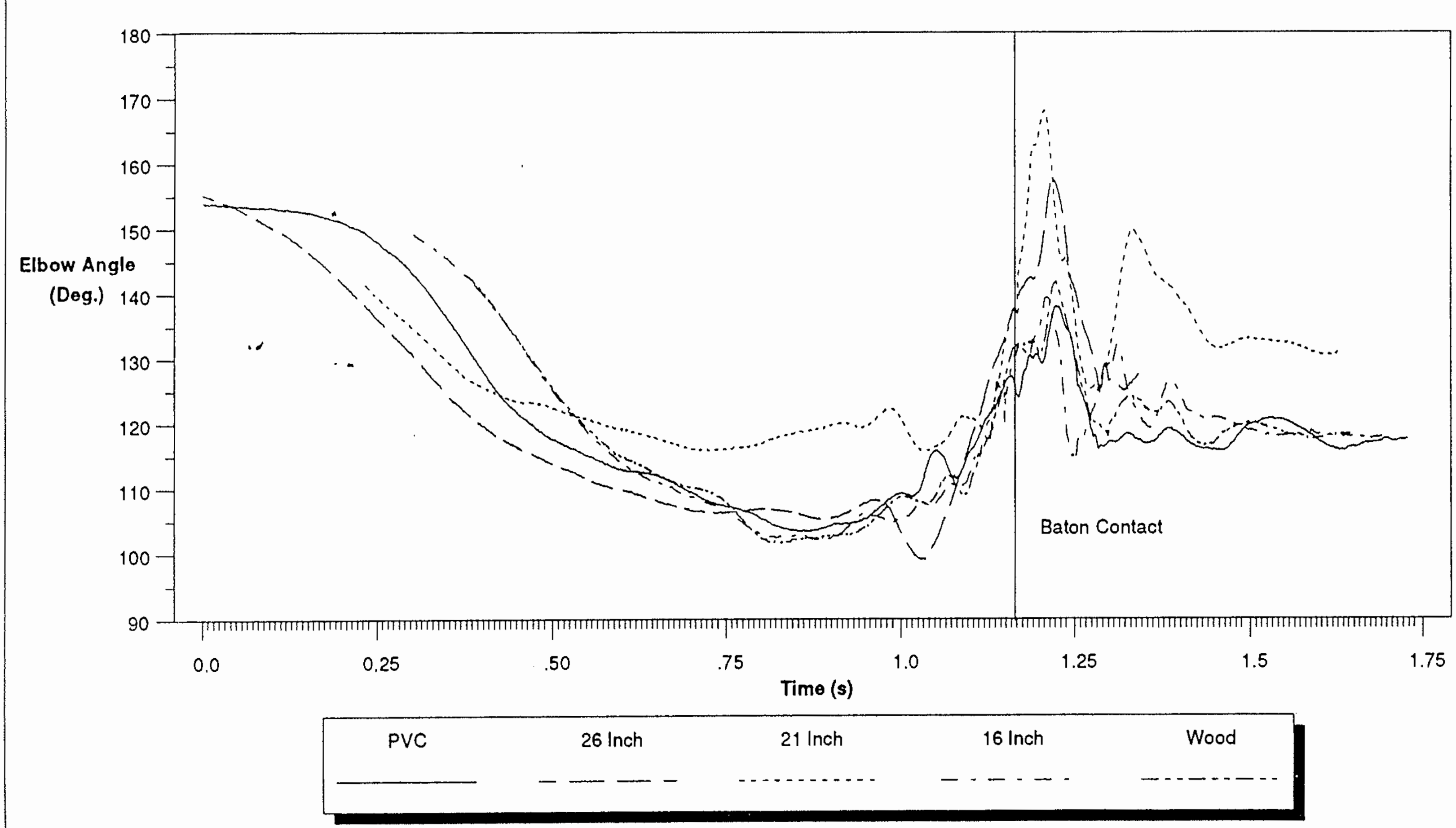


Figure 8
ARM EXTENSION DURING THE IMPACT SWING
Subject 2

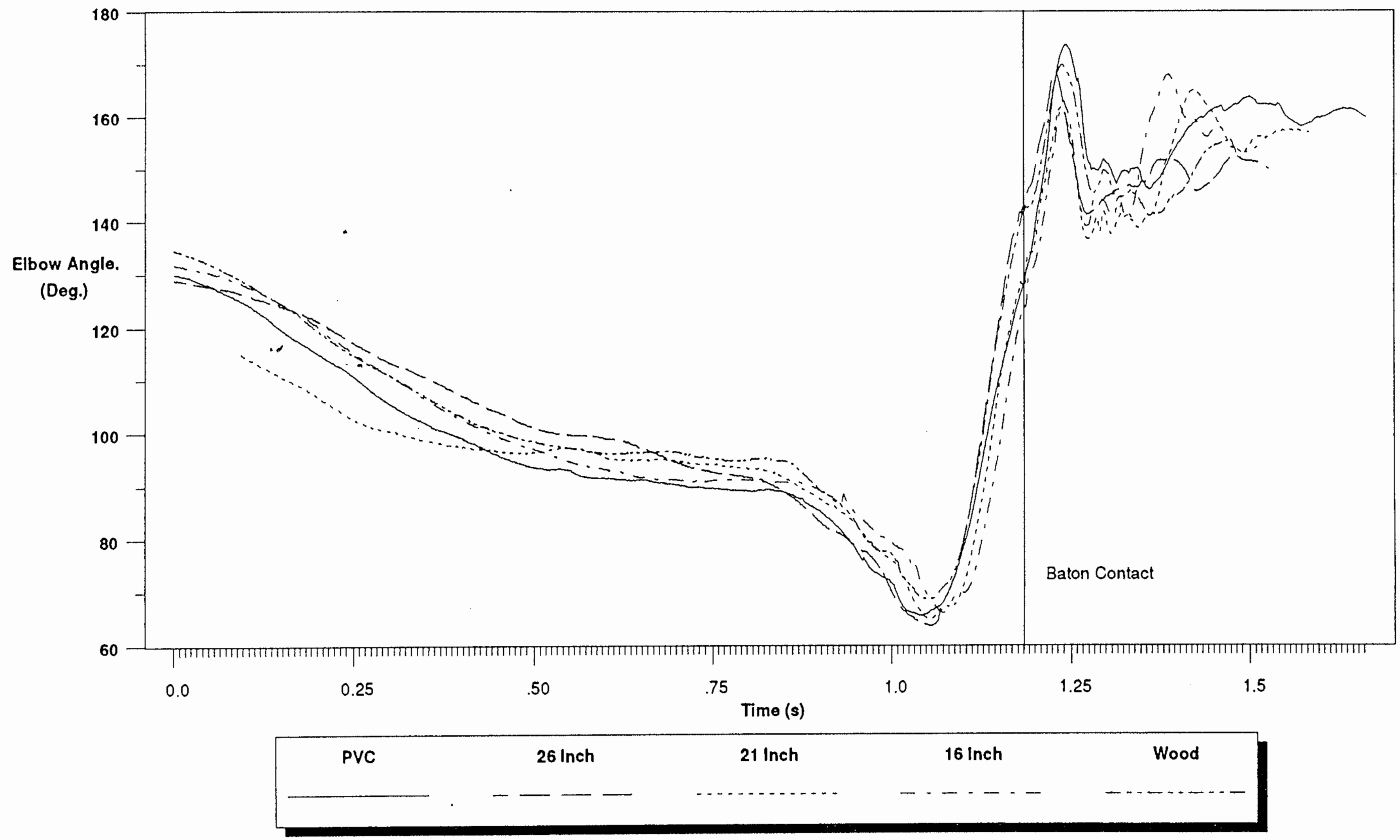


Figure 9

ARM EXTENSION DURING THE IMPACT SWING

Subject 3

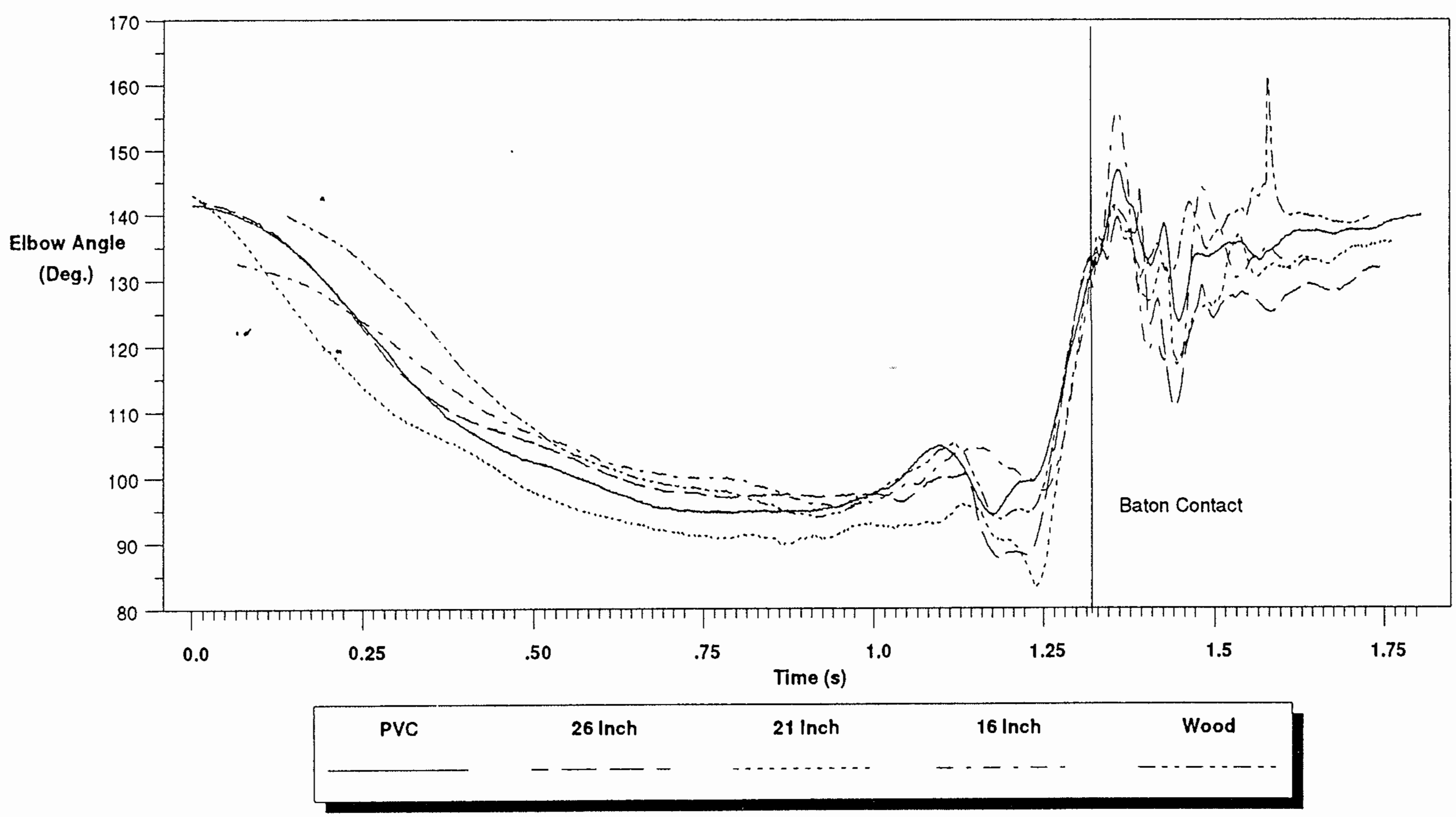


Figure 10
ARM EXTENSION DURING THE IMPACT SWING
Subject 4

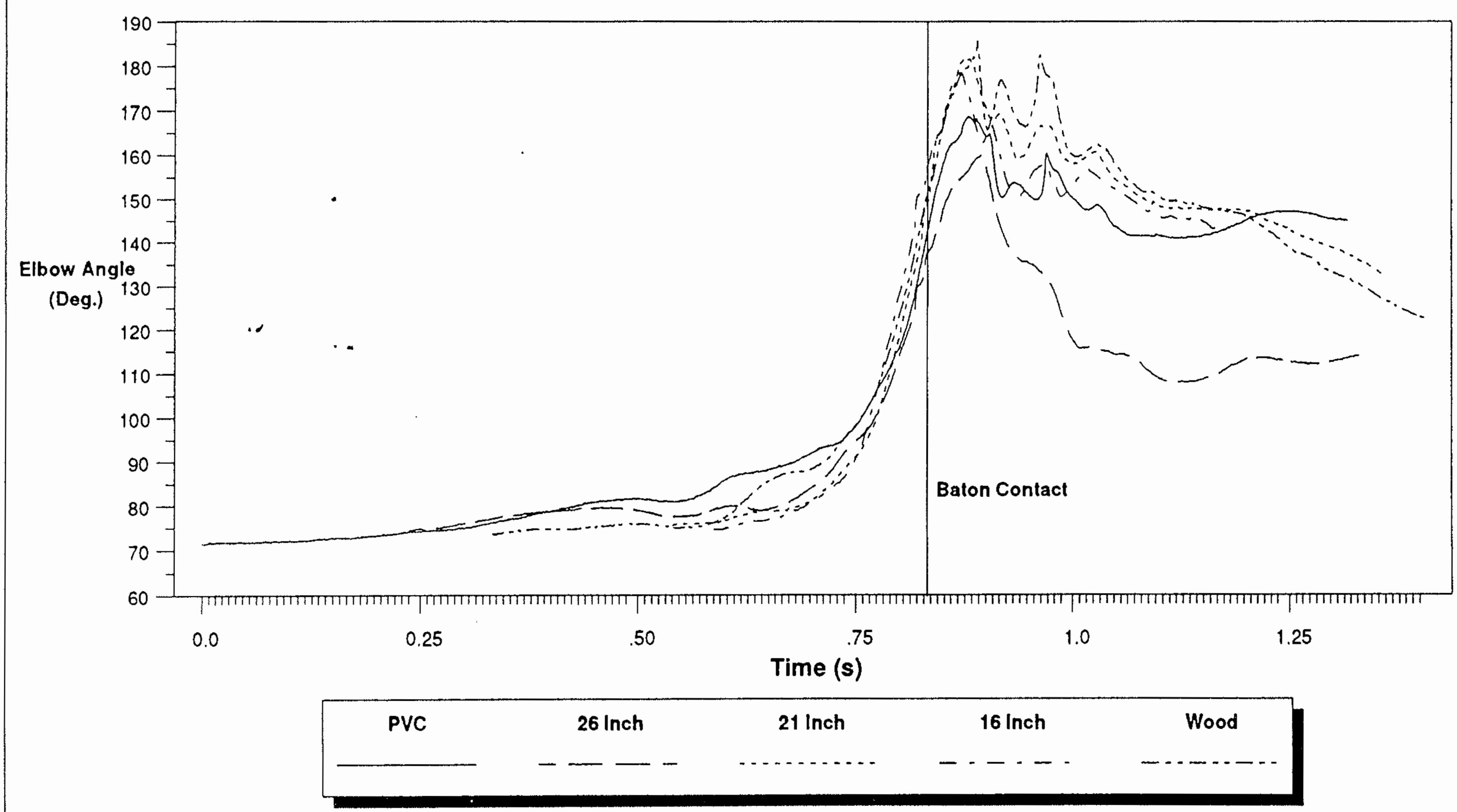


TABLE 3 TEMPORAL SEQUENCING MAXIMUM FORCE AS % OF FULL IMPACT SWING					
	PVC	**16 inch**	**21 inch**	**26 inch**	**Wood**
SUBJECT 1	67.82%	83.47%	52.2%	63.44%	70.20%
SUBJECT 2	60.60%	61.65%	70.97%	79.01%	70.71%
SUBJECT 3	75.34%	62.91%	90.53%	90.29%	72.97%
SUBJECT 4	70.57%	77.47%	71.09%	74.94%	72.07%
AVERAGE	**68.58%**	**71.38%**	**71.2%**	**74.36%**	**72.8%**
SNAP	78.19%	70.30%	82.59%	80.05%	78.19%

All subjects with all batons produced an effective swing in which contact and maximum force was achieved while the arm was still speeding up. Comparing the results for the Impact swing to those found for the forehand/backhand strikes (Table 4), all strikes, with the exception of the backhand portion, reached maximum speed much earlier in the swing than when maximum force was reached for the impact swings. One can speculate that with the lack of an explicit target maximum force, as reflected by speed, is reached earlier in the swing and uses up to 40% of the swing to slow the baton down. With the absence of a target or contact this slowing down is the body's natural protective mechanism against the momentum of the baton. However this practise may be in contradiction to the concept of specificity of training.

TABLE 4 MAXIMUM BATON VELOCITY AS % OF ELBOW EXTENSION					
A. FOREHAND STRIKE					
	PVC	**16 inch**	**21 inch**	**26 inch**	**Wood**
SUBJECT 1	70.00%	75.00%	76.92%	56.25%	73.33%
SUBJECT 2	64.29%	50.00%	60.00%	60.00%	50.00%
SUBJECT 3	46.15%	62.50%	66.67%	63.64%	53.85%
SUBJECT 4	55.56%	58.82%	58.82%	56.52%	65.22%
AVERAGE	**59.00%**	**61.58%**	**65.60%**	**59.10%**	**60.60%**
B. FOREHAND OF FORE/BACKHAND STRIKE					
SUBJECT 1	66.67%	78.57%	61.54%	60.00%	54.55%
SUBJECT 2	63.64%	66.67%	58.33%	72.73%	50.00%
SUBJECT 3	57.14%	66.67%	66.67%	57.14%	58.33%
SUBJECT 4	47.62%	64.29%	69.23%	62.50%	70.00%
SUBJECT	**58.77%**	**69.05%**	**63.94%**	**63.09%**	**58.22%**
C. BACKHAND OF FORE/BACKHAND STRIKE					
SUBJECT 1	100.00%	83.33%	50.00%	90.00%	63.64%
SUBJECT 2	69.23%	66.67%	61.54%	66.67%	61.54%
SUBJECT 3	77.78%	72.73%	90.00%	77.78%	70.00%
SUBJECT 4	47.62%	53.33%	64.29%	50.00%	55.56%
AVERAGE	**73.66%**	**69.02%**	**66.46%**	**71.11%**	**62.68%**

The impact strikes as performed in the laboratory may be considered as ideal representations of these skills. In the field other factors may be as equally important as maximum force or pressure with respect to an officer's safety and that of the public when it comes to controlling an assailant's hostilities. The frequency of the blows or the quick repetitiveness of the blows an officer can deliver to the assailant, the safer the situation. Striking swings with the PVC baton and 26" expandable baton on average took the longest to complete (Table 5). With the exception of one subject (subject 3) it took the officers longer to complete the swing with the PVC for the Forehand and Forehand/Backhand strikes.

Two subjects in the Forehand/Backhand took equally as long to complete the entire swing with 26" as they did with the PVC. Due to it's reduced moments of inertia (rotational resistance) resulting from it's reduced weight and shorter length, the 16" tactical baton, on average, provided for the most rapid swings. Therefore, although it may not produce the greatest forces the potential frequency of strikes is greatest in the 16" baton followed closely by the 21" tactical baton. However, the proximity of the officer to the assailant may put that officer at greater risk. An officer's safety may be compromised if they have to get too close to the assailant to deliver a blow regardless of how rapid or how forceful that blow may be. The closer the officer the less the potential options and possible reaction time they may have to an unexpected threatening move or event from the attacker.

TABLE 5
DURATION OF STRIKING CYCLE(S)

	PVC	16 inch	21 inch	26 inch	Wood
A. FOREHAND STRIKE					
SUBJECT 1	0.80	0.54	0.58	0.65	0.65
SUBJECT 2	0.97	0.85	0.85	0.90	0.83
SUBJECT 3	0.56	0.44	0.58	0.71	0.54
SUBJECT 4	1.19	1.02	0.95	1.12	0.92
AVERAGE	**0.88**	**0.71**	**0.74**	**0.85**	**0.74**
B. FOREHAND/BACKHAND STRIKE					
SUBJECT 1	1.04	0.54	0.80	0.83	0.94
SUBJECT 2	1.24	1.12	1.11	1.22	1.12
SUBJECT 3	1.09	0.83	0.97	1.09	1.04
SUBJECT 4	1.28	1.12	1.09	1.28	1.22
SUBJECT	**1.16**	**0.91**	**0.99**	**1.11**	**1.08**

The maximum forward reach that was achieved with each strike with each baton is given in Table 6. Measured from the subject's shoulder to the end of the baton, the 26" tactical baton had the greatest frontal reach during the course of the strikes investigated. Even though the PVC is longer there was a tendency on the part of the subjects to choke up on the baton thus reducing it's effective length. As would be expected the 16" tactical baton provided the smallest forward reach. The 21" tactical baton had a mean reach that was only 5 cm and 1 cm less than the PVC for the Forehand and Forehand/Backhand strikes respectively.

TABLE 6 MAXIMUM REACH (M)					
A. FOREHAND STRIKE					
	PVC	**16 inch**	**21 inch**	**26 inch**	**Wood**
SUBJECT 1	0.95	0.78	0.89	0.99	0.93
SUBJECT 2	0.90	0.76	0.85	0.90	0.88
SUBJECT 3	0.87	0.78	0.83	0.99	0.87
SUBJECT 4	0.92	0.77	0.86	0.97	0.88
AVERAGE	**0.91**	**0.77**	**0.86**	**0.96**	**0.89**
B. FORE/BACKHAND STRIKE					
SUBJECT 1	0.91	0.84	0.86	0.98	0.91
SUBJECT 2	0.98	0.89	0.95	1.01	0.94
SUBJECT 3	0.91	0.78	0.87	1.00	0.93
SUBJECT 4	0.88	0.78	0.96	1.02	0.96
AVERAGE	**0.92**	**0.82**	**0.91**	**1.00**	**0.94**

To effect the contacting surface with the baton mechanical work must be performed. As was indicated earlier in equation form, the baton speed is a very significant factor with respect to the observed change in energy (ΔE). Figures 11, 12, 13, and 14 illustrate the baton's end point speed for one trial with each baton for each subject during the Forehand strike swing. The curves for each subject, for the Forehand swing, with the different batons were quite similar in pattern differing mostly in amplitude only. On average all had higher peak speeds with respect to the speed achieved with the PVC baton with the exception of subject 2 who's 16" speed was approximately the same (Figure 12).

Figures 15, 16, 17, and 18 are illustrations of baton speed for a representative trial with each baton for each subject performing the Forehand/Backhand technique. In the Forehand/Backhand swings the patterns were again quite similar with amplitude differences. There was however temporal differences also. As has been previously discussed these temporal differences indicate consistently higher frequency with the 16" and 21" tactical batons. Meaning that the officers reached maximum backhand baton speed earlier after the forehand maximum speed with the 16" and 21" tactical batons than with the other three batons tested. With the exception of subject 3, which appeared to be the most proficient with the use of the batons, the wood and ASP 26" batons reached backhand peak speed at approximately the same time in the movement pattern. All subject for the forehand portion

Figure 11
FOREHAND SWING: BATON SPEED
Subject 1

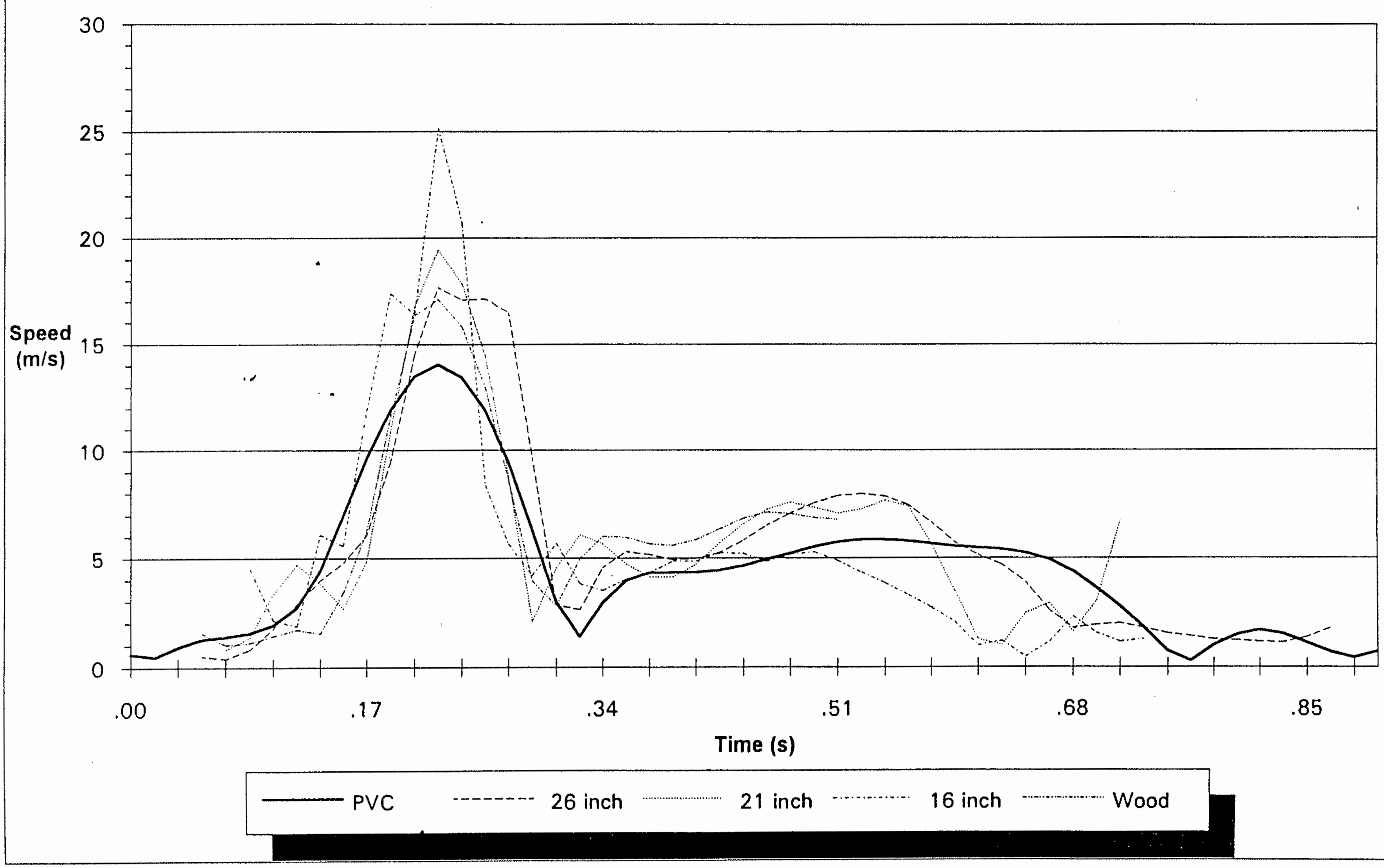


Figure 12
FORHAND SWING: BATON SPEED
Subject 2

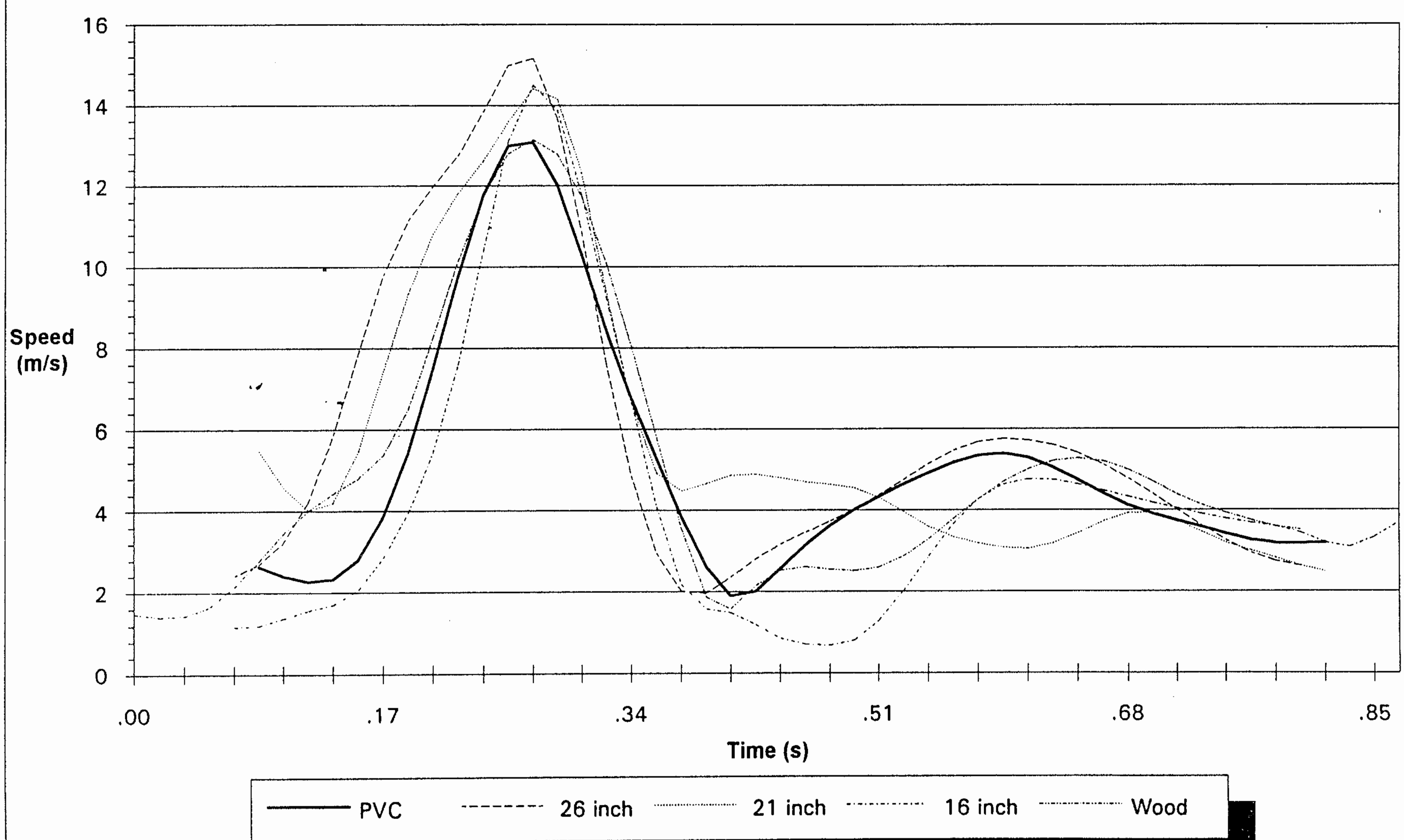


Figure 13
FOREHAND SWING: BATON SPEED
Subject 3

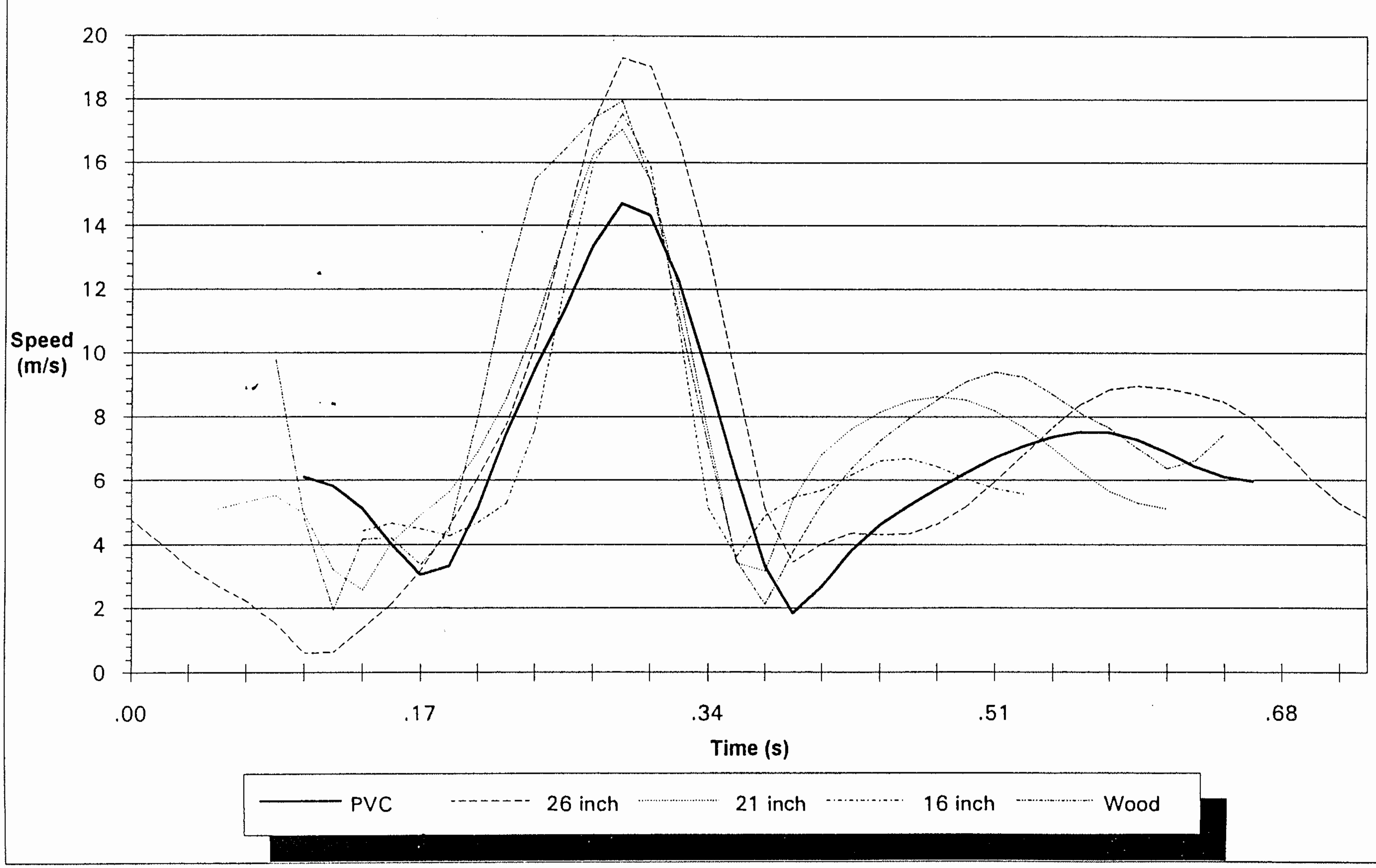
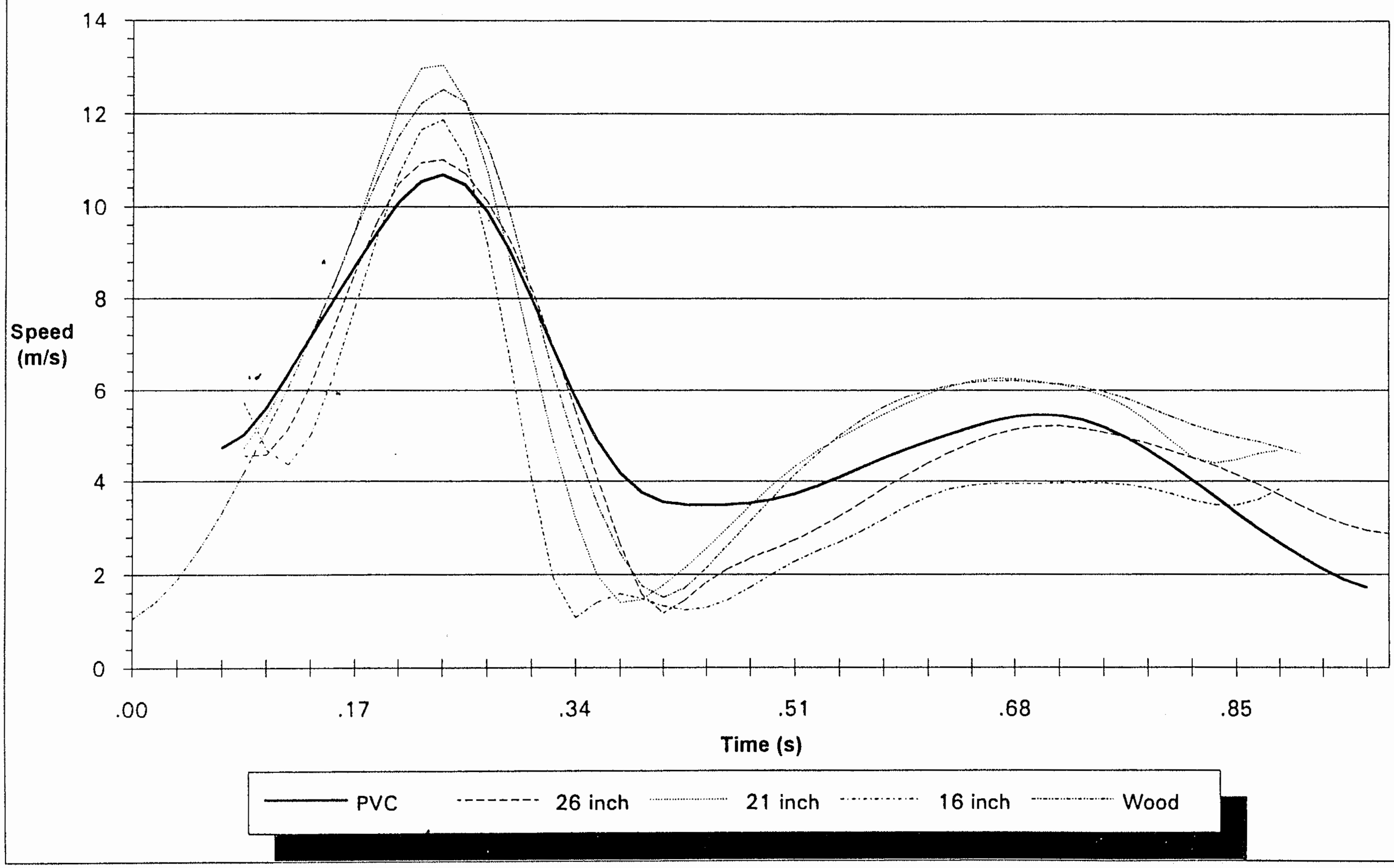


Figure 14
FOREHAND SWING: BATON SPEED
Subject 4



of the Forehand/Backhand swing generated greater speed with the other batons than they could produced with the PVC baton. However in the backhand portion of the Forehand/Backhand swing there was greater variance. Two of the subjects (subject 1 and 4) generated the least speed with the traditional duty baton for the backhand portion of the skill. Subject 2 (Figure 16) had 3 of the 4 swings with the different batons greater than the PVC in the backhand portion with the exception that the wood was slower than the PVC. Subject 3 yielded more speed with the Wood and ASP 26" batons and was slower with the two shorter batons, 16" and 21" for the backhand portion of the Forehand/Backhand swing.

THE SNAP

Subject 3, attempted a number of separate trials with a movement technique that emphasized a proximal to distal segment sequencing. The **snap** swing was quite similar to the other traditional technique of swinging the baton in the impact swing with the exception that the wrist action (adduction) was delayed. The wrist was uncocked at a point that corresponded to maximum arm extension velocity. Therefore the swing was initiated with some trunk rotation followed by elbow extension followed with a rapid wrist snap to contact. As each body segment reached near maximum velocity, the segment was stopped which transferred momentum to the more distal segment. This is the theory associated with the striking movement as described in such skills as the squash stroke discussed by Woo and Chapman (1991). This wrist snap in the swing has the potential to positively influence the baton's striking velocity, a factor that contributes to the magnitude of the work done by the striker. The peak impact forces measure for subject 3 using the traditional technique and the snap were not considered significantly different. Comparing the impact swing done with the more traditional impact swing with the impact using the snap technique had contact occuring at a slightly less extended arm position for subject 3 (Table 1). A review of the data listed in Tables 2 and 3 indicated that contact and maximum force were arrived at later in the swing with the PVC and Wood Duty batons and the 16" tactical baton. The snap performed with the 21" and 26" tactical batons resulted in an earlier contact and earlier maximum force when compared to the impact swing performed with the more traditional swing. Although it does not explain the timing seen in the 16" tactical, the two traditional duty batons had a later contact and thus reached maximum force later in their swing due mainly to their added rotational inertial which would reduce the baton's speed when momentum was transferred to it from the stop of the wrist. It maybe that this technique is warranted with the duty batons yet with only one snap trial per baton and with only one subject it is difficult to make any generalizations, however the theoretical implication do suggest that further investigation should be pursued.

Figure 15
FOREHAND/BACKHAND SWING: BATON SPEED
Subject 1

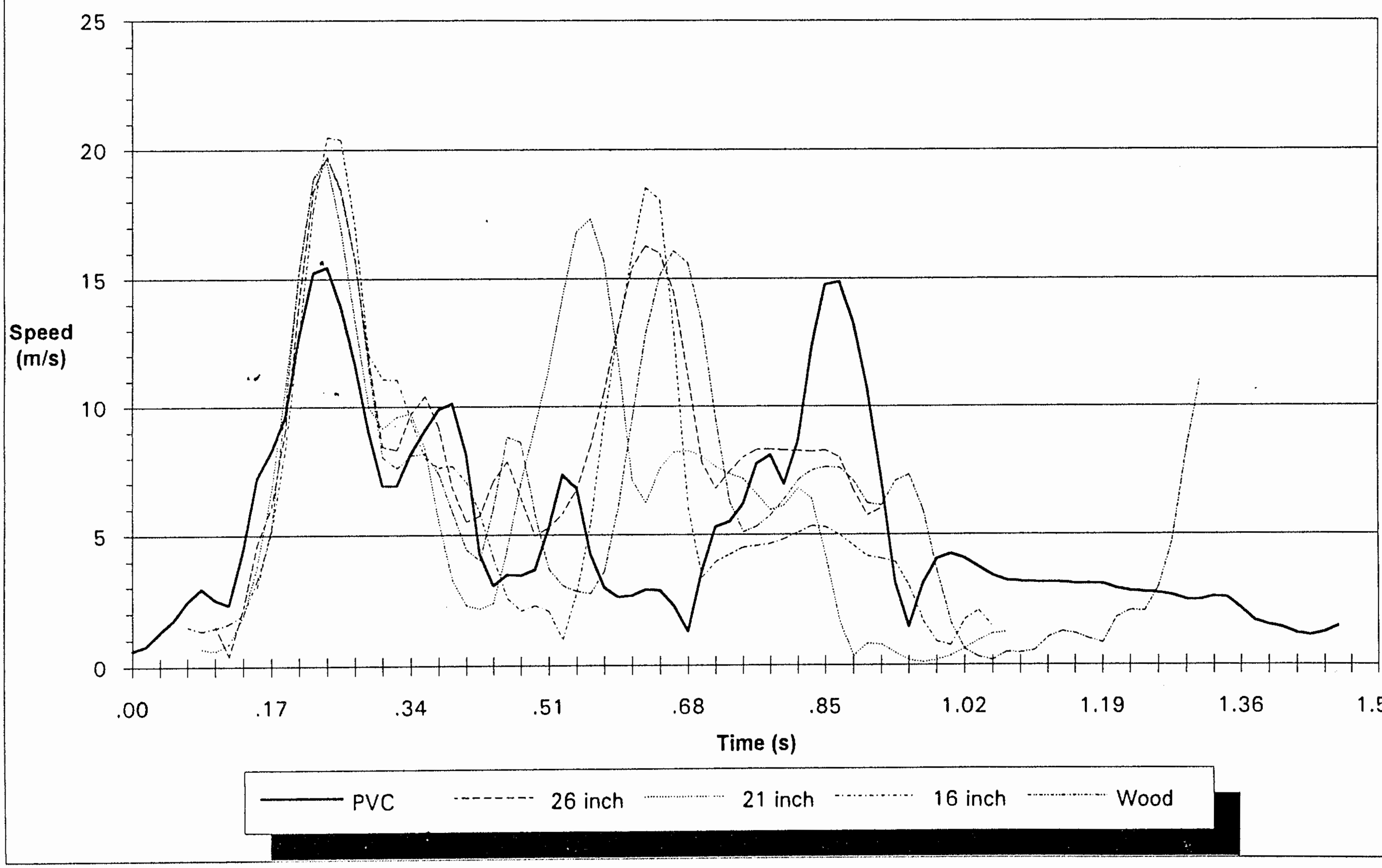


Figure 16
FOREHAND/BACKHAND SWING: BATON SPEED
Subject 2

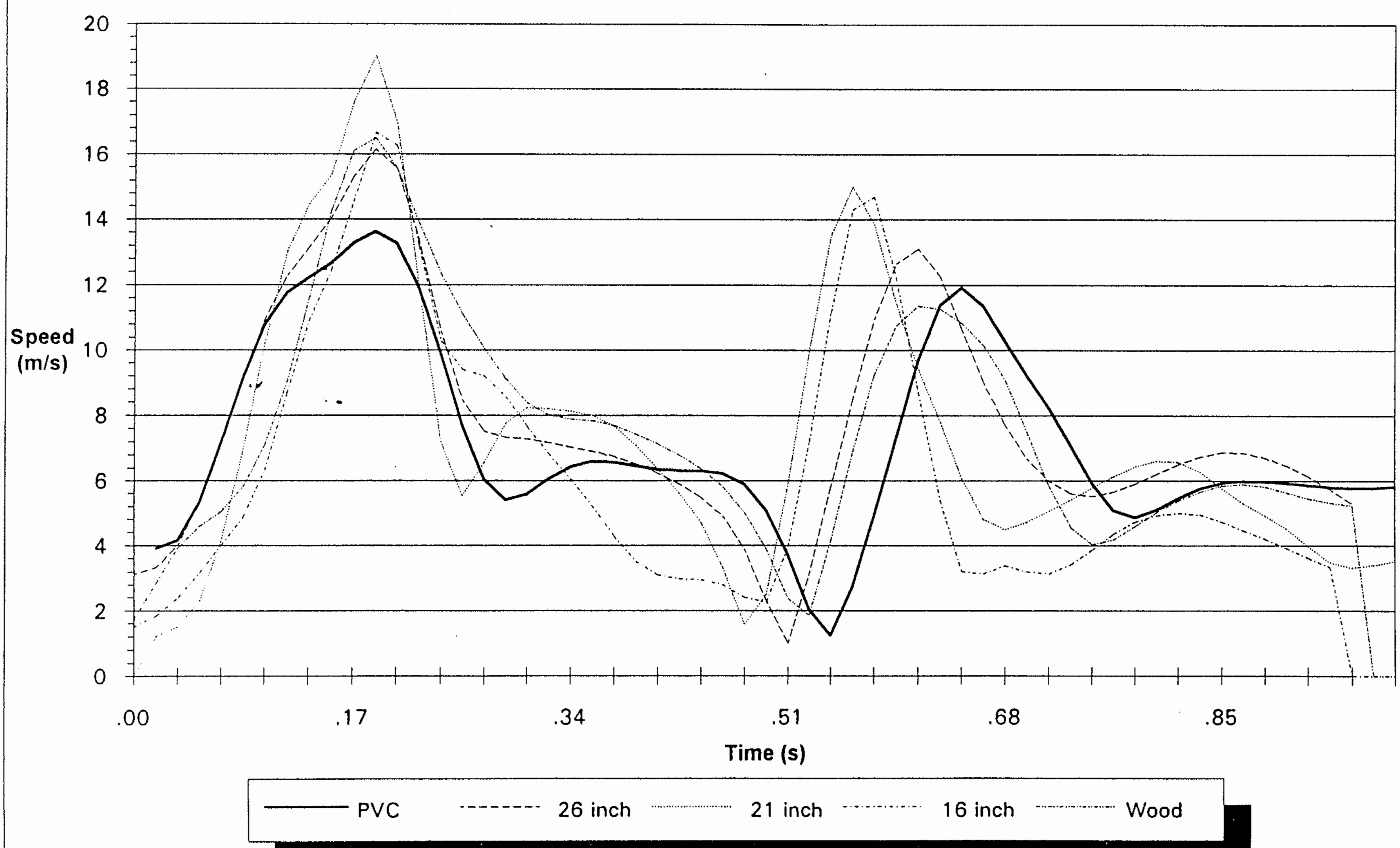


Figure 17
FOREHAND/BACKHAND SWING: BATON SPEED
Subject 3

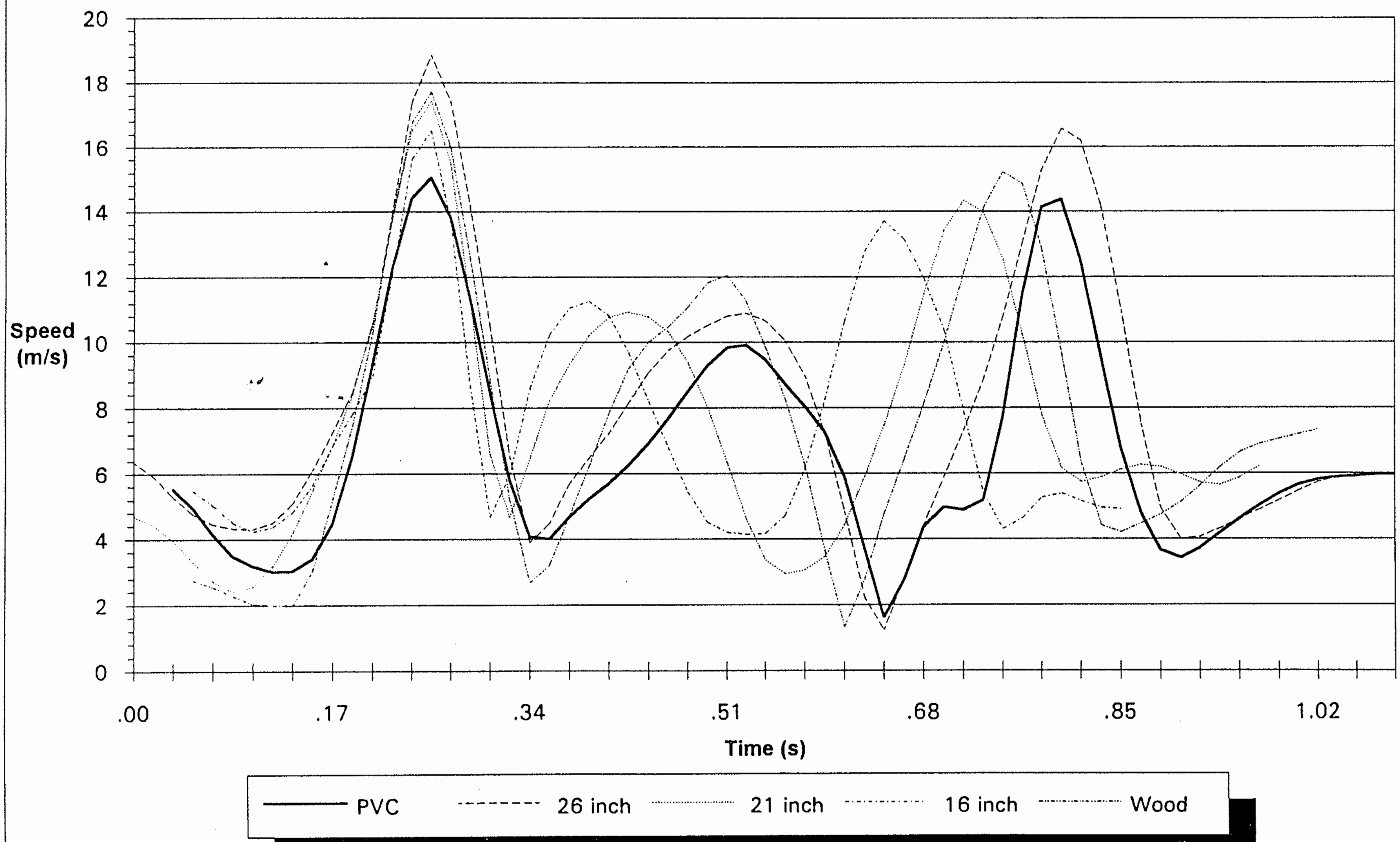
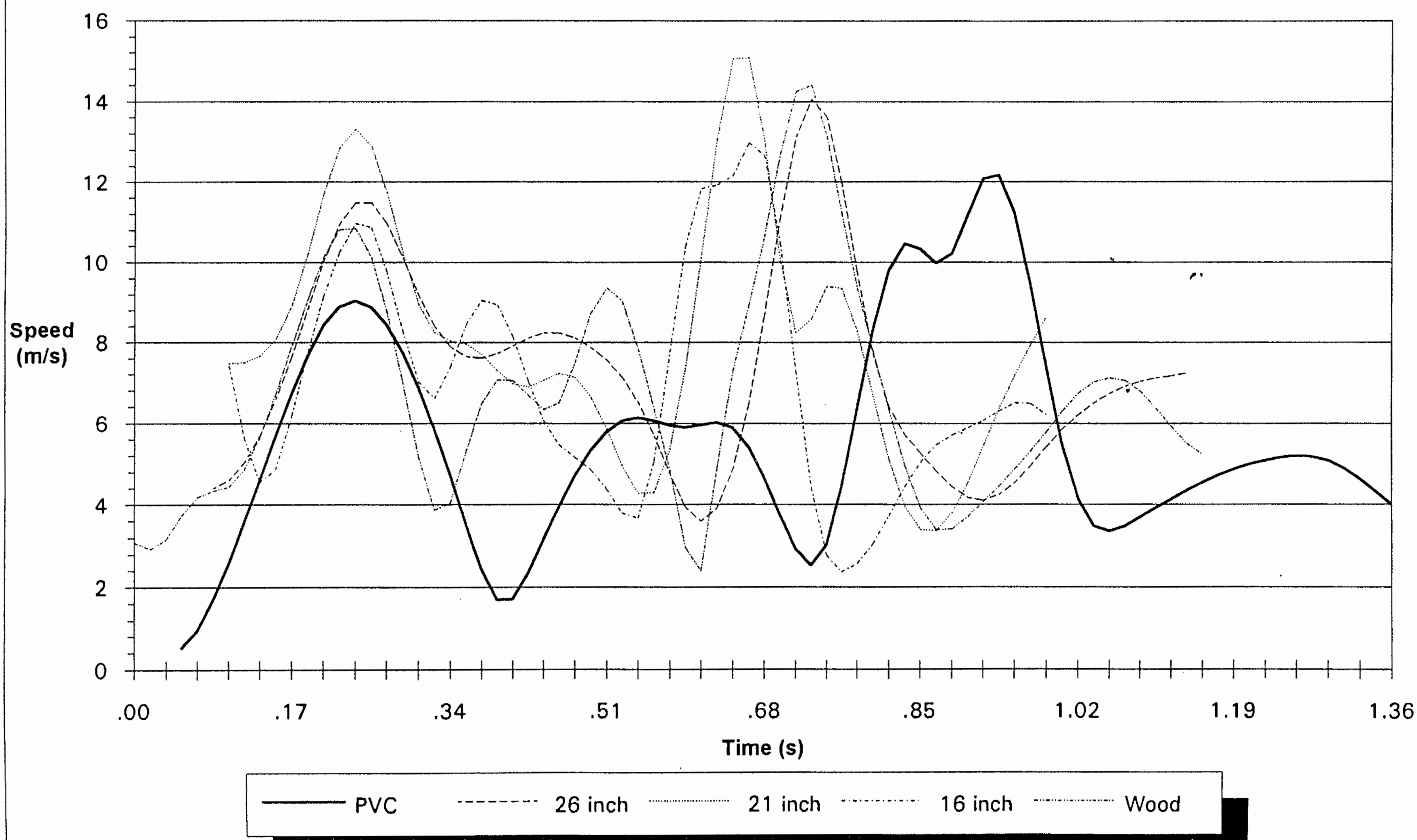


Figure 18
FOREHAND/BACKHAND SWING: BATON SPEED
Subject 4



SUMMARY

The main purpose of this project was to conduct a biomechanical comparison between various sizes of expandable tactical batons and the standard issue PVC duty baton. Comparison was made on those quantifiable mechanical variables, as suggested in the literature, that were deemed significant with respect to trauma and the intended use of the baton as an intermediate weapon. The study proceeded under the assumption that the baton if used as intended will be an impact device that can effectively control an assailant's hostilities.

The three APS Tactical batons, the side handle baton and wood duty baton all produced smaller impact forces when compared to what was achieved with the PVC duty baton. In a theoretical model of impact pressure, the expandable batons produced on average higher impact peak pressures than those produced with the PVC baton. The impact pressures ranged from approximately 50% to 135%, 110% to 230%, and 125% to 275% of the PVC maximum for the 16", 21" and 26" extendable tactical batons respectively. It must be stresses that these measures were collected under ideal laboratory conditions. The recorded impact forces and pressure values, would in most likelihood far exceed the impact loads that could be generated in the field during an actual confrontation with an assailant. In addition to these considerations the amount of mechanical work done on the assailant, which dictates the resulting stresses, is dependent on the material or tissue struck. A large muscle group which is fully contracted will experience far less trauma than if the same blow were delivered to an area with little muscle of adipose tissue over the bone.

The physical characteristics of the tactical batons are different from those of the standard issue PVC duty baton. The movement patterns for two baton training skills were also investigated to determine the possible influence these physical differences may have on the use of the batons. The officers in this study tended to swing all the batons faster than the PVC baton for forehand strikes. The officers also had greater strike frequencies when swinging the 16" tactical batons. Another factor that may also influence the officer's safety is the proximity the striker must be to the opponent to actually deliver a maximal blow or a series of blows. The 26" expandable baton afforded the greatest reach and the 16" expandable baton the least. The 21" expandable, PVC and Wooden baton differed between 1 cm and 5 cm with respect to reach.

In summary, a large number of interdependent factors which relate to the effective and appropriate use of these intermediate weapons must be considered in their evaluation. In light of their intended use, no single factor can conclusively dictate a baton's superiority over another with respect to the inherent risks to an officer or an assailant.

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APPENDIX

INFORMED CONSENT

Biomechanics Laboratory

Department of Physical Education and Sport Studies

University of Alberta

Title: The Tactical Baton

Researcher: Pierre Gervais, Ph.D.

I, ______________________ authorize the University of Alberta, Department of Physical Education and Sport Studies to administer, for the purposes of research only, the test outlined. I understand that as a subject I am free to withdraw consent and discontinue participation in the project at any time without prejudice. The investigation and my part in the study have been defined and fully explained. A written description of the tests to be administered and any risks have been provided to me and have been discussed in detail. I have also been given an opportunity to ask questions concerning the tests and all such questions have been answered to my satisfaction. I understand that any data, generated as a result of my participation, will be used for research purposes only.

I certify that to the best of my knowledge and belief, I have no physical illness that would increase the risk to me of participation in this study. I acknowledge that I have read this form and understand the test procedures to be performed and the inherent risks, and I give my consent for participation.

date: ______ signature: ________________________

witness: __________________________

I the undersigned, have explained the investigation to the above subject.

investigator's signature: ___________________________