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Protective Equipment Evaluation

Suzanne Tylko
Biokinetics and Associates Ltd.

TECHNICAL REPORT
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NOTE: Further information about this report can be obtained by calling the CPRC information number (613) 998-6342

SUMMARY

Protective equipment manufactured by Bonowi® Security equipment was evaluated on the basis of hazards and conditions likely to be encountered by riot police. The Bonowi® Security Equipment supplied for testing consists of a vest with attached upper and lower arm protection and a pair of gloves. The vest and arm protection shell appears to be black ⅛" polypropylene. Areas adjacent to the chest bone, spine and shoulders are lined with ½" cross-linked polyethylene foam. The perimeter of the vest is finished with a vinyl/cloth backed ¼" closed cell foam. The upper and lower arm pieces are lined with a similar cloth-laminated ¼" closed cell foam. The gloves are leather with ⅛" aluminum plate inserts over the posterior aspect of the digits and hand. A cloth covered closed cell foam forms the liner.

Protective qualities which are important to consider in injury prevention include: the ability to distribute a load, absorb energy and resist penetration. Comfort qualities which may directly or indirectly contribute to an officer's safety and which can be measured in a laboratory setting, include: material stiffness , coverage and heat transfer. Qualities which contribute to the durability of the protective equipment include: resistance to repeated impacts, dimensional stability and temperature sensitivity. Only empirical tests, reproducible within a laboratory setting were conducted for this evaluation.

SOMMAIRE

Le matériel de protection fabriqué par Bonowi® Security equipment a été évalué en fonction des risques auxquels font face les policiers anti-émeute dans différentes situations. La compagnie nous avait fourni une veste avec des protecteurs de bras et d'avant-bras ainsi qu'une paire de gants. Le revêtement extérieur de la veste et des protecteurs est du polypropylène noir de ⅛ de pouce. Le sternum, la colonne vertébrale et les épaules sont protégés par de la mousse de polyéthylène réticulé de ½ po. La veste est doublée en mousse vinylique à alvéoles fermés recouverte de tissu, tout comme les protecteurs de bras et d'avant bras. Les gants sont en cuir et des plaques d'aluminium de ⅛ de pouce protègent le dos de la main et des doigts. Le gant est doublé en mousse vinylique à alvéoles fermés recouverte de tissu.

Il est important, au moment d'évaluer les propriétés protectrices de la veste, de mesurer les facteurs suivants : dissipation des charges, absorption de l'énergie et résistance à la pénétration. Il est aussi possible de mesurer en laboratoire le niveau de confort de la veste, ce qui peut contribuer directement ou indirectement à la protection du policier. On mesure alors les facteurs suivants : rigidité du matériel, niveau de couverture et dissipation de la chaleur. Les facteurs qui influent sur la durabilité du matériel sont la résistance à des chocs répétés, la stabilité dimensionnelle et la sensibilité à la chaleur. Nous avons procédé uniquement à des essais empiriques reproductibles en laboratoire.

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1.0 INTRODUCTION

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2.0 *Protective Qualities*

2.1 Low Velocity Crush

2.1.1 Apparatus

Steel Ball (Mass: 0.2545kg, Diameter: 39.72mm)
Tape Measure
Anthropometric Test Dummy (ATD)

2.1.2 Set-Up and Procedure

An ATD was used as support to simulate human form. The vest was fastened to the ATD which lay flat on the floor. A 0.2545kg ball bearing was dropped from heights of 1m and 2m, three times at each height, being careful not to impact the same site twice. This created an impact velocity of 3.13m/s (11.3km/h) for the 1m drop and 4.43m/s (15.94km/h) for the 2m drop. If an impact left a mark, the diameter of the mark was recorded.

Similarly, the same ball bearing was dropped on the glove. The glove was placed palm down on the testing surface.

2.1.3 Calculations

d = Diameter of depression caused by impact
r = Radius of ball bearing (diameter/2)

Sample calculation:

Depth of Depression $= r - (r^2 - (0.5d)^2)^{1/2}$
$= 39.72 - (394.42 - (0.5*1.0))^{1/2}$
$\approx 0.1cm$

2.1.4 Results

IMPACT SITE	1M DROP	OBSERVATION	2M DROP	OBSERVATION
Vest: 1	No Mark		No Mark	
Vest: 2	No Mark		No Mark	
Vest: 3	No Mark		No Mark	
Glove: 1	Small mark	Disappeared quickly	2 mm deep indentation	Glancing Blow
Glove: 2	Small mark	Disappeared rapidly	1 mm deep indentation	None
Glove: 3	Small mark	Disappeared quickly	1 mm deep indentation	None

Table 1: Observation of impact sites for 1m and 2m drops of a ball bearing

2.2 HIGH VELOCITY CRUSH TEST

2.2.1 Apparatus

Slingshot (Robert's Rocket wrist supported, folding slingshot)
4.002kg mass
Ruler
C-Clamp
Standard Golf Ball (Titleist "DT" 6) (4.258 cm diameter, 0.0452kg mass)
Stool
Anthropometric Test Dummy (seated in chair)

2.2.2 Set-up and Procedure

The slingshot was calibrated by fixing it to the lab bench such that its spring was hanging freely over the table's edge. The 4.002kg mass was then hung from the slingshot and its displacement measured to determine the spring constant. The ATD, fitted with the vest, was positioned in a chair and the slingshot was placed on a stool such that when the spring was extended back horizontally, but not stretched, its distance from the ATD's lower chest and upper abdomen was 1m. A standard golf ball was used as the projectile. The slingshot and ball were drawn back 0.25m and released the ball with a velocity of 23.2m/s (83.4 km/h). Three impacts were made to the vest in different locations.

2.2.3 Calculations

m = Mass of ball
v = Velocity of ball
k = Elasticity Constant of the spring
KE = Kinetic energy
x = The distance the spring is stretched

Sample Calculation

KE of the spring = KE of the ball

$0.5\ k\ x^2 = 0.5\ m\ v^2$

$$v^2 = \frac{0.0452}{(388.3)(0.0625)}$$

v = 23.2 m/s (83.4 km/h)

2.2.4 Results

IMPACT SITE	OBSERVATIONS
Left upper abdomen	No apparent Damage
Vented area of left abdomen	No apparent Damage
Lower chest	No damage but ball rebounded violently from this padded region of the vest

Table 2: Observations of the impact sites of golf ball propelled by a slingshot

2.3 LOW VELOCITY PENETRATION TEST

2.3.1 Apparatus

Playing Dart
Tape Measure
Anthropometric Test Dummy (ATD)
Vernier Calipers

2.3.2 Set-Up and Procedure

An ATD was used as a support resembling human form. A playing dart of mass 0.0213kg was dropped onto the vest, fitted to the ATD, from heights of 1m and 2m. The dart was dropped three times from each height to obtain an average. No site was impacted more than once. The depth of penetration was measured if the dart remained embedded in the vest or glove. Penetration was measured using the Vernier Calipers.

2.3.3 Results

IMPACT NUMBER	DAMAGE FROM 1M DROP	OBSERVATIONS	DAMAGE FROM 2M DROP	OBSERVATIONS
Vest: 1	Small indentation	None	Small indentation	None
Vest: 2	Small indentation	None	Small indentation	None
Vest: 3	Small indentation	None	Dart took chip off of the top of a vent	Dart did not penetrate vent
Glove: 1	Penetrated leather outer	Did not stay in puncture	Penetrated leather outer	Did not Stay in puncture
Glove: 2	Penetrated leather outer	Did not stay in puncture	Penetrated leather outer	Did not stay in puncture
Glove: 3	Penetrated leather outer	Did not stay in puncture	Became embedded in glove's finger	Could have struck finger of wearer

Table 3: Observation of impact sites for 1m and 2m drops of a playing dart

2.4 HIGH ENERGY PENETRATION TEST

2.4.1 Apparatus

Drop tower: free fall system guided by stainless steel rods
Base: MEP pad protected with a block of foam
Conical penetrator anvil (drop mass = 2.708kg)
Velocimeter: VS200.

2.4.2 Set-Up and Procedure

Two areas of the vest not previously impacted were selected. The vest was positioned on the impacting surface and impacted at Site 1 from a height of 0.5m and at Site 2 from a height of 1.0m. The impacted velocity was recorded and the vest inspected for signs of penetration. The procedure was repeated for the gloves.

2.4.3 Results

IMPACT NUMBER	IMPACT VELOCITY m/s	IMPACT ENERGY J	OBSERVATIONS
#1 Vest	2.08	12.42	indentation
#2 Vest	4.41	27.2	penetration
#1 Glove	2.03	12.01	indentation
#2 Glove	4.37	26.72	slippage & penetration between plates

Table 4: Observations of penetration test.

2.5 ENERGY ABSORPTION

2.5.1 Apparatus

Drop tower	
MEP pad	
Hemispherical anvil	
Accelerometer:	Endevco Model 7702A-50
Charge Amp:	Endevco Model 101
Velocimeter:	VS200 Velocimeter
Data Acquisition and Storage:	Sample rate 10 khz
	Full scale range ± 10.00v
	Quantization 1.1 mv
Absolute Accuracy ± 0.03%	

2.5.2 Set-Up and Procedure

The hemispherical anvil was dropped on to the bare MEP pad from 0.45m and from 1 m to determine baseline energy and acceleration levels. A number of test sites corresponding to padded and non-padded regions of the vest were selected and tagged. Impact sites were no closer than 7cm.

2.5.3 Results

	DROP HEIGHT m	IMPACT VELOCITY m/s	IMPACT ENERGY J	PEAK ACCELERATION G
Baseline #1	0.45	2.78	11.7	327.6
Baseline #2[1]	1.0	4.35	28.6	547.8
Test #1	0.45	2.87	12.5	106.4
Test #2	1.0	4.36	28.8	223.1
Test #3	2.0	6.24	58.9	546.8
Test #4	0.45	2.83	12.1	149.4
Test #5	1.0	4.34	28.5	305.6
Test #6	0.45	2.83	12.1	137.2
Test #7	1.0	4.33	28.4	257.3
Test #8	1.0	4.35	28.6	241.6

Table 5: Peak acceleration readings as a function of drop height and impact energy.

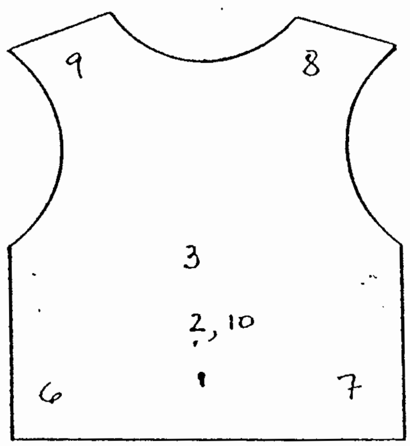

Figure 1: Location of selected sites for impact tests.

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[1] Baseline measurements were not performed at heights greater than 1 metre due to the very high acceleration levels observed.

3.0 COMFORT

3.1 STIFFNESS

3.1.1 Apparatus

4.002 kg mass
Ruler
Clamps
Electronic Balance (Scale)

3.1.2 Setup and Procedure

The riot vest was fastened to the lab bench using clamps such that there was an overhang of greater than 16 cm as shown in Figure 2. A point 16 cm from the fulcrum was chosen and its position was measured. A 4.002 kg mass was then suspended from that point and the resulting displacement was measured. The procedure was repeated three times at each point to obtain an average. The points were chosen as shown in Figure 3. The experiment was conducted at room temperature and humidity (23°C and 68% respectively).

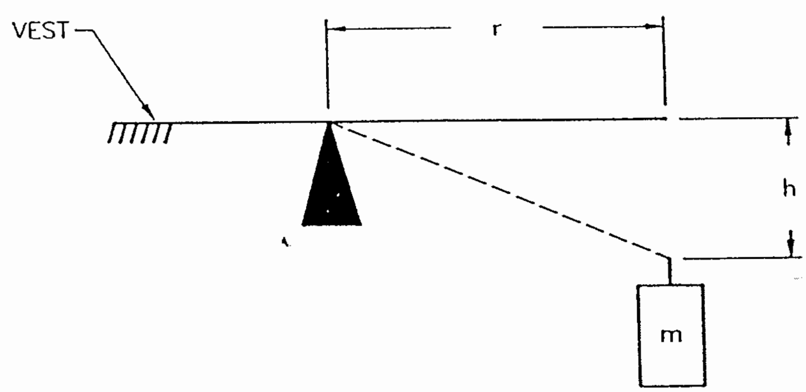

Figure 2: Test set-up

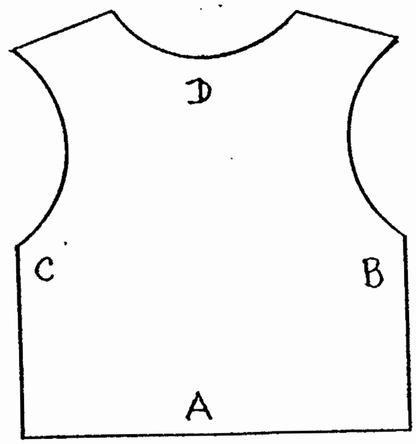

Figure 3: Location of selected sites for torsional stiffness test.

3.1.3 Calculations

F = Force
m = Mass
a = Acceleration
τ = Torque
h = Average Displacement
r = Distance of mass from fulcrum

Sample calculation at point 1:

$F = ma$
$F = (4.002kg)(9.80\ m/s^2)$
$F = 39.22\ N$

$\tau = rF$
$\tau = 0.16m(39.22N)$
$\tau = 6.28\ N\ m$

Force required to cause deflection at a distance of 16mm $= \tau/h$
$= 6.28Nm/\ 0.027m$
$= 232.6N$

3.3 HEAT TRANSFER

3.3.1 Apparatus

1000 Watt hot plate (14cm diameter element)
Yellow Springs Co. Incorporated Model 44T Thermocouples
Retort Stand and Clamp
Timer

3.3.2 Set-up and Procedure

The vest was held over the heat source by the retort stand and clamp. Two portions of the vest, one padded, without vents, the other not padded but with vents, were heated over the radiant heat source. Temperatures of the element, heated air, the internal surface of the vest, its external surface, and room temperature were recorded every three minutes for the duration of the 30 minute experiment. The heated air temperature was adjusted such that it was between 35 and 40 degrees Celsius.

3.3.3 Calculations

Percentage of heat retained = Inside surface temperature - Outside surface temperature
Inside surface temperature - Air temperature

T_2 = internal surface temperature c°
T_e = external surface temperature c°
T_a = air temperature

$$\text{Heat Retained} = \frac{T_2 - T_e}{T_2 - T_a}$$

Sample Calculation

$$\%\ \text{Heat Retained} = \frac{39 - 27}{39 - 23}$$

$$\text{Heat Retained} = 75\%$$

3.3.4 Results

REGION HEATED	OBSERVATIONS
Chest area (padded, no vents)	75 % of heat was retained
Right side (no padding, vented)	27% of heat was retained

Table 8: Observation of two areas exposed to radiant heat

4.0 Durability

4.1 Resistance to Repeated Impacts

4.1.1 Test Procedure

One site was selected for repeated impact during the energy absorption test. Peak accelerations were recorded and compared.

4.1.2 Results

	Impact Velocity m/s	Impact Energy J	Peak Acceleration G
Baseline	4.36	28.8	223.1
Test #1	4.35	28.6	241.6
Test #2	4.35	28.6	547.8

Table 9: Comparison of Peak G values for repeated impacts.

4.2 Dimensional Stability

4.2.1 Test Procedure

A section of the armour was placed beneath a 5kg and 10kg mass for a four hour period.

4.2.2 Results

No dimensional changes were observed.

4.3 Temperature Sensitivity

4.3.1 Procedure

The protective gear was subjected to temperatures of -20°C and +40°C.

4.3.2 Results

No dimensional changes were observed.

5.0 SUMMARY AND CONCLUSIONS

Testing of the Bonowi® vest and gloves demonstrated that this equipment offers good load distribution and penetration protection. The materials were resistant to low and high velocity impacts with virtually no observable trace of the impact. Penetration protection is good as demonstrated by the small degree of penetration resulting from the 1 meter drop of the conical impactor. The vent holes of the vest are small enough and angled in such a way, that the probability of penetration at these locations is reduced. In the gloves, there are aluminum plates which are for all intents and purposes impenetrable, however they do not overlap each other. This means that when struck, a small diameter penetrator, such as an ice pick or knife, could easily slip off the plate and into the crevice thus causing injury.

The energy absorption capabilities of this equipment was not ideal. The vest was selectively padded over the sternum, shoulders and spine. When impacted at energy levels of approximately 12J, equivalent to the energy produced by the golf ball flung at 83.4 km/h, peak acceleration levels ranged from 106.4 to 149.4 G's. Although these values are significantly less than the baseline reading of 327.6 G's they are a concern. The energy produced by an aggressively swung baseball bat can be of the order of 100J. Impacting a padded section of the vest with 58.9J resulted in peak values of 546.8 G's. The likely peak values experienced by a human subject would certainly be less than those measured on the MEP pad but this difference could not be large enough to eliminate the risk of injury. The good load distribution characteristics coupled with the lack of energy absorption may increase the risk of multiple rib fractures, particularly if impact occurs on the lateral aspect (side of the chest).

The rigidity of the material is well compensated for through the equipments articulation and hence range of motion should not be restricted.

Frontal and rear coverage of the chest includes the clavicle and ribs. Lateral coverage ends at approximately the 7th rib leaving the 6th and 5th ribs exposed. The liver and spleen may or may not receive protection from direct blows and would not be protected from an upward strike. The kidneys are not protected.

Arm protection is restricted to the lateral aspects of the humerus and ulna, leaving the anterior aspect or front exposed. The olecranon or elbow joint is protected. The radius or wrist bone is protected by the gloves.

Heat retention may contribute to discomfort with this equipment. The region of highest heat retention (75%) is adjacent to the cardiac region. This may contribute to physical stress, however, field trials should be conducted to determine if this can be compensated for through heat dissipation from the axillae (underneath the arms).

The materials are resistant to cold and warm conditions and do not alter their shape when compressed for extended time durations.

In summary it appears that the vest and arm protection would offer low to moderate impact protection from golf balls and poor protection from baseball bats. The gloves are of impressive quality and would offer a high degree of protection given the amount of mobility available.