The XXIXth Annual Occupational Ergonomics and Safety Conference
Seattle, Washington, USA
June 1-2, 2017

Scaling Environmental-Condition (EC) Aversiveness: Direct Estimation and Borg-10 Comparison for Felt-Recoil

Alvah C. Bittner

Bittner & Associates, Kent, WA 98042-3532 USA

Corresponding author's Email: drbittner@comcast.net

Author Note: The current effort was largely motivated by the findings uncovered and integrated during the course of preparation of Prasad et al (2017a). This research truly represented a team-effort which was supported by funding from the U.S. Nuclear Regulatory Commission (NRC) under Contract Number NRC-HQ-60-14-D-0028.

Abstract: Direct-Estimation (DE) and Borg-10 methods – for prospectively accessing the relative "*aversiveness*" of a spectrum of environmental conditions (ECs) – were illustratively explored for 4-levels of "*felt-recoil*" (i.e., 3.36, 15.35, 17.14 and 27.04 ft-lbs). During a single session (<3-hr), both methods were jointly applied in 5-Blocks during which each of the 4-recoil levels were randomly experienced. This research was motivated by recent findings of profound: (a) Holes in the EC-performance knowledge base, but also (b) Neuro-chemical and -imaging evidence that essentially-equivalent levels of discomfort, anxiety, and/or risk-perception associated aversiveness could result in respectively comparable cognitive and motor performance across ECs (Prasad et al., 2017a). Log_{10}-transformed DE and Borg-10 felt-recoil aversiveness-assessments proved very-highly: (a) Reliable across blocks (***r***s >0.97, ***p***s < 0.0001); and (b) Correlated with Log_{10}-transformed recoils (respectively ***r*** = 0.96 and 0.98, ***p***s < 0.0001). Evaluation of an intermediate felt-recoil (5.5 ft-lbs) – 3-weeks after the initial study – provided indications of the temporal stabilities of both scales. Direct-Estimation and Borg-10 altogether appear very reliable and efficient methods for future scalings of: (1) Felt-recoil aversiveness (re: handgun) and (2) Aversiveness of a wide-spectrum of environmental conditions (ECs) with regard to prospectively mapping common performance impacts.

Keywords: aversiveness, Borg-10, direct-estimation, environmental-conditions, felt-recoil, performance mapping

1. Introduction

Prasad et al. (2017a) recently reported evidence of both significant holes and remarkable research opportunities in their integrated review of the performance impacts of 11 *environmental conditions* (ECs). Regarding holes, they found 44% "Gaps" in their examination of 99 combinations of these ECs and 9 "*performance demands*" (PDs); while, conversely only 8% and 29% at their first and second highest levels of information. This may be somewhat surprising to those daily concerned with "shirt-sleeve condition" performances of a couple of the 9 PDs which range from Detecting & Noticing to Teamwork-Communication.[1] Alternately, likely unsurprised would be those involved with the more aversive levels of the 11 ECs (i.e., Heat, Cold, Noise, Vibration, Lighting, Humidity, Wind, Precipitation, Standing & Moving Water, Ice & Snowpack, and Lightning).[2] Beyond identifying the afore mentioned holes, Prasad et al (2017a) also report recently emergent research that point toward opportunities for efficiently filling them:

1) *Higher levels of aversiveness – associated with discomfort, anxiety, and perceptions-of-risk (POR) – broadly affect both human cognitive and motor performance via common mechanisms of action (MOAs) across a wide range of ECs (e.g., Peyron et al.,2000;Lupien et al. 2007; Basbaum et al., 2009; Dovan, 2013; Taylor et al, 2014)*
2) *Matched levels of EC aversiveness could be associated with respectively parallel cognitive and motor performance effects as well as potential for easy accumulation of combined impacts (Prasad et al., 2017a, Sec 6.13).*

[1] PDs include: Detecting & Noticing, Understanding, Decision-making, Action—Fine Motor Skills, Action—Gross Motor, Action –Other Neurophysiological, Teamwork—Reading &Writing, and/or Teamwork—Communication.
[2] For these latter, Prasad (2017b) elsewhere succinctly delineates a quantitative modeling approach that utilizes the extant EC information presented in Prasad (2017a): *System for Performance Impact from Conditions in the Environment (SPICE).*

These altogether imply that by characterizing the performance-demand effects of a set of aversiveness levels for one EC, one could directly predict these same characterizations for other ECs with matched aversiveness levels.

The present investigation is an exploration of the potential of two methods for scaling aversiveness, Borg-10 (Borg, 1998) and Direct-Estimation (Stevens, 1975), with regard to later verifications of the utility of predicting EC-PD effects from cross-matched ECs. With regard to aversiveness, the Borg-10 appeared particularly suitable, as (a) it employs verbal-labels (ratio-scale scored) that might serve as matching targets across ECs and (b) Variations have been widely employed for monitoring both "pain" and "exertion" (Borg, 1998). Direct-Estimation (DE), alternatively , appeared especially suitable due to its successful applications across sensory modalities and internal-states (e.g., Stevens, 1975; Aghazadeh et al., 2004). "Felt-recoil" was selected for study as it was: (a) convenient to study, and (b) representative of especially difficult to scale stimuli (i.e., very-short, intense & complex).

2. Method

2.1 Participant and Recoil Delivery System

Felt-recoil pulses were delivered to an experienced (74y/o 1.91m-100kg male) range-officer via a single-action revolver Blackhawk (45LC with 5.5 in barrel; ~3.4lb). Cartridge loadings (L1:L4) resulted in computed 3.36, 17.14, 15.35 and 27.04 ft-lbs *Free Recoil Energy* (Handloads.com, 2016).[3] Wearing appropriate eye-hearing protection and fingerless "weightlifter" gloves, the participant employed: (1) a two-handed overlapping grip and (2) a supporting stance slightly modified – for handguns -- from the rifle "arm-rest standing" position shown in Figure 1 (BSA, 1990, p. 46). Modifications included emphases on (a) lower body stability with knees slightly bent and tail tucked, (b) pointing left foot in target direction, (c) tightly-bracing the supporting (left) side elbow into side, and (d) opposing tension between support (left) and control (right) side arms (with latter elbow maintained parallel to ground). These modifications provided for enhanced control during recoils and faster post-recoil recoveries.

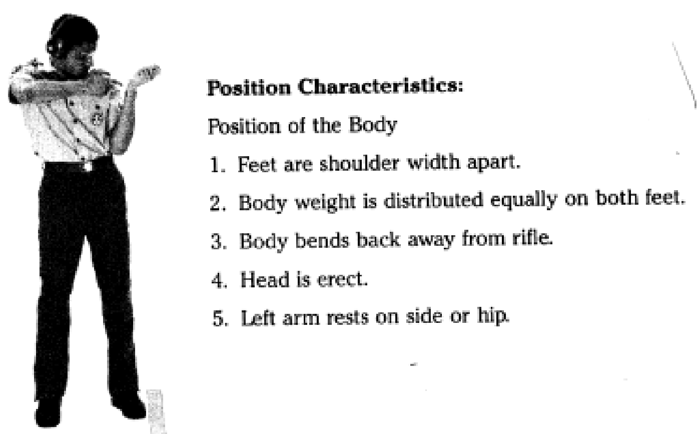


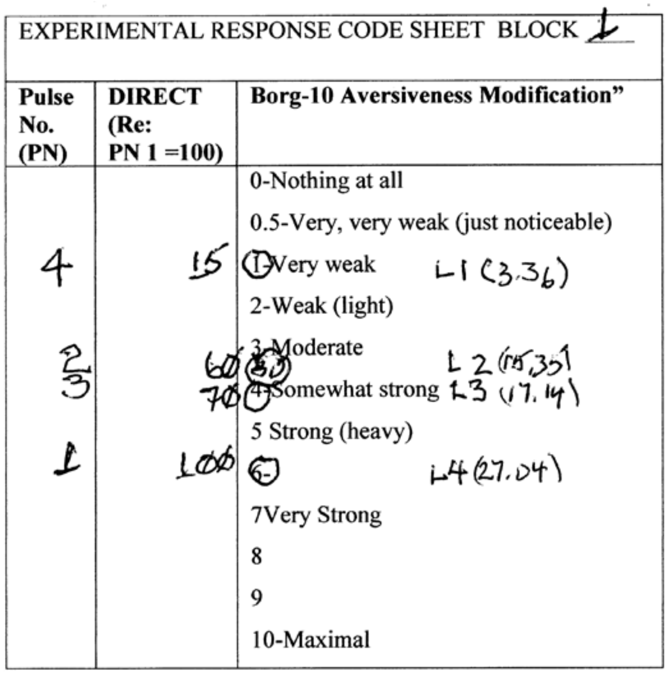
Figure 1. Classic Arm-Rest Standing Position (BSA, 1990).

2.2 Experimental Procedure

Four recoil levels (L1-L4) were randomly experienced at least once in each of 5 blocks, with Direct and Borg-10 judgements recorded after each pulse.[4] Of note, the first DE in a block was initially scored as 100 with all subsequent direct-judgements then made relative to the first (thus, if a load appeared half the first, it would be scored 50; whereas, if twice, then 200). In the final three blocks, a random pulse-load was added for ultimately a total of 23 recoil pulse comparisons.

[3] Sample means of (12) relevant component masses and (18) muzzle velocities served as inputs to the felt-recoil software (Handload.com)

[4] Randomization was achieved by cylinder blind-loading randomly-drawn loads for each of the 5-blocks (of 4 or 5), recording respective judgements with the pulse number, and then recovering load values from case markings after completing a block's firing sequence.



EXPERIMENTAL RESPONSE CODE SHEET BLOCK 1		
Pulse No. (PN)	**DIRECT (Re: PN 1 =100)**	**Borg-10 Aversiveness Modification"**
		0-Nothing at all
		0.5-Very, very weak (just noticeable)
4	15	(1)-Very weak L1 (3.36)
		2-Weak (light)
		3-Moderate
2	60	(3.5) L2 (15.35)
3	70	(4)-Somewhat strong L3 (17.14)
		5 Strong (heavy)
1	100	(6) L4 (27.04)
		7Very Strong
		8
		9
		10-Maximal

Figure 2. Coding Sheet Illustration

Judgements within each block were recorded on scoring sheets, sequentially half Borg first with DE second and then the reverse. After each block of data was collected, DE scores were renormalized for analysis – dividing all scores within a block by that for the largest recoil (L4:27.04 ft-lbs). Figure 2 illustrates the experimental scoring sheet for first block (remarkable only as the first pulse was L4). Examining this figure, it may be seen that the first pulse (PN1) was directly scored 100, with Borg10 a 6, as seemingly halfway between "Strong (heavy)" and "Very Strong." In turn the second (PN2) was respectively scored 60 (60% of PN1 and 3.5 (as seemingly half way between "Moderate" and "Somewhat Strong"). After completion of the remainder of the first block of judgements, successive case codings were determined and appended on the right side of the form across from respective PNs. Renormalization of the initial directly estimated (DE) scores – in this case – was unnecessary as the first recoil pulse happened to be the largest (L4:27.04).

3. Results

Analyses – of Log_{10}–transformed "aversiveness" and recoil-pulses (ft-lbs) – were conducted in three phases following Stevens (1975).[5] During the first phase, Log_{10}(Direct) and Log_{10}(Borg) scores for duplicate pulses in the last three blocks were averaged toward accessing their reliabilities using 2-way (4-Pulses x 5 Blocks) ANOVAs (Winer et al., 1991, Appx. E). These analyses revealed that Log_{10}(Direct) and Log_{10}(Borg) – averaged over 5 blocks – were respectively both highly reliable: $\boldsymbol{r}$ = 0.97 and 0.99 ($\boldsymbol{p}$s < 0.0001). During the second phase, Log_{10}(Direct), Log_{10}(Borg), and Log_{10}(Pulse) were cross-correlated across the entire set of 23 assessments. This revealed that: (1) Log_{10}(Direct) and Log_{10}(Borg) scores were very-highly correlated: $\boldsymbol{r}$ = 0.97 ($\boldsymbol{p}$ < 0.0001) and (2) both were highly correlated with Log_{10}(Pulse) with respective $\boldsymbol{r}$s = 0.96 and 0.98 ($\boldsymbol{p}$s < 0.0001). The final phase involved a graphical examination of the relationships between the three variables. Figure 3 graphically illustrates the nature of this relationships between the three variables.

[5] Stevens (1975) broadly reported linear relationships between log-transformed physical stimuli (physical units) and log-transformed subjective values (e.g., directly estimated). This was altogether in-keeping with his classical power law: $\psi(I) = K(I)^a$ where $\psi(I)$ is the subjective magnitude (e.g., directly estimated in current case) of sensation evoked by stimulus I in physical units (e.g.,, recoil pulse in ft-lbs in current case), a is an exponent that depends on the type of stimulation, and K is a proportionality constant (dependent on physical units and subjective method).

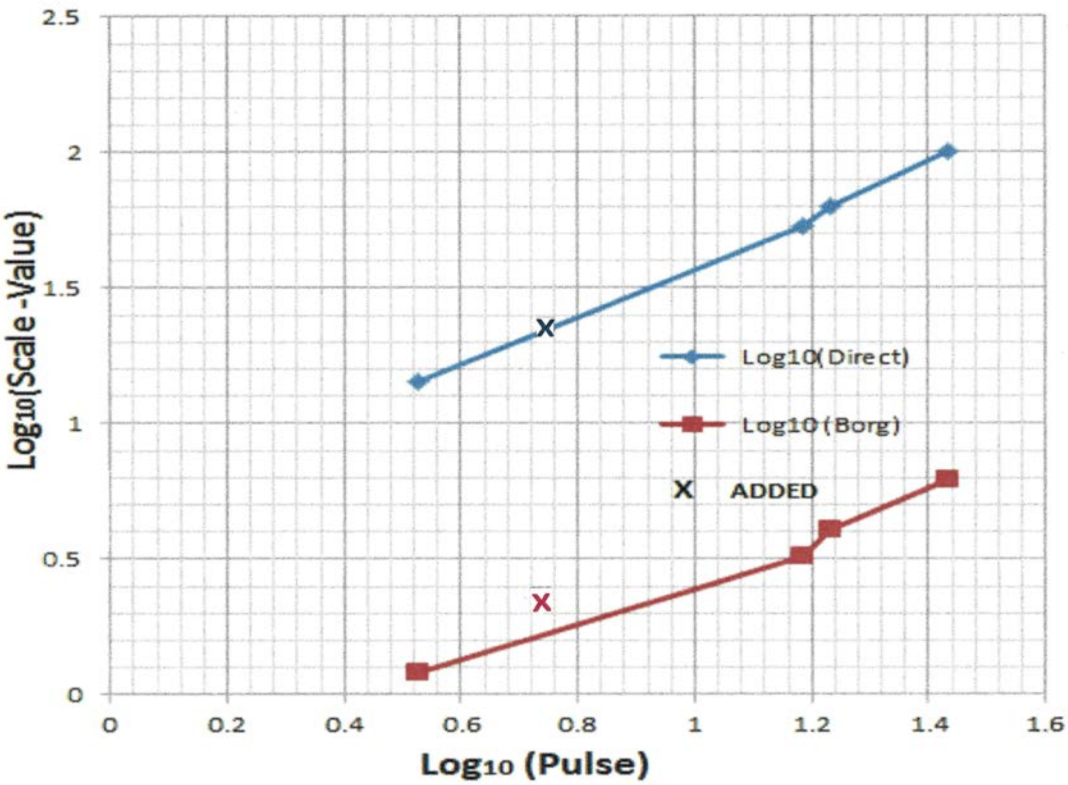


Figure 3. Direct and Borg-10 Scale Relationships with Felt-Recoil

Examining this figure, one may appreciate the essential linear relationships between Log_{10}(Direct), Log_{10}(Borg), and Log_{10}(Pulse) as implied by their substantial inter-correlations (all ***r***s $\geq$ 0.96; ***p***s < 0.0001). Nonetheless, the relationships of both Log_{10}(Direct) and Log_{10}(Borg) with Log_{10}(Pulse) "appear" to be slightly concave upward. To explore this potential concavity, an intermediate pulse (computed Free Recoil = 5.5 ft-lbs with Log_{10}(Pulse) = 0.74) was captured three weeks after conclusion of the above-delineated primary study.[6] Resulting Log_{10}(Borg) and Log_{10}(Direct) results were 0.352 and 1.35, respectively which were appended to the above figure (with respectively color coded "Xs"). In the case of Log_{10}(Borg), the intermediate pulse (X) added little except to slightly strengthen the linear relation with Log_{10}(Pulse). Whereas, for Log_{10}(Direct), the intermediate value (X) fell directly on the intermediate line between the earlier values. The added intermediate (X) values consequently served more to support the temporal robustness of the current aversiveness assessment methodology than provide any significant enhancement to understandings of the relationships.

4. Discussion and Conclusion

This investigation primarily explored the Borg-10 and Direct-Estimation (DE) methods in preparations for their prospective use in verifying predictions of EC-PD effects from those of "aversiveness" cross-matched ECs. As may be recalled, the Borg-10 was initially selected, as (a) it employed verbal-labels (ratio-scale scored) that might serve as matching targets across ECs, and (b) variations have been widely employed for monitoring both "exertion" and "pain" (Borg, 1998). This selection was supported by findings – in the (<3Hr.) main study – which revealed Log_{10}(Borg) "aversiveness" as both: very highly reliable ***r*** = 0.99 (***p*** < 0.0001) and substantially related to *"Felt Recoil*" (i.e., Log_{10}(Pulse) with ***r*** = 0.98 (***p*** < 0.0001). However, within the same (<3Hr) main study, DE – initially appearing especially suitable due to its history across

[6] This involved 3 blocks of 6 random loads: 2 each the new intermediate (X) and heaviest L4 and one each L1 and L2. An associate randomly drew from a box with these 6 loadings and sequentially placed them in the next available cylinder avoiding adjacent loadings of of the same load. The supplemental study followed the same procedure as the first after all cylinders were loaded (though only the resulting intermediate (X) values were incorporated into Figure 3.

ISBN: 97819384965-5-4

sensory modalities and internal-states – was similarly supported. Specifically, Log_{10}(Direct) "Aversiveness" also was seen both very highly reliable $\boldsymbol{r}$ = 0.97 ($\boldsymbol{p}$ < 0.0001) and substantially related to *"Felt Recoil*" (i.e., Log_{10}(Pulse) with $\boldsymbol{r}$ = 0.96 ($\boldsymbol{p}$ < 0.0001). Remarkably, though not surprising in light of the strong similarities in their results, these seemingly alternative methods are strongly interrelated (cross-correlating $\boldsymbol{r}$=0.97 ($\boldsymbol{p}$ < 0.0001). Of note, we had not anticipated the strength of this relationship. In large part, this was because the Borg-10 scale-value descriptions (0, *Nothing-at-all* to 10, *Very-Very-Hard 'Maximal')* were based on scaling efforts some decades ago (and subject to some word meanings drift). Additionally, the earliest associations had been between the descriptors and exertion heart rates where 60-200 beats/min. – scaled $1/10^{th}$ as 6 to 20 – were later renormalized between 0 and 10 (as in Figure 3). However, perhaps the direction of our results might have been anticipated as elsewhere (Borg & Borg, 2000) had found that their CR-100 (an expanded Borg-10) performed somewhat better than Absolute Magnitude Exertion (DE variation).[7] In any case, the Borg-10 both (a) currently appears essentially equivalent to DE, if not have slight reliability-validity advantages, and (b) its verbal scale points would appear to have potential as "target anchors" in predictions of EC-PD effects from aversiveness cross-matched ECs. We currently would favor the Borg-10 in future EC-PD cross-matching efforts, but – with the meager marginal costs seen in this study – could certainly argue for including DE.

"Felt-recoil" was selected for study as it was: both (a) convenient to study, and (b) representative of especially challenging to scale stimuli (i.e., very-short, intense & complex). Convenience, it is noteworthy, was afforded by both: personal access to the aforementioned recoil-delivery and testing systems, and extended (~23 Yrs.) experience with variations of the "classic arm-rest standing position." The scaling challenge may be seen in a comprehensive definition of felt recoil as "…a mental representation of the impact intensity experienced by the shooter, a subjective estimation that encompasses pain, discomfort, propensity to flinch, and other factors" (Morelli et al., 2014). This complexity, and the brevity of recoil pulses (<10ms) has prompted most researchers to formulate mechanical models and test systems that focus on the dynamic response of shooters (e.g., Hall 2008, re: shoulder fired impulse response; Zimmerman, 2014 re: resultant handgun accuracy). Morelli et al. (2017), in contrast, have very recently developed a Perceived Recoil Grid (PRG) "…that was developed to query spacial distribution and relative magnitudes of individualized firing experience across four surface contact areas employed by [rifle] shooters during firing: cheek, support hand, firing hand, and shoulder." This, though arguably still in development, does not presently appear to provide an integrated rating as in the present study (with Borg-10 and DE). We currently anticipate that integrated measures of felt-recoil – as seen in the present study -- will become increasingly important in future investigations concerned with understanding the contributions of "situational" and "felt-recoil to aiming accuracy.

Borg-10 and Direct-Estimation (DE) altogether appear very reliable and efficient methods for future scalings of: (1) *Felt-recoil* aversiveness (re: handgun) and (2) *Aversiveness* of a wide-spectrum of environmental conditions (ECs) with regard to prospectively mapping common performance impacts.

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[7] Teghtsoonian (2009, pp. 25-26) notes these and a seeming wealth of methods – and applications – that have emerged over the past 25 years, but also the important advantages of using well-proven methods (e.g. arguably Borg-10, DE, etc.)

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