Kybernetes

Too resilient for anyone's good: "Infant psychophysics" viewed through second-order cybernetics, part 2 (re-interpretation)

Lance Nizami,

The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0368-492X.htm

Too resilient for anyone's good

"Infant psychophysics" viewed through second-order cybernetics, part 2 (re-interpretation)

Lance Nizami
Independent Researcher, Palo Alto, USA

Abstract

Purpose – This paper aims to extend the companion paper on "infant psychophysics", which concentrated on the role of in-lab observers (watchers). Infants cannot report their own perceptions, so for five decades their detection thresholds for sensory stimuli were inferred from their stimulus-evoked behavior, judged by watchers. The inferred thresholds were revealed to inevitably be those of the watcher–infant duo, and, more broadly, the entire Laboratory. Such thresholds are unlikely to represent the finest stimuli that the infant can detect. What, then, do they represent?

Design/methodology/approach – Infants' inferred stimulus-detection thresholds are hypothesized to be attentional thresholds, representing more-salient stimuli that overcome distraction.

Findings – Empirical psychometric functions, which show "detection" performance versus stimulus intensity, have shallower slopes for infants than for adults. This (and other evidence) substantiates the attentional hypothesis.

Research limitations/implications – An observer can only infer the mechanisms underlying an infant's perceptions, not know them; infants' minds are "Black Boxes". Nonetheless, infants' physiological responses have been used for decades to infer stimulus-detection thresholds. But those inferences ultimately depend upon observer-chosen statistical criteria of normality. Again, stimulus-detection thresholds are probably overestimated.

Practical implications – Owing to exaggerated stimulus-detection thresholds, infants may be misdiagnosed as "hearing impaired", then needlessly fitted with electronic implants.

Originality/value – Infants' stimulus-detection thresholds are re-interpreted as attentional thresholds. Also, a cybernetics concept, the "Black Box", is extended to infants, reinforcing the conclusions of the companion paper that the infant-as-research-subject cannot be conceptually separated from the attending laboratory staff. Indeed, infant and staff altogether constitute a new, reflexive whole, one that has proven too resilient for anybody's good.

Keywords Second-order cybernetics, Attention, Infant, Black Box, Physiology, Psychophysics

Paper type Research paper

1. Introduction

Infants are difficult subjects for stimulus-detection or stimulus-discrimination tasks. Nonetheless, more than 50 years ago, Fantz and colleagues (Fantz *et al.*, 1962; Fantz, 1963, 1965) began testing the visual acuity of infants. They instructed an observer (a *watcher*) to record how long and how often an infant visually fixated each of two alternative stimuli, a procedure called "preferential looking" (Nizami, 2018). Throughout, Fantz and colleagues made a profound assumption, one which actually underlies all studies of infant perception,

The author would like to thank Dr Claire S. Barnes PhD for her valuable assistance. He would also like to thank the two anonymous reviewers and Dr. Philip Baron and the other Editors for their gracious assistance.

Kybernetes
© Emerald Publishing Limited
0368-492X
DOI 10.1108/K-05-2018-0238

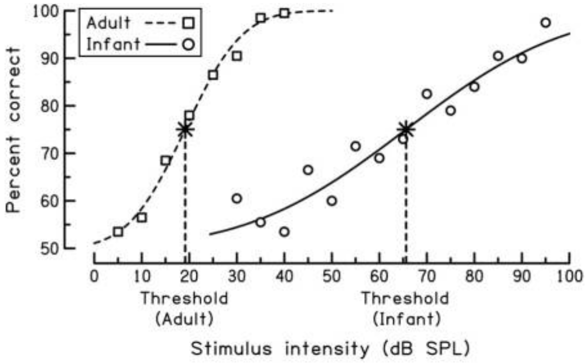
and which still remains unproven: namely, that a "differential response" of the infant, whatever that is judged to be, indicates perception.

Later, Teller and colleagues (Teller *et al.*, 1974; Teller, 1979) obliged the watcher to judge which way the infant looked (two-alternative forced-choice), after which the watcher was informed whether they had judged correctly. Percentages-correct scores could then be plotted versus the stimulus characteristic being altered, to construct *psychometric functions*. As explained elsewhere (Nizami, 2018), if the salient property of the stimulus (the property adjusted by the experimenter, e.g., the width of stripes in a visual "grating", or the intensity of a tone) is plotted on the x-axis, and the percentage of presentation times that the infant is judged to have responded to it is plotted on the y-axis, then a set of {stimulus, response} data-points appears. Such a data-plot tends to be crudely S-shaped; it, or any smooth curve fitted to it, is the psychometric function (Green and Swets, 1966/1988; Macmillan and Creelman, 1991). The psychometric function ideally has an upper asymptote that approaches 100 per cent and a lower asymptote that approaches chance performance, which averages to 50 per cent in two-alternative forced-choice tasks.

To test *auditory*-stimulus-detection thresholds, visual stimuli were replaced by two loudspeakers. Werner and colleagues (Olsho *et al.*, 1987; Werner and Gillenwater, 1990; Werner and Bargones, 1991; Werner *et al.*, 1992; Bargones *et al.*, 1995) further modified Teller's technique, to obtain auditory detection thresholds in infants of 6 months of age or younger. However, the scheme is now two-alternative *one-interval* forced choice. The pair of loudspeakers is replaced by a single insert earphone. The watcher must decide only whether the stimulus has been presented at all. The infant receives reinforcement when the watcher is correct.

Published psychometric functions for stimulus-detection by infants do not usually show results from a single infant alone, because individual infants have insufficient attention span to produce enough percentage-correct scores to build-up a psychometric function. Hence, the percentage-correct scores are typically averaged over the responses of several infants. Psychometric functions for infants' vision and infants' hearing prove to have remarkably shallow slopes as compared to those of adults (Nizami, 2018). Figure 1 shows a schematized example of the difference between infants' and adults' psychometric functions. The slopes suggest the abruptness of threshold. The data and their implications are described presently in greater detail.

The Werner method has become the standard for the psychophysical testing of infants. But when infant-psychophysics methods are examined from a second-order-cybernetics viewpoint, focusing on the role of the observer, pressing problems emerge (Nizami, 2018). For example, the detection task is actually performed by the watcher-infant duo, not simply the infant. This may seem obvious to cyberneticians, but it has a multitude of implications. Consider that if the watcher correctly decides that a stimulus was presented, then a mechanical toy, usually hidden from the infant, is activated to reward the *infant*. However, the infant may not understand why this reward sometimes appears, and sometimes not. The watcher's task is confounded by the finding that cues from the infant may differ by stimulus intensity, and that infants may differ in their expressiveness. Overall watcher-infant performance is confounded too, because one watcher's criterion for stimulus detection by the infant may differ from another's. Yet another confound is that the watcher's ability to "read" the infant may itself improve with the infant's age, confusing any interpretations of changes in infant perception with maturation. To confuse things further still, the infant's look *duration*, a possible clue to attention, changes in a non-linear fashion over the first 20 weeks of life.



Notes: The squares or circles are examples of actual percentages-correct achieved by the research subject. They are regression-fitted by a smooth curve (here, a cumulative Gaussian function). The centroid of that curve (the asterisk) indicates the auditory stimulus intensity (in dB SPL) that is customarily taken as the stimulus-detection threshold, indicated by the dashed vertical line. Because there are two alternatives (correct or incorrect), the average chance performance is 50% (Green and Swets, 1966/1988; Macmillan and Creelman, 1991)

Figure 1.
Examples of psychometric functions for adults and for infants (see text) in a hearing experiment of the kind popularized by Olsho *et al.* (1987; see Nizami, 2018)

Clearly, an alternative interpretation of infants' "stimulus-detection thresholds" is needed. The present paper supplies that interpretation. Additionally, it goes on to view the infant through the cybernetics notion of the "Black Box", emphasizing physiological "measures" of what happens inside the box, measures that allegedly indicate stimulus-detection threshold.

As noted in the companion paper (Nizami, 2018), the study of infants' auditory detection/discrimination ability is ongoing. Therefore, as in the companion paper, much of the material will be discussed here using the present tense. The literature is also sometimes quoted, to convey original intent and flavor. Throughout, the abbreviation dB SPL is used, meaning "decibels sound-pressure-level" (Hartmann, 1998), which is the standard for research measurement of objective auditory waveform pressure.

2. An alternative interpretation of infants' "detection thresholds": the inattention hypothesis

2.1 Werner and Bargones (1991): infants' thresholds elevated by "distraction"

Werner and Bargones (1991) tested a hypothesis which, ironically, might explain far more about infant's "detection thresholds" than the authors may have intended. They hypothesized that if infants' detection thresholds for a tone are elevated by a simultaneous "white" noise, *beyond the elevation shown by adults in the same circumstances*, then the infants must be insufficiently attentive compared to adults. The experimental details are important, and are as follows. The stimulus to be detected was a pulsed 1-kHz tone. It could be turned on and off simultaneously with 4-10 kHz white noise (i.e. having equal energy at all waveform frequencies from 4 to 10 kHz). When, as here, the noise frequency-range does not overlap with the frequency of the tone, then the tone "stands out" from the noise. The noise intensity was 40 dB SPL or, in separate blocks of trials (forced-choices), 50 dB SPL. In the listening interval, either noise+tone appeared, or noise alone. In other blocks of listening trials, either the tone appeared alone or no stimulus appeared at all. Regarding noise, then, there were three testing conditions: 50 dB SPL noise, 40 dB SPL noise, or no noise at all. Nine six-month-olds were tested; only four produced thresholds in all three of the testing conditions. All of the listening tasks were also completed by groups of adults, for comparison purposes.

For the adults, the noise elevated the tone-detection threshold by, on average, less than 2 dB. Such a difference might well represent typical error-limits. However, amongst infants, the change averaged 10 dB for either of the simultaneous noises. Given these results, we might speculate that the mere distraction offered by the noise reduces the infant's attentiveness to the tone.

Werner and Bargones likewise speculate, particularly regarding possible alternatives, that "one might argue that when the masker is on continuously, the infant 'learns' to ignore the masker and thus does not show distraction effects" (p. 408; original internal quotation marks). Hence, they did a second experiment, in which the 40 dB SPL noise was played continuously. Twenty infants were tested. Tone-detection thresholds were now elevated by 5 dB for infants, but they were 2 dB lower for adults, all compared to the tone-detection threshold without noise. [Werner and Bargones (1991) do not note that the latter change, along with the 2-dB elevation found earlier for adults, suggests an overall measurement error of 2 dB.] Werner and Bargones (1991) concluded that the inattention hypothesis could not be ruled out.

Note well the common use of amplitude-modulated stimuli (pulsation) in the hearing studies reviewed above, and in those to be mentioned below. Its obvious purpose – which is not dwelt-upon in the literature – is to attract and maintain the infant's attention.

2.2 Infants' inattentiveness as the possible source of all infant-adult threshold differences

2.2.1 Tharpe and Ashmead (2001). We might suppose that "noise" itself is not needed to distract an infant. That is, the infant has a potential plethora of distractions – lights, sounds, objects, people, daydreams and so on. As such, *all* "detection thresholds" for infants may be attentional thresholds, i.e. thresholds for overcoming irrelevant stimuli (distractors). If so, one might expect thresholds for "detecting" the target stimulus to increase with the number and saliency of any other stimuli.

To minimize *visual* distractions, Tharpe and Ashmead (2001) tested infants' hearing in a dark room. Unfortunately, they did not minimize the greatest potential distraction of all, *the behavior of the person holding the infant*. In fact, and contrary to the usual protocol, the infant-holders apparently removed their stimulus-blocking headphones whenever they wished (p. 106).

2.2.2 Hicks et al. (2000). Contemporaneously to Tharpe and Ashmead (2001) and at the same institution, a perhaps more-revelatory study was performed by Hicks *et al.* (2000). Hicks *et al.* attempted to simplify the infant's task, and to improve the strictness of the stimulus-detection *criterion*, in the overall hope of reducing ambiguity. The experimental details are crucial, as are the findings. Hicks *et al.* used only a single loudspeaker, just 40 cm from the infant's right ear. The stimuli were brief trains of short bursts of "speech noise", which attracts more attention from infants than do artificial tones or noise (Hicks *et al.*, citing Thompson and Thompson, 1972; see Nizami, 2018). Intensities of 35, 45, 55 or 65 dB SPL were used, to provide one intensity below the *expected* detection thresholds and three above. The soundproof chamber contained only a nightlight, and an LED display in front of the infant (as a visual fixation point). The mother was in the booth but out of the infant's sight, with the infant being "placed in a cradle-type apparatus" (Hicks *et al.*, 2000, p. 3). An infrared camera allowed two external observers to watch; each independently judged whether the infant responded to the stimulus. The stimulus was randomized between two presentation intervals on each trial. When *both* watchers judged correctly, they were informed of their correctness, and the infant received a video-show "reward", which lasted no longer than 4 seconds "to prevent habituation" (Hicks *et al.*, 2000, p. 4). The infants did indeed attend to the video. (Habituation to reward had been identified as a problem in earlier literature.)

Five 2-month-old and six 4-month-old infants were tested. Regarding the 2-month-olds, Hicks *et al.* (2000, p. 4) concluded that "on many of the trials, the infants appeared to be unresponsive" and that no intensity-dependence was apparent in the inferred thresholds. Intensity-dependence was evident, however, for the 4-month-olds. Hicks *et al.* (2000, p. 6) concluded that "the evidence seems to suggest that for 2-month-old infants, there is a natural lack of responsiveness to sound".

Finally, Hicks *et al.* (2000, p. 6) explain that these and other factors cast doubt upon psychometric functions obtained by Werner and Gillenwater (1990) for infants as young as 2 to 5 weeks old (Nizami, 2018).

2.2.3 Bargones et al. *(1995): relatively shallow slopes for infants' psychometric functions.* Published psychometric functions for infants show percentage-correct scores that have typically been averaged over the responses of several infants. But Bargones *et al.* (1995) provide an unusual exception. They obtained psychometric functions for individual 6- to 9-month-old infants. Adults provided comparison psychometric functions, based on the same stimuli. Bargones *et al.* found that for four pulsed 500-millisecond 1-kHz tones, the *slopes* of the S-shaped psychometric functions were not statistically significantly different between adults and infants. The reason for this unexpected lack of difference remains unclear. Regardless, the averaged infant *threshold itself* (from the centerpoint of the psychometric function; see Figure 1) was higher than the average adult threshold. Bargones *et al.* (1995) tried other stimuli. When the stimulus was a single 300-millisecond 1-kHz tone, presented with or without continuous background noise, or was a train of 20 1-kHz tone-bursts (each 32-milliseconds long), infants' psychometric-function slopes were indeed shallower, and thresholds were higher, than for adults (see Figure 1).

With such shallow slopes, assigning a particular stimulus intensity as "threshold" does not seem meaningful. Clearly, given the range of sound-pressure-levels spanned by the psychometric function, the infants are having difficulty.

Bargones *et al.* (1995, p. 100) postulate that whatever causes elevated thresholds in infants also causes the infants' psychometric functions to be shallower. Bargones *et al.* hypothesize the following:

> Increases in neural noise, or an increase in the variability in the neural representation of intensity, would not only result in a poorer threshold, but in most cases would also lead to a decrease in the slope of the psychometric function for detection.

Such neural-noise explanations are hardly new in psychophysics, and are usually proffered with little or no supporting evidence. Other factors could cause the same outcome, such as distraction; as Bargones *et al.* themselves suggest (p. 100), "Immature attention could also contribute to infants' poor thresholds", thresholds that (by implication) are commensurate with shallower psychometric functions.

2.2.4 Allen and Wightman (1994, 1995): further relatively shallow slopes for infants' psychometric functions. There is a further suggestion that inattention, rather than purely physiological factors, is responsible for shallower psychometric-function slopes. Here, the subjects were children 3 to 5 years old, but the overall conclusion likely applies to infants too, as follows. Allen and Wightman (1994) exposed children to any of three frequencies (0.501, 1 or 2.818 kHz) of tones, presented in simultaneous broadband noise (maximum bandwidth 0-5 kHz), with the tone frequency fixed within any block of forced-choice trials. Unlike in infant studies, the tones were not presented as brief sets of bursts, but were presented individually (the tradition for adults). Allen and Wightman's child subjects themselves indicated which one of two intervals containing the noise also contained the tone. For all three tone frequencies, not only did detection thresholds prove higher than for adults (13 dB higher, when averaged over all frequencies and all children), but the slopes of the psychometric functions (functions made by averaging across children) were substantially shallower than for adults.

In the same paper, Allen and Wightman then replicated the whole experiment, finding similar results. They speculate (p. 213) that children "responded randomly, or 'guessed' on a proportion of the trials, regardless of the signal [i.e. tone] level on those trials" (original internal quotation marks). That is, broader psychometric functions (i.e. shallower slopes) might be the expected outcome of some factor that reduced each percentage-correct score by some fixed fraction. Allen and Wightman (p. 213) state that "it is not obvious what would cause a child to guess on a proportion of trials". Perhaps the child's attention simply wanders for a fixed proportion of the time.

The similarity of the Allen and Wightman (1994) trends to those of Bargones *et al.* (1995) suggests that the *specific* age of the research subject may not be the crucial detail to explain less-than-adult performance on auditory tasks. A likelier explanation is an incapability to apply an adult level of attention. That is, if a lack of *physiological* maturation explained the higher thresholds of infants as compared to adults, it would be difficult to apply the same explanation to 3-5 year olds, given that physiological maturation is believed to proceed relatively rapidly from birth.

The interpretation that distraction alone may explain less-than-adult auditory performance gains further support from results of concurrent experiments reported in Allen and Wightman (1995) with the same research subjects as described above. This time, the pure tone to be detected in noise on each block of forced-choices was not fixed, but was one of 0.501 kHz or 2.818 kHz, randomly assigned on each forced-choice trial. The findings in Allen and Wightman (1994) of higher thresholds and shallower psychometric-function slopes for children than for adults were confirmed (Allen and Wightman, 1995). Another experiment was then performed, with the tone to be detected being fixed in frequency at 1 kHz, but now with *another* tone, of randomized frequency and intensity, being added to the noise in every listening interval. The task was, therefore, to identify which of the two intervals on each trial contained the 1-kHz tone. The psychometric functions for *adults* proved yet shallower in slope, and showed yet higher thresholds, than without the added tone. The same effect occurred, on average, for the children, but with some children's psychometric functions being flattened so much that detection thresholds could not be meaningfully inferred. And indeed, shallow psychometric-function slopes may generally be accompanied by a lack of firm saturation (flattening-out) of the psychometric functions at the highest employed intensities. Here, this means that, for some young experimental research subjects, even the loudest stimuli used did not result in ideal performance.

Taken together, Allen and Wightman's (1994, 1995) findings suggest that children are much more distractible in listening tasks than adults are, to the point that, with different simultaneous auditory stimuli, children may not be able to do the task at all.

3. A complementary second-order-cybernetics perspective: the infant's mind as "Black Box"

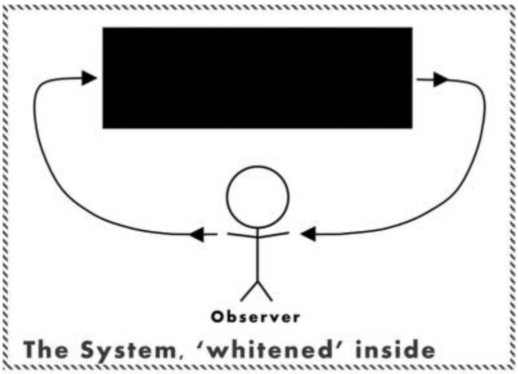
3.1 Ranulph Glanville and the "Black Box"

For the sake of directness, the discussion up to this point has ignored an important cybernetics concept that proves to be highly relevant to the involvement of observers in inferring the stimulus-detection abilities of infants. That is, the cybernetics concept in question is the "Black Box" (Glanville, 1982, 2007, 2009a, 2009b). Briefly, Glanville (1982) defines the Black Box as a "phenomenon", whose actual mechanism can only be *inferred* rather than known. Glanville (2009b, p. 154) states that "Our Black Box is not a physical object, but a concept [. . .] It has no substance, and so can neither be opened, nor does it have an inside". Nonetheless, it has a *mechanism* (Glanville, 1982, 2007, 2009a, 2009b). That mechanism can be *inferred* by an outside "observer".

In the present context, the Black Box represents the infant's *mind*, which includes the infant's perceptions, such as the sensations of light or sound. Whatever underlies the sensations can be considered the associated mechanisms. The infant's observer presents stimuli, the inputs, and records the box's outputs, the behaviors (Glanville, 1982, 2007, 2009a, 2009b). Figure 2 schematizes the Black Box and its observer. Altogether, the observer obtains a "functional description" of the Black Box (Glanville, 1982, p. 1). The functional description "whitens" the Black Box (Glanville, 1982).

Note also the involvement of *reflexivity*, as follows. Glanville (1982, 2009a, 2009b) declares that the *observer* himself can be considered a "Black Box", from the *Black-Box's* viewpoint. That is, the *output* of the Black Box can be considered as an *input* to the observer. The observer's consequent input to the Black Box can be considered as an *output from* the observer, such that the Black Box itself is now an "observer" (Glanville, 1982, p. 7), one that "whitens" the *original* observer. The Black Box and the original observer now altogether constitute a *system*, which Glanville designates a *white box* (Glanville, 1982). Altogether, "The Black Box and the observer act together to constitute a (new) whole" (Glanville, 2009a, p. 1; see also Glanville, 2009b, p. 161).

This "new whole" would seem to well-characterize the psychophysical experiment; the infant produces an (hopefully stimulus-evoked) input (namely, a behavior) to the observer, where "observer" now represents the laboratory staff, beginning with the watcher. Those



Notes: Presently, the infant's mind is the Black Box and the laboratory staff are "the observer"

Figure 2. (After Glanville, 1982) The Glanville notion of "The System", comprising the Black Box and its observer (see text)

staffers provide a subsequent, and consequent, input to the infant, namely, the next stimulus. Altogether, the infant and the surrounding staffers form a white box.

The "white box" notion may initially seem to contradict an important distinction introduced in Nizami (2018), namely, that the infant is merely a blunt probe of the stimuli given to it by the laboratory staff, and that the ultimate true "observer" of stimuli is the union of infant-plus-staff. But we are presently using the word "observer" merely to describe who observes the infant; thus, there is no contradiction.

The new whole that is "The System" (Figure 2) has been perpetuated for 50 years. Of course, alternative methods of inferring visual or auditory thresholds were explored concurrently. Some of them deserve a brief description, followed by scrutiny through second-order cybernetics. But, because the infant's mind is still a "Black Box", the alternatives too seem destined to have significant problems of interpretation, as follows.

3.2 Probing the "Black Box": physiological correlates of perception

3.2.1 Alternative methods of inferring auditory thresholds. From Olsho *et al.* (1987) onward, Lynne Werner Olsho (later Lynne A. Werner) and co-authors obtained auditory stimulus-detection thresholds from children under the age of 6 months. Olsho *et al.* (1987) is still cited as the premier study in the field (He *et al.*, 2007; Smith and Trainor, 2011; Bonino and Leibold, 2017). Indeed, Grieco-Calub *et al.* (2008, p. 236; repeated in Grieco-Calub and Litovsky, 2012) state that the Olsho *et al.* (1987) method "is commonly used in infant psychoacoustics and has proven to be accurate in determining auditory sensitivity". This statement is quite curious, given that the word *accurate* implies some objective comparison standard. *Presumably*, that objective comparison standard consists of electronic recordings of physical and/or electrophysiological responses of infants to stimuli, involving methods that were developed concurrently with infant psychophysics.

In auditory research, there has been ongoing use of non-invasive (i.e. non-surgical) electrophysiological recordings. One such recording is the auditory steady-state response (ASSR, an aspect of the electroencephalogram [EEG]), which is recorded from electrodes on the infant's scalp. The ASSR is evoked by frequency-varying and/or amplitude-varying tones, used because they "allow the generation of an 'evoked potential audiogram' that can reflect the pattern of a subject's hearing thresholds" (Rance *et al.*, 2005, p. 292; original internal quotation marks).

ASSRs can be obtained from *sleeping* infants younger than 3 months old (Cone-Wesson *et al.*, 2002b; Rance *et al.*, 2005). The record of electrical potentials is processed mathematically, after which "the presence or absence of a response [i.e. electrical response to the auditory stimulus] was then determined automatically with a statistical detection criterion" (Rance *et al.*, 2005).

There is another electrophysiological trace that is both found in the EEG and that can be recorded from sleeping infants, namely, the auditory brainstem response (ABR). Like the ASSR, the ABR requires electrodes on the head, as well as statistical criteria for judgments of whether a response is "normal" or "abnormal" (Sena-Yoshinaga *et al.*, 2014). The stimulus can be a rapid train of clicks (van Straaten, 1999; Cone-Wesson *et al.*, 2002b; Sena-Yoshinaga *et al.*, 2014), or can be pulsed tones (Cone-Wesson *et al.*, 2002a). The ABR has advantages and disadvantages compared to ASSR (Cone-Wesson *et al.*, 2002a, and citations therein). For example, ABRs are typically recorded in response to click-trains, each click effectively containing a broad range of auditory waveform frequencies. This tests the hearing system's frequency response as a whole; conversely, it lacks the frequency-specificity of the modulated tones used in ASSRs, and hence is less useful for diagnosing hearing loss at *specific* auditory waveform frequencies.

ABRs and ASSRs both continue to be used and explored. However, there is a third, very popular non-invasive method involving otoacoustic emissions (OAEs). These are relatively low-amplitude sound-pressure-waves in the ear canal, which can occur naturally or can be evoked by specific auditory stimuli, and result from the peripheral hearing apparatus working *backward*. OAEs can be used by themselves, or as immediate predecessors to other measures, such as ABRs (Hall *et al.*, 2004) or ASSRs. Indeed, OAEs assess different levels of auditory physiology than do ABRs and ASSRs. That is, OAEs depend upon the mechanical properties of the peripheral hearing organ, the cochlea, whereas ABRs and ASSRs represent the neurons that emanate from the cochlea, and their brainward projections (Eggermont and Moore, 2012).

3.2.2 What do non-behavioral auditory thresholds really indicate? ASSRs, ABRs and OAEs have been obtained in clinics, and various authors recommend them because they are inexpensive and because the stimulus exposure itself may take only a few minutes (Cone-Wesson *et al.*, 2002a). Some OAEs and ABRs have been obtained while the infant is lightly sedated (Hall *et al.*, 2004), and some OAEs have been done when infants are awake but calm (Silva *et al.*, 2015). However, all of the various kinds of recordings are typically done when the infant is most cooperative, that is, when it is asleep, which ensures the fastest and, hence, most convenient testing (Cone-Wesson *et al.*, 2002b; Hall *et al.*, 2004; Rance *et al.*, 2005; Sena-Yoshinaga *et al.*, 2014; Silva *et al.*, 2015).

Cone-Wesson *et al.* (2002a, p. 178) found that ASSRs and click-evoked ABRs "have strong and statistically significant ($p < 0.05$) correlations with the pure-tone audiogram in infants and children with various degrees of hearing loss", where the pure-tone audiogram (thresholds versus pure-tone waveform frequency) is established using the same sort of behavioral methods reviewed in Nizami (2018). But there is a problem: those behavioral methods probably overestimate the true stimulus-detection thresholds (Nizami, 2018). Further, Cone-Wesson *et al.* (2002a) obtained ASSRs and *tone-based* ABRs on sleeping *adults*, namely, women who had normal pure-tone detection thresholds – and found that the average thresholds estimated from electrophysiology were higher, indeed, *as much as 40 dB higher*, than the thresholds *reported* by the women themselves when awake. Likewise, Delaroche *et al.* (2011) found that thresholds inferred from click-evoked ABRs in infants less than 6 months old tended to substantially exceed those inferred behaviorally (using a variation of the methods reviewed in Nizami (2018)), but that nonetheless, the two sets of thresholds were well-correlated. There is a clear implication that stimulus-detection thresholds that are inferred electrophysiologically, like those established behaviorally, are probably substantially higher than the *true* stimulus-detection thresholds. This implies, in turn, that too many infants may be diagnosed as "hearing-impaired". Some will, therefore, inevitably be fitted with implanted electronic hearing aids, which are expensive and which may, in the long term, actually disadvantage the infant through unnatural hearing.

There is a great deal more literature that supports this conclusion. The earliest relevant literature appeared at least four decades ago, and the literature on ASSRs, ABRs and OAEs in infants is large enough to deserve its own book.

4. Summary and conclusions on infant "detection thresholds"

Bargones and Werner (1994, p. 170) flatly declare that "infants' auditory detection thresholds are higher than adult thresholds". That is, for the infant to just barely hear a stimulus, it must be of greater intensity than a stimulus of the same frequency spectrum given to adults. In other words, from the adult's point of view, it must be made louder. In later work, Bargones *et al.* (1995, p. 99) declare that "infants' sound detection thresholds are worse than those of adults", and further that "the finding that infant thresholds are higher than those of adults is well established" (see also Werner *et al.*, 2009, p. 1040; Werner, 2012, p. 4).

Such confident statements are quite curious, given that infants' behavior displays what the sociologist Peterson (2016) calls "untamable variability". Indeed, as Peterson notes:

> Infant subjects occupy a liminal space [between animals and human adults] because they are as unpredictable and resistant to instruction as animals and yet bear the inviolable rights of human beings (Peterson, p. 2).

Peterson himself was "embedded" for a while in several infant-perception laboratories. He found that the untamable variability of the infants apparently extends also to the laboratory staff, such that a liminal space (so-to-speak) develops in-between the reported laboratory standards and those that are actually followed. That is, he noted various unprofessional practices, some of them driven by the desire for "statistical significance" in the data.

It is presently proposed that infants' inferred "detection thresholds" are actually those for overcoming distraction – the *attentional* thresholds. Consider that, during the experiment, the infant has a plethora of distractions – lights, sounds, objects, daydreams, new people and, not the least, the behavior of its holder. These distractions may overcome any distraction offered by a stimulus at the *true* detection threshold. The "attentional hypothesis" has empirical support, although perhaps inadvertently. Several studies suggest that infants' detection thresholds for a tone are elevated by a simultaneous noise, *beyond what is expected for adults under the same circumstances*, showing that the infants cannot overcome the distraction provided by the added noise.

Others have tried to minimize laboratory distractions, using a soundproof chamber containing only a nightlight and a visual fixation point, with the infant's mother being in the booth (a common practice) but, this time, out of the infant's sight. Even in this situation, 2-month-old infants were so unresponsive as to be inadequate experimental subjects. More support for the "attentional hypothesis" comes from studies of children 3 to 5 years old who, unlike infants, can indicate unambiguously which one of two intervals containing a noise also contained a tone. Again, detection thresholds prove higher than for adults, and slopes of psychometric functions are shallower, the latter perhaps because of inattention.

Second-order cybernetics offers a further perspective not yet employed in infant psychophysics, as follows. An experimental research subject who cannot report their impressions of stimuli, such as an infant, cannot express their mind. Anyone's mind is a "Black Box", having mechanisms – such as those underlying vision or hearing – that can only be *inferred* by an outside "observer", rather than being overtly uncovered. In infant psychophysics, the infant produces an input to the "observer", which is now the laboratory staff. Staffers then provide an input to the infant, namely, the next stimulus. Altogether, the infant and the laboratory staff constitute a new whole, called the "white box". This new whole represents a resilient experimental method that has persisted for half a century.

Of course, alternative methods of inferring auditory stimulus-detection thresholds were concurrently being explored worldwide. The ASSR (an aspect of the EEG) is evoked by frequency-varying and/or amplitude-varying tones. It is recorded from electrodes on the infant's scalp. Importantly for laboratory convenience, ASSRs can be obtained from *sleeping* infants. So can the ABR, another electrophysiological trace that is found in the EEG, for which the stimulus can be a rapid train of clicks, or pulsed tones. There is a third and very popular method, one that does not involve electrodes: the recording of OAEs from the ear canal, using a microphone. OAEs depend upon the mechanical properties of the peripheral hearing organ, the cochlea, whereas it is the neurons that emanate from the cochlea, and their brainward projections, which are represented in ABRs and ASSRs.

Unfortunately, all of these methods have a common weakness; they depend upon human-chosen statistical criteria for in-laboratory judgments of whether a response is "normal". That is, like infant psychophysics, they all ultimately depend upon the judgment of someone other than the infant research subject. Not surprisingly, then, stimulus-detection thresholds that are inferred physiologically, like those established behaviorally, are probably substantially higher than infants' *true* stimulus-detection thresholds. (They explore the infant's body, but not the infant's mind.) All of this implies, in turn, that auditory testing leads to infants being misdiagnosed as "hearing-impaired", perhaps being needlessly fitted with expensive electronic implants.

Let us ultimately return to the literature that inspired Nizami (2018), the first of the two present papers. In *American Scientist*, Hamer (2016) praised Davida Teller's "forced-choice preferential looking" technique of assessing infants' visual stimulus-detection thresholds. But Hamer (2016, p. 96) offers the following caution, on his very first page: "How can we know what infants see? Or how can we know what any beings see if they cannot tell us, via language or other unambiguous communicative gesture, of their internal experience?" How, indeed? In place of "see", we might just as well say "hear, taste, or smell".

References

Allen, P. and Wightman, F. (1994), "Psychometric functions for children's detection of tones in noise", *Journal of Speech and Hearing Research*, Vol. 37 No. 1, pp. 205-215.

Allen, P. and Wightman, F. (1995), "Effects of signal and masker uncertainty on children's detection", *Journal of Speech and Hearing Research*, Vol. 38 No. 2, pp. 503-511.

Bargones, J.Y. and Werner, L.A. (1994), "Adults listen selectively; infants do not", *Psychological Science*, Vol. 5 No. 3, pp. 170-174.

Bargones, J.Y., Werner, L.A. and Marean, G.C. (1995), "Infant psychometric functions for detection: mechanisms of immature sensitivity", *Journal of the Acoustical Society of America*, Vol. 98 No. 1, pp. 99-111.

Bonino, A.Y. and Leibold, L.J. (2017), "Behavioral assessment of hearing in 2 to 4 year-old children: a two-interval, observer-based procedure using conditioned play-based responses", *Journal of Visualized Experiments*, Vol. 119, pp. 1-7, available at: http://dx.doi.org/10.3791/54788

Cone-Wesson, B., Parker, J., Swiderski, N. and Rickards, F. (2002b), "The auditory steady-state response: full-term and premature neonates", *Journal of the American Academy of Audiology*, Vol. 13, pp. 260-269.

Cone-Wesson, B., Dowell, R.C., Tomlin, D., Rance, G. and Ming, W.J. (2002a), "The auditory steady-state response: comparisons with the auditory brainstem response", *Journal of the American Academy of Audiology*, Vol. 13, pp. 173-187.

Delaroche, M., Gavilan-Cellié, I., Maurice-Tison, S., Kpozehouen, A. and Dauman, R. (2011), "Is behavioral audiometry achievable in infants younger than 6 months of age?", *International Journal of Pediatric Otorhinolaryngology*, Vol. 75 No. 12, pp. 1502-1509.

Eggermont, J.J. and Moore, J.K. (2012), "Morphological and functional development of the auditory nervous system", in Werner, L., Fay, R.R. and Popper, A.N. (Eds), *Human Auditory Development*, Springer Science+Business Media, New York, NY, pp. 61-105.

Fantz, R.L. (1963), "Pattern vision in newborn infants", *Science (New York, NY)*, Vol. 140 No. 3564, pp. 296-297.

Fantz, R.L. (1965), "Visual perception from birth as shown by pattern selectivity", *Annals of the New York Academy of Sciences*, Vol. 118 No. 21, pp. 793-814.

Fantz, R.L., Ordy, J.M. and Udelf, M.S. (1962), "Maturation of pattern vision in infants during the first six months", *Journal of Comparative and Physiological Psychology*, Vol. 55 No. 6, pp. 907-917.

Glanville, R. (1982), “Inside every White Box there are two Black Boxes trying to get out”, *Behavioral Science*, Vol. 27 No. 1, pp. 1-11.

Glanville, R. (2007), “A (cybernetic) musing: Ashby and the Black Box”, *Cybernetics and Human Knowing*, Vol. 14, pp. 189-196.

Glanville, R. (2009a), “Darkening the Black Box”, *Abstract, Proceedings of the 13th World Multi-Conference on Systemics, Cybernetics and Informatics (Section on Complexity, Reflexivity and Reusability of Knowledge)*, *Orlando, FL*, *International Institute of Informatics and Systemics*.

Glanville, R. (2009b), “Black Boxes”, *Cybernetics and Human Knowing*, Vol. 16, pp. 153-167.

Green, D.M. and Swets, J.A. (1966/1988), *Signal Detection Theory and Psychophysics*, Peninsula Publishing, Los Altos, CA.

Grieco-Calub, T.M. and Litovsky, R.Y. (2012), “Spatial acuity in two-to-three-year-old children with normal acoustic hearing, unilateral cochlear implants and bilateral cochlear implants”, *Ear and Hearing*, Vol. 33 No. 5, pp. 561-572.

Grieco-Calub, T.M., Litovsky, R.Y. and Werner, L.A. (2008), “Using the observer-based psychophysical procedure to assess localization acuity in toddlers who use bilateral cochlear implants”, *Otology and Neurotology*, Vol. 29 No. 2, pp. 235-239.

Hall, J.W. III, Smith, S.D. and Popelka, G.R. (2004), “Newborn hearing screening with combined otoacoustic emissions and auditory brainstem responses”, *Journal of the American Academy of Audiology*, Vol. 15 No. 6, pp. 414-425.

Hamer, R.D. (2016), “The visual world of infants”, *American Scientist*, Vol. 104 No. 2, pp. 96-101.

Hartmann, W.M. (1998), *Signals, Sound, and Sensation*, Springer-Verlag, New York, NY.

He, C., Hotson, L. and Trainor, L.J. (2007), “Mismatch responses to pitch changes in early infancy”, *Journal of Cognitive Neuroscience*, Vol. 19 No. 5, pp. 878-892.

Hicks, C.B., Tharpe, A.M. and Ashmead, D.H. (2000), “Behavioral auditory assessment of young infants: methodological limitations or natural lack of auditory responsiveness?”, *American Journal of Audiology*, Vol. 9 No. 2, pp. 1-7.

Macmillan, N.A. and Creelman, C.D. (1991), *Detection Theory: A User’s Guide*, Cambridge U. Press, New York, NY.

Nizami, L. (2018), “Too resilient for anyone’s good: ‘infant psychophysics’ viewed through second-order cybernetics, part 1 (background and problems)”, *Kybernetes*.

Olsho, L.W., Koch, E.G., Halpin, C.F. and Carter, E.A. (1987), “An observer-based psychoacoustic procedure for use with young infants”, *Developmental Psychology*, Vol. 23 No. 5, pp. 627-640.

Peterson, D. (2016), “The baby factory: difficult research objects, disciplinary standards, and the production of statistical significance”, *Socius: Sociological Research for a Dynamic World*, Vol. 2, pp. 1-10.

Rance, G., Roper, R., Symons, L., Moody, L.-J., Poulis, C., Dourlay, M. and Kelly, T. (2005), “Hearing threshold estimation in infants using auditory steady-state responses”, *Journal of the American Academy of Audiology*, Vol. 16 No. 5, pp. 291-300.

Sena-Yoshinaga, T.A., Almeida, M.G., Côrtes-Andrade, I.F. and Lewis, D.R. (2014), “Neonatal hearing screening with automated auditory brainstem response: using different technologies”, *Audiology – Communication Research*, Vol. 19 No. 1, pp. 19-24.

Silva, G.C., Delecrode, C.R., Kemp, A.T., Martins, F. and Cardoso, A.C.V. (2015), “Transient evoked and distortion product otoacoustic emissions in a group of neonates”, *International Archives of Otorhinolaryngology*, Vol. 19 No. 3, pp. 255-258.

Smith, N.A. and Trainor, L.J. (2011), “Auditory stream segregation improves infants’ selective attention to target tones amid distractors”, *Infancy*, Vol. 16 No. 6, pp. 655-668.

Teller, D.Y. (1979), “The forced-choice preferential looking procedure: a psychophysical technique for use with human infants”, *Infant Behavior and Development*, Vol. 2, pp. 135-153.

Teller, D.Y., Morse, R., Borton, R. and Regal, D. (1974), "Visual acuity for vertical and diagonal gratings in human infants", *Vision Research*, Vol. 14 No. 12, pp. 1433-1439.

Tharpe, A.M. and Ashmead, D.H. (2001), "A longitudinal investigation of infant auditory sensitivity", *American Journal of Audiology*, Vol. 10 No. 2, pp. 104-112.

Thompson, M. and Thompson, G. (1972), "Response of infants and young children as a function of auditory stimuli and test methods", *Journal of Speech and Hearing Research*, Vol. 15 No. 4, pp. 699-707.

van Straaten, H.L.M. (1999), "Automated auditory brainstem response in neonatal hearing screening", *Acta Paediatrica (Oslo, Norway : 1992), Supplement*, Vol. 88 No. 432, pp. 76-79.

Werner, L.A. (2012), "Overview and issues in human auditory development", in Werner, L.A., Fay, R.R. and Popper, A.N. (Eds), *Human Auditory Development*, Springer Science+Business Media, New York, NY, pp. 1-18.

Werner, L.A. and Bargones, J.Y. (1991), "Sources of auditory masking in infants: distraction effects", *Perception and Psychophysics*, Vol. 50 No. 5, pp. 405-412.

Werner, L.A. and Gillenwater, J.M. (1990), "Pure-tone sensitivity of 2- to 5-week-old infants", *Infant Behavior and Development*, Vol. 13 No. 3, pp. 355-375.

Werner, L.A., Marean, G.C., Halpin, C.F., Spetner, N.B. and Gillenwater, J.M. (1992), "Infant auditory temporal acuity: gap detection", *Child Development*, Vol. 63 No. 2, pp. 260-272.

Werner, L.A., Parrish, H.K. and Holmer, N.M. (2009), "Effects of temporal uncertainty and temporal expectancy on infants' auditory sensitivity", *Journal of the Acoustical Society of America*, Vol. 125 No. 2, pp. 1040-1049.

Corresponding author
Lance Nizami can be contacted at: nizamii2@att.net