DEFINING FREQUENCY: A NATURAL SCIENTIFIC TERM

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The ultimate expression of science lies in the discovery of basic laws that explain regularities in the universe. Throughout history branches of science have formed seeking to understand lawful events in nature. For instance, Physics studies our world by examining the movement of objects, the structure of sound, light, electricity and heat, and the "fundamental constitution of matter" (Wolpert, 1992, p. 1). Astronomy explores planetary and celestial phenomena, Medicine investigates human biology and physiology, Chemistry researches chemical activity, and Behavior Analysis studies behavior. All branches of science have something in common, the use of standardized and objective measurement. "Measurement is how scientists operationalize empiricism. Objective measurement enables (indeed, it requires) scientists to describe the phenomena they observe in precise, consistent, and publicly verifiable ways." (Cooper, Heron, & Heward, 2007, p.73) These measurements accurately capture the phenomena scientists intend to measure. Moreover, standardized measurements avoid confusion and therefore enhance communication within the professional communities.

Frequency represents a standard measurement that pervades all motion and movement. "Combining observation time with count yields one of the most widely use of measures in applied behavior analysis, rate (or frequency) or responding, defined as the number of responses per unit of time." (Cooper, et al., 2007, p.76) By providing the number of occurrences over time, a frequency measurement can precisely describe the dimensional quantity of a repeating event. A standard measurement must be applied precisely in all cases. Once the fundamental properties of the event are chosen, a standard measurement can be implemented and used across all cases without yielding faulty interpretation. For example, when instances of a repeating event are of interest, frequency offers precise measurements across any behavior topography such as typing, walking, running, and so on. The National Institute of Standards and Technology, or NIST, defines the time interval as "one of the four basic standards of measurement (the others are length, mass, and temperature). Of these four basic standards, the time interval (and frequency) can be measured with the most resolution and the least uncertainty (NIST, 2007).

A measurement remains standardized in any occurrence, which is especially true within natural science. NIST defines frequency as the time of a repetitive event. If T equals the period or time interval elapse for a repetitive event, then frequency, or f, is its reciprocal or $f = 1/T$ (NIST, 2006a). An example of a special unit of measurement for frequency is the Hertz, named after Heinrich Hertz. A hertz represents 1 crest of a wavelength passing a given point per second (Hazen & Trefil, 1990). In other words, we want to measure the frequency of sound by capturing the number of repetitive crests of the wave moving per second. T equals one second. Frequency of one Hz is one cycle of wave moving per second. As an example of a Hertz measure, the musical note “A” corresponds to a frequency of 440 crests of the wave moving per second, known as 440Hz, and middle “C” on a piano equals 246 Hz. By using standardized measurement of sound frequency, we can identify and compare various musical notes. Frequency settings also play a vital role beyond science in technology mediums such as television and radio broadcasting. Although seconds are commonly used in frequency measurement, the passage of time can vary depending on the repeated events of interest. The frequency quantity may include units of waves per second, cycles per minute, responses per hour, or occurrences per given period of time.

Importance of Measuring Frequency in Behavior Science

In behavioral science, quantitative data of behaviors are collected and converted to units of measurement for purpose of comparison. Skinner had long maintained the importance of frequency when measuring behaviors. In Skinner’s words: “It follows that the main datum to be measured in the study of the dynamic laws of an operant is the length of time elapsing between a response and the response immediately preceding it…” (1938, p. 58). Visual inspection of the cumulative number of responses occurring in time, or the number of events over time, played a critical role in the discovery of basic principles of behavior. Ferster and Skinner (1957) explained how graphic displays of frequency and the manipulation of schedules of reinforcement demonstrated reliable changes in the likelihood of an organism’s response. In *Science and Human Behavior,* Skinner (1953) described how frequency advanced the concept of the probability of a response: “When we come to refine the notion of probability of response for scientific use, we find that here, too, our data are frequencies and that the conditions under which they are observed must be specified” (p. 63).

On many occasions, Skinner also used the word “rate” referring to frequency. “Rate of responding” allowed Skinner to articulate patterns of behavior occurring as the number of events in a given time frame. In practice, rate and frequency have been used interchangeablely, expressed by number of responses over time. While others have discussed the difference in more details (Johnston & Pennypacker, 1993a, 1993b), recent treatments of the terms rate and frequency suggest it may be useful revisiting the distinction and proper usage of our terminology.

Sometimes researchers portray frequency as a count only. For instance, Alberto and Troutman (2006) stated, “The frequency of behavior is simply the number of times a student engages in it” (p. 55). In other words, the “frequency” of a student’s out of seat behaviors is 6 (e.g. out of seat six times during math period). No temporal data are provided when reporting counts. On the other hand, rate is stated as, “frequency expressed in a ratio with time.” (Alberto, et al., 2006, p. 55). Therefore frequency and rate are defined having different dimensions, which is inconsistent with Skinner’s usage and other behavior analysts’ definitions (e.g., Cooper, et al. 2007; Johnston & Pennypacker, 1993a). This discrepancy causes confusion for what researchers and clinicians mean when a quantity is reported.

As a natural scientist, Skinner recognized behavior occurred in time and took full advantage of frequency as a dimensional quantity. Johnston and Pennypacker (1993a) suggested any good measurement should allow behavior analysts to describe, compare, and predict measured events. Report of frequency of responding meets these requirements.

- Description: When describing Lexi’s behavior of matching pictures to the sample, behavior analysts can report frequency measurement as: 17 pictures matched to sample per minute.

- Comparison: Behavior analysts can also compare the behaviors of multiple students. If Lexi has 17 correct matches per minute while Dennis has 36 correct matches per minute, the levels of response proficiency can be differentiated.
- Prediction: Behavior analysts can also predict the trend of a behavior. The weekly acceleration of Lexi's behavior of matching pictures correctly per minute grew exponentially by a factor of x 1.5 (i.e., Monday – 17 correct matches/minute, following Monday -26 correct matches/minute). The following Monday, if the prediction holds true, Lexi should have correct matches at a frequency of approximately 39 correct matches per minute.

Characteristics of Frequency

Frequency reveals every small change of behavior and therefore is considered the basic datum of the science of the behavior (Skinner, 1966). The unit of frequency measurement (i.e., performance over time) is ready to be converted to other units for ease of comparison (e.g., 30 responses within 10 minutes equal 3 response per minute). Pennypacker, Gutierrez, and Lindsley (2003) suggest that units used for frequency, like other units used in the natural sciences, has three important characteristics as a dimensional quantity of measurement: they are standard, absolute, and universal.

Standard means that everyone can agree upon the dimensions of the measure. Contemporarily, standard measures may not seem groundbreaking, but turning back the clock to eighteenth century France one would encounter over 250,000 different units of measurement (Alder, 2002). The diversity of nonstandard units of weights rendered the dimensions of one measure to the next meaningless. If town A used the term *jigger* for the capacity of liquid town B might use *jigger* to measure another dimension such as length. Without standard measurement, commerce remained chaotic. Analogously, behavior analysts using terms such as frequency without reference to its standard meaning, namely as defined in the natural sciences, may encounter problems in communication and interpretation of data. Using frequency to refer to counts distorts the nature of standard measurement units.

Beyond frequency's standard feature, its value does not change from one instance to the next (Pennypacker et al., 2003). In other words, frequency exemplifies an *absolute* quality. Other units of measurement like the meter also represent an absolute measure of length. The meter has the following absolute measurement, "the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second" (NIST, 2006b). Anyone using the meter uses the same objective measurement criteria on all occasions. At the same time, the meter is not used to measure any dimensions of observations, such as weight or volume, other than length. Measuring frequency, like measuring length with meter, demands that users faithfully maintain the absolute quality and quantity explicitly defined. For instance, under a section describing "Event-based methods for recording and reporting behavior," Richards, Taylor, Ramasamy, and Richards (1999) separated frequency and rate**,** "Frequency involves recording the number of responses that occur during an observation session. The length of the observation sessions needs to remain constant…" (p. 52) while "rate is a measure of frequency that is directly linked to the length of observation periods. When observation sessions vary in length, rate must be used rather than frequency…" (p.53). Proposing that frequency can only be used under the condition of consistent observation periods overlooks the temporal nature of frequency and therefore bends its absolute quality. Behavior analysts who dichotomize rate and frequency or use the term frequency to mean how *many*, or *counts* of behavior foster a potentially undesirable situation, namely, creating a terminological disconnect between the behavior analytic lexicon and the language universally used in natural science. Not only does it create confusion in communication, but it also fails to secure the construct validity of measurement.

Universal refers to explicit application of the unit to all cases of the dimension in nature (Pennypacker et al., 2003). Coherent systems of units require the consistent handling of natural phenomena. Therefore, whether measuring a pulse (beats per minute), the speed of a car (miles per hour), a washing machine's spin cycle (revolutions per minute), or a global positioning system broadcast signal (megahertz) frequency applies to all examples. Every behavior can be expressed in a manner of frequency.

Conclusion

Using terms that facilitate accurate, repeatable quantification distinguishes science from other approaches for gaining knowledge. The term frequency suggests a two-dimensional measurement (i.e., numerical and temporal), corresponding to a uniform and specific measure endorsed in natural science. Using such a measure as expressed in science presents a number of benefits for behavior analysts and may also serve as a catalyst for discovery. As a behavioral scientist who regularly employed the natural scientific usage of frequency Lindsley (1991) understood the power of using standard units of measurement and said the following about frequency:

> *When we looked at light qualities we accomplished little, but when we looked at light merely as differences on a frequency spectrum, we accomplished wonders of radiance. When we listened to sound qualities, we accomplished little, but when we placed sounds on a frequency spectrum we developed instruments and amplifiers far purer than the best ever crafted by quality artisans. When we puzzled over differences in the qualities of electricity, we accomplished little, but when we sprinkled electrical events over a frequency spectrum, we made great strides in electrical control and discovery (p. 254).*

One can only wonder at the discoveries that await our decision to properly use and adopt frequency for what it is- the *standard*, *absolute* and *universal* measure of behaviors.

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