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The promise of mobile technologies and single case designs for the study of individuals in their natural environment ☆

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ABSTRACT

Mobile technologies are growing rapidly around the world to broad demographics of society. These technologies hold great promise for their integration with Single Case Designs (SCDs) and the study of individuals in their natural environment. This paper discusses the theoretical, methodological and analytic implications of these tools for the advancement of the contextual behavioral etiology of behavioral disorders, and their remediation. We hope this paper will highlight the scientific advantages of combining mobile technologies and SCDs and encourage their adoption among CBS scientists.

Psychology is rooted in the study of individuals. Skinner (1938), whose work is very familiar to behavioral scientists, derived the principles of positive and negative reinforcement from the study of individuals from two single species (*rattus norvegicus* and *columba livia*). The development of applied interventions in areas such as education (e.g., Layng et al., 2004), psychopathology (e.g., ; Kazdin, 1977; Wolpe, 1968), addiction (e.g., McDonell et al., 2013; Petry et al., 2006), or developmental disabilities (e.g., Sisson et al., 1993), draw directly from the principles derived from such individual analysis. Further, many experiments in other fields of psychology relied on single individuals to validate scientific hypotheses and theories. For example, Ebbinghaus (1913) discovered new insights into memory and cognition through experiments he conducted primarily on himself.

Creating models to explain individual variation has the advantage of generating knowledge that is directly transportable to clinical practice. In areas such as medicine, these designs have become increasingly popular (e.g., Backman and Harris, 1999; Kravitz et al., 2008; Shamseer et al., 2012), such that an extension of the CONSORT guidelines is currently being developed in the medical field (e.g., CENT guidelines: Shamseer et al., 2012). This revival of SCD methods has its origin in ethical, financial and methodological arguments. Authors such as Lillie et al. (2011) argue that these methods are central for the development of personalized medicine. In their view, despite the fact that a central axiom in medicine is that of providing treatment to the individual patient, it is surprising that SCD methods remained exclusive to areas such as education, a point also made by Kravitz et al. (2008). Riley et al. (2013) discussed the benefits of SCDs for pilot trials, given their flexibility, cost-efficiency and ability to quickly generate data. In the authors' view, SCDs play a central role in what they call rapid, responsive and relevant research, since these methods can reduce the costs of exploring the feasibility of new interventions and accelerate scientific innovation. Finally, the use of randomization tests (or permutation tests) allows the statistical analysis of SCDs without relying on the assumptions of most frequentist statistical techniques (i.e., random sampling, independence, normality). As this special issue shows, randomization tests have a long history (Dugard, 2014), are quickly evolving, and can be run with freely available software packages (Heyvaert & Onghena, 2014).

1. Mobile technologies: a 21st century tool for CBS scientists

Throughout history, scientists have taken advantage of any tools available to interact with their subject of study. In astronomy, the telescope substituted for the bare eye in the observation of stars and planets, leading to a greater precision in the definition of astronomical terms. Likewise, the microscope was a critical source of innovation in biology. Computer technology had a similar effect across scientific disciplines. The software and hardware revolution of the 1950s had a great impact in science, both in terms of computation power and of speed of transfer of information (Fertig,

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1985). However, aside of the availability of word processors, data analysis and communication software (e.g., internet, email), this revolution did not have a profound impact on the basic tools for studying the individual in its natural environment. Mobile technologies are changing this.

Mobile technologies have been defined as "wireless devices and sensors (including mobile phones) that are intended to be worn, carried, or accessed by the person during normal daily activities" (Kumar et al., 2013, p. 228). This definition includes a broad range of devices, from cellphones and portable digital assistants (PDAs) to state of the art smartphones. It is also broad enough to include devices that can be used for a variety of purposes, such as help people monitor behavior, provide therapeutic content or respond to time sensitive self-report data. For example, smartphones are enabling behavioral scientists to model, instigate and reinforce individual behavior change in "real-world" settings, and the active and passive assessment of outcomes. The sophistication and capabilities of these new mobile technologies are such that they are "a dream come true" from a contextual behavioral science standpoint. Further, mobile devices are already carried by 83% of individuals in the United States, and smartphones are used by 34% of the population (Smith, 2012). The popularity of mobile technology is reflected by the fact that there are currently 12,000 health related apps in the market (Mobihealthnews, n.d.), and by 2016 it is estimated that there will be 146 million downloads of mobile health apps (iHealthBeat, n.d.).

Despite the fact that very few mobile health apps have been empirically tested (Chen et al., 2012; Déglise et al., 2012), these technologies have created great excitement in the field (e.g., Miller, 2012), including major research funding institutions (e.g., Kumar et al., 2013; Nilsen et al., 2012). Mobile technologies allow for the feasible implementation of SCDs in an individual's natural environment, providing real time assessment and testing of contextual behavioral hypothesis and theories. Currently, a number of papers have discussed the use of mobile technologies in the social and behavioral sciences (e.g., Aguilera and Muench, 2012; Chen et al., 2012; Dallery et al., 2013; Kumar et al., 2013; Miller, 2012; Morris and Aguilera, 2012; Nilsen et al., 2012), but none has elaborated on their value from a CBS perspective. Furthermore, some studies have discussed the implications of SCDs for the rapid testing of technology-based interventions (e.g., Dallery et al., 2013), but not the scientific implications of mobile technologies for the implementation of SCDs. Therefore, the goal of this paper is to discuss the theoretical, methodological and analytic implications of combining mobile technologies and SCDs for the study of individuals in their natural environment from a CBS standpoint.

2. Theoretical advantages: examining the impact of verbal influence in natural contexts

Mobile technologies are a means to an end, rather than an end themselves. From a scientific perspective these technologies are an empty shell if not at the service of testing specific hypotheses or theories. One of the most innovative behavioral theories that came out of the contextual behavioral tradition is Relational Frame Theory (RFT; Hayes et al., 2001). RFT was built upon Skinner's (1957) classic work on verbal behavior and Kantor's (1963) interbehaviorism. This scientific approach to language and cognition targets the ecological determinants of individual behavior, and studies how over time, the verbal context experienced by a single individual and its consequences, form a relational repertoire (a.k.a. "relational network"). RFT reignited the naturalistic and non-reductionist study of areas such as self-awareness (e.g., Dymond and Barnes, 1997), cognition (e.g., Golijani-Moghaddam et al.,2013), values-driven behaviors (e.g., Hooper et al., 2012) and metaphor (e.g., Stewart et al., 2004), and has informed the development of psychotherapy models such as Acceptance and Commitment Therapy (Hayes et al., 2011). A more detailed description of RFT and its historical and current status can be found elsewhere (e.g., Dymond, 2013; Hughes et al., 2012).

RFT attempts to understand how specific *verbal cues* (e.g., naming, comparing, contrasting) put forward by individuals in the social environment have an impact on individual's experiences (thinking, feeling, wanting) and overt behavior. These verbal cues have been traditionally experienced through different forms of writing, but more recently through other media, such as text messaging or websites. One example of verbal event is the common experience of receiving and responding to a text message. A specific verbal cue (e.g., "how are you doing"), in combination with a specific physical context (e.g., a restaurant, an empty classroom or an open space), has the function of prompting an emotional, relational or overt behavioral response (e.g., feeling connected, responding back, ignoring it, providing another verbal cue, etc.). These antecedents, behaviors and consequences will shape the overall verbal context of this individual and influence future interactions.

In that way, mobile technologies have the potential to serve as a platform to study the impact of verbal cues on individuals' behavior in their natural environment. Furthermore, the combination of mobile technologies and measurement procedures such as ecological momentary assessments (e.g., Wenze and Miller, 2010) and a variety of mobile sensors (Ali et al., 2012; Plarre et al., 2011; Preece et al., 2009) have enabled the gathering of real time environmental and observational data, a possibility that haunted the field almost from its inception (Dougher and Dougher, 2000).

These devices provide an excellent opportunity to RFT and clinical CBS researchers. By deliverately manipulating a variety of daily verbal cues, researchers can extend the reach of their experimental verbal manipulations to real world settings. These verbal cues can be designed to enhance more flexible repertoires such as deictic relations (Vilardaga et al., 2012), motivative augmentals (Dahl et al., 2009), or combinations of relational cues (e.g., in the form of metaphors). These mobile technologies, when combined with an RFT analysis of language can also be used as stand-alone interventions or to enhance existing face-to-face interventions. In addition, mobile technologies can enable researchers to study the contextual antecedents and consequences of specific verbal cues and potentially design functionally appropriate schedules of verbal prompting that are unique to a particular individual. For example, machine learning algorithms can be programmed to track specific sequences of events, behaviors and consequences to readjust the ratio of motivative augmentals provided to a specific individual for a specific target behavior. Furthermore, if deictic relations are at the core of rigid forms of sense of self and a range of clinical phenomena, as argued by ACT and RFT researchers (e.g., Barnes-Holmes et al., 2000; Vilardaga et al., 2012), then it would be expected that a mobile texting intervention in which machine learning algorithms are used to modulate the delivery of deictic contextual cues could have the effect of increasing individual's levels of psychological flexibility. Machine learning algorithms have already been used to improve behavioral interventions (e.g., Burns et al., 2011), although to our awareness, not using RFT.

3. Methodological advantages: increasing the precision, scope and depth of contextual behavioral research

Precision, scope and depth are important qualities of scientific theories (Biglan and Hayes, 1996). *Precision* is attained by having a limited number of concepts referring to a given phenomenon. This requires tools that can bridge the concept and the phenomena