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Future Directions in the Developmental Science of Addictions

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Abstract

This essay addresses important future directions for the study of addictions, emphasizing the incorporation of developmental perspectives into how we think about substance use and disorder as unfolding processes over time and context for a heterogeneous group of individuals. These perspectives articulate complexities in the developmental processes that underlie change and continuity in human behavior over time. We consider two key developmental concepts, namely 'time' and 'heterogeneity'. We argue that a lack of attention to time sampling creates ambiguity in the meaning of time-linked assessments, challenges in discerning which of multiple clocks may govern behavior, and the inability in some instances to distinguish which of multiple etiological processes may be driving behavior within our samples. Moreover, artificial divisions among disorders that commonly co-occur with substance use are a barrier to the further integration of the study and treatment of addictions with that of psychopathology. Similar to recent changes in the study of psychiatric disorders more broadly, we argue that identifying common deficits among commonly comorbid disorders, rather than patterns of comorbidity per se, is key to identifying early emerging risk factors for substance use and disorder, with important implications for identifying risk populations and developmental periods as well as potentially malleable intervention targets. Attention to time sampling in theory-driven research designs and attempts to identify more homogenous groups of individuals who use and eventually abuse substances over time are two examples of ways to better understand some of the complexity underlying the development of addictions.

> "…there was one very important thing about your quest that we couldn't discuss until you returned…..It was impossible….but if we'd told you then, you might not have gone—and, as you've discovered, so many things are possible just as long as you don't know they're impossible." From *The Phantom Tollbooth* (Juster, 1961, p. 247)

Human development is complex. And the development of addictions is no exception. However, developmental perspectives have played a limited role in shaping our understanding of addictions. Developmental perspectives, such as those offered by Developmental Science (Magnusson & Cairns, 1996) and Developmental Psychopathology (Cicchetti & Cohen, 1995), focus on describing, understanding and predicting the complex processes that underlie change and continuity in the outputs of human development over ontogeny. These system perspectives embrace the complexity of the processes that underlie

development and define development as the study of individuals in contexts. More broadly, developmental sciences view individuals as products of multiple interacting internal systems (e.g., involving genes, neurons, and endocrinology as well as cognition, affect and behavior) engaged in continuous transactions with their environments (e.g., peers, families, and siblings as well as communities, cultures, and societal structures), each with the potential to change over time. Given the resulting theoretical complexity such developmental perspectives dictate, some may reasonably question their utility and deem intractable the study of human behavior based on such principles.

In contrast, we propose that it is in fact the utility of developmental perspectives that make them essential to the study of complex human behavior such as addictions. These perspectives offer a tool for the higher-level integration of an increasing mass of published findings regarding addictions. In so doing, these perspectives have the potential to shape meaningful questions that move the field forward, pursuing the goals of understanding, predicting, and indeed intervening and changing addictive behaviors over time. Previous writings highlight the importance of developmental models for understanding risk and protective pathways to substance use and disorder, which in turn provide invaluable windows for preventive intervention (Dodge et al., 2009; Ialongo et al., 2006). The transactional nesting of addictions within these developmental processes has also been noted, though less frequently, with growing evidence suggesting that developmental pathways not only impact risk for substance use but that substance use also impacts developmental processes in terms of cognitive development (Brown & Tapert, 2004), emotional functioning (Trim, Meehan, King, & Chassin, 2007), and responsiveness to reward (Koob, 2006). In the following essay, we add to this literature by sharing reflections on our experience in applying developmental perspectives to the study of addictions, with the goal of demonstrating not only the utility of these principles but also the necessity of understanding addiction as a developmental process. These reflections center on the contributions of unpacking developmental processes in addiction with respect to time and individual heterogeneity.

Time

Every time we administer a survey, conduct an experiment, or observe an interaction, we are time sampling. This is a fact that we tend to ignore in cross-sectional studies but with repeated assessments this is often a design goal. In their essential synthesis of social science methodology for quasi-experimental studies, Shadish, Cook, and Campbell (2002) identify four elements of research design including assignment to groups, measurement, selecting comparison groups and manipulation/treatment. These elements are relevant to understanding the validity of causal inference across a range of non-experimental and experimental research designs. A potential fifth element to add to this list is time sampling. Each research design includes a decision about when to measure or manipulate a construct, how often, and over what lag. These decisions about time sampling are ideally aligned with theory regarding how a mechanism or process unfolds over time; though, in practice, theory and methods rarely align perfectly. The implications of any misalignment are important for understanding the mechanisms underlying the development of addictions because etiological processes in fact unfold over time.[1]

Several challenges follow from the misalignment of theory and method surrounding time sampling. First, the meaning of an assessment at any single point in time may be unclear because we have not time sampled over the process as it unfolds. As a result, a core challenge to the field is that time samples are often so narrow or arbitrary that we cannot tell whether a single assessment of addictive behaviors (or related processes) is drawn from an upward, stable or downward pattern of behavior over time. For example, the same score (say a '3' reflecting moderate levels of alcohol consumption) may have different meaning for individuals depending on whether they are increasing over time (say a '3 becoming a 5' reflecting daily consumption) or decreasing over time (say a '3 becoming a 0' reflecting abstinence). Differences in the meaning of a single score may then translate into different associations with predictors. In our example, factors associated with improvement (i.e., recovery, decreasing rates of use) versus deterioration (i.e., escalating use, onset of addiction) may show different correlations with "moderate" alcohol consumption because our scores of moderate alcohol consumption mean different things across individuals. In other words, all '3's are not alike and our limited time sampling makes it impossible for us to know the difference.

Moffitt (1993) articulated this point in her differentiation of life-course-persistent and adolescent-limited forms of antisocial behavior. Apart from their different trajectories of antisocial behavior over time, these forms of behavior differ in associated etiological factors and their prognostic significance (see Moffitt, 2006). In brief, she argues that because antisocial behavior is ubiquitous in adolescence for both life-course-persistent and adolescent-limited youth, studies that time sample only during adolescence are unable to differentiate these subgroups. In other words, 15-year olds who score high on antisocial behavior may be either life-course-persistent or adolescent-limited in their behavioral trajectories. We cannot tell. To differentiate these substantively meaningful groups based on their reports of antisocial behavior, we at least need a broader time sample. Although Moffitt's primary argument is for the consideration of heterogeneity in groups of antisocial youth, her theoretical model also illustrates the important substantive implications of thinking about our assessments as time samples of a broader developmental process. Similar differentiations among the developmental course of trajectories within the field of alcoholism have also been posited (Zucker, 2006).

Concern with aligning time sampling with the mechanisms underlying addiction has partly motivated the growing number of intensive repeated measure studies of substance use that use daily diary, experience sampling or ecological momentary analysis (Shiffman, 2009). Focusing on associations over hours, days or weeks, these studies emphasize the momentary experiences that underlie risk for substance use. Many of these studies focus on continuous experience, such as stress or mood, as predicting substance use depending on context and individual risk factors (for a review, see Colder, Chassin, Lee, & Villalta, 2010; Kassel et al., 2010). These intensive time sampling protocols typically characterize the processes underlying substance use as they may occur within a 2 to 8 week period. An under-utilized technique, referred to as the "burst" design, combines these intensive time sampling

[1]Although some may argue that there are addiction processes that are relatively stable and thus not governed by development, a developmental perspective would argue that unfolding processes are still at work in maintaining the continuity of behavior over time.

protocols with longer-term longitudinal studies (Dishion & Medici Skaggs, 2000). This is an intriguing design that permits us to address the question of whether processes captured in a given time series are stable or change over longer periods of assessment. For example, using data from two 21-day experience sampling protocols completed by 79 youth the summer before and after entering high school, Gottfredson and Hussong (2011) showed that daily associations between sadness and drinking strengthened across the transition to high school, but only for youth whose parents had lower involvement in their children's lives. This experience sampling method allowed us to demonstrate that negative mood is a reliable signal of risk for drinking on any given day without relying on self-reports of coping motives (avoiding the problems of retrospective biases and poor insight into drinking triggers). Extending this to a burst design allowed us to then track the salience of that trigger over development.

These repeated assessment models, however, do not address a second core challenge in the time sampling of developmental processes like those that govern addiction; namely, that human development is often governed by more than one clock. There are many examples of the "multiple clocks" problem in the literature. The classic age-period-cohort distinction formalized by Schaie (1965) extends our typical daily, monthly, or annual clocks for studying addictions to a broader time metric. Back to our repeated assessments of alcohol use (for example), any pattern of change in alcohol use over time may reflect trends following a maturational clock (indexed grossly by age), a historical clock (indexed by calendar year), or a cohort effect (indexed by birth year). Age-period-cohort analyses aim to disentangle the effects of maturation (being 20- versus 15-years old), historical period (the cultural context of 1968 versus 2008), and cohort (being born in 1972 versus 1989, with cohorts defined as sharing the same cultural contexts at the same points in maturation). Although these three clocks are necessarily confounded, current analytic methods address this confounding by making less restrictive assumptions than traditional models and, as a result, have revived interest in this problem (e.g., O'Brien, Hudson, & Stockard, 2008; Winship & Harding, 2008; Yang & Land, 2008).

A classic issue in epidemiology, the problem of cohort effects masquerading as a maturational trend is increasingly a challenge for studies of long-term longitudinal datasets with assessments reaching over decades. For example, analyses by our group of two long-term longitudinal studies of high-risk youth showed unique age and cohort effects on patterns of several drugs of abuse from adolescence into early adulthood (Burns et al., 2013). Importantly, for a subset of these outcomes, cohort and age effects interacted, suggesting that developmental trajectories of some drugs of abuse will differ over birth cohort. Because our predictive models often focus on intra-individual patterns of change in substance use over time (a maturational trend), controls for cohort effects are needed to effectively isolate the 'clock' governing change in substance use over the assessment period. Unfortunately, the time sample in our analysis is better designed to capture maturational trends than cohort effects, with implications for appropriately interpreting patterns of substance use over "time". Nonetheless, this work demonstrates that multiple time trends may intersect and reflect different etiological mechanisms impacting the development of addictive behavior. Although important to many areas of psychopathology, multiple clocks

may be particularly relevant to the study of substance use given changes over time in access and the popularity of particular drugs.

A second version of the "multiple clocks" problem concerns the differentiation of time trends in substance use due to maturation versus experience with substance use (denoted by stage of substance use, number of years of use, or "course"). A strong maturational trend in drinking behaviors is well-established in the literature, with peak rates of heavy drinking occurring in the early 20s that decrease thereafter. A second important time trend is demarcated by the progression of substance use itself, often denoted by initiation at one end and the cyclical relapse/recovery patterns of addiction at the other, with disorder onset somewhere in the middle. The relative importance of these two time trends is exemplified in our own work predicting telescoping (an accelerated progression from alcohol use initiation to disorder onset) in a high-risk sample of 10-25 year olds (Hussong, Bauer, & Chassin, 2008). Using survival analysis, we found a counter-intuitive effect in which girls who started drinking later in adolescence progressed to an alcohol use disorder (if they were going to do so) faster than girls who started drinking earlier in adolescence. However, closer examination showed that this finding was attributable to the intersection of a maturational trend (all girls peaked in their risk for having an alcohol use disorder at age 18 as shown in the lower panel in Figure 1) and a substance use "course" trend. The course trend showed that the relative risk for having an alcohol use disorder flipped from being greater for later-onset girls in the first 3-5 years after drinking onset to being greater for early-onset drinking girls 8 years post drinking onset (see upper panel in Figure 1). The cross-over in risk patterns beginning 8 years post-drinking was likely due to a prolonged period of risk exposure for early-onset girls (i.e., they had "more opportunities" or more years in which to have a disorder), resulting in an overall greater risk for alcohol use disorder in early-onset girls versus later-onset girls. These findings show two "clocks" at work. The first marks the time course for the progression of substance use from initiation to disorder (the course "clock") and the second marks the maturational "clock", each of which uniquely predicted differential hazards of first evidencing symptoms of an alcohol use disorder over time. Both clocks (i.e., when you first started drinking and how old you are) are relevant in predicting patterns of alcohol involvement and related risk for disorder over the early life course.

A final reflection on the insights that arise when we consider the importance of time sampling is that *we rarely have a time point zero*. Time point zero is the point in time when the etiological process under study has not yet started for any of the individuals in the sample or, colloquially, the starting line.[2] It is the point at which we are able to establish temporal precedence of our predictors over our outcomes. Although temporal precedence is a useful tool to increase the validity of causal inference using experimental design, we rarely have a true time point zero in our non-experimental and quasi-experimental studies. For example, consider predictions of the social context model (Dishion, Patterson, & Griesler, 1994) in which poor parental monitoring leaves adolescents free to wander into deviant peer

[2]One may argue that we often have a zero-point in studies of substance use if we catch a sample prior to initiation to observe the onset of drinking for everyone. However, the risk processes that underlie the emergence of drinking are difficult to pin-point in time (see section on Heterogeneity). Even more so, it is difficult to align samples to capture the point of drinking initiation at a single time point for all (though some examples can be noted, as per our example in Hussong et al., 2008) and even more difficult to align samples to capture the point of onset for the risk mechanism per se for all.

associations which become a proximal risk factor for substance use. Evocative parenting models (Pardini, 2008; Racz & McMahon, 2011), on the other hand, suggest that child behavior in turn guides the choices parents make in responding to their children; in other words, adolescents' substance use could evoke a response from parents to increase monitoring.[3] Together these two models represent a classic ecological transaction in developmental science in which parenting influences adolescent behavior and vice-versa over time. Figure 2 depicts an over simplified example of three children, each of whom displays behaviors that follow this model. Unfortunately, the underlying developmental process is unfolding at different points in maturation for these children. As a result, the time samples for waves 1 and 2 (at ages 11 and 12) in our hypothetical study capture periods when there is no association (for Kristie), a negative association (as suggested by the social context model, for Annie), and a positive association (as suggested by the evocative parenting model, for Patrick). Although we have temporal precedence in that parenting behaviors are assessed at wave 1 and substance use outcomes are assessed at wave 2, we have captured youth at different points in the process and are unable to align them at time point 0 (when the same process unfolds for everyone) to see the communality of their experiences.

In sum, a lack of attention to time sampling creates ambiguity in the meaning of our time-linked assessments, challenges in discerning which of multiple clocks may govern behavior, and the inability in some instances to distinguish which of multiple etiological processes may be driving behavior within our samples. What can we do to take into account the important facets of time in studying addictive behaviors? As others have noted, we can thoughtfully time sample. We should consider such questions as: 'what is the time frame we need to characterize (prospectively or, if not possible, retrospectively) to meaningfully interpret our assessments of addictive behavior and related developmental processes', 'are there design features or comparison samples available to help rule out confounding cohort or historical effects in studies of maturational trends', 'how does the age of participants interact with their substance use histories to change the meaning of the addiction behavior', and 'is there a transitional event that would permit us to capture an approximate time point zero'? As acknowledged by others previously, the advancement of science is predicated on asking the right questions.

Capturing Heterogeneity

> ".. For instance, from here that looks like a bucket of water," he said, pointing to a bucket of water; "but from an ant's point of view it's a vast ocean, from an elephant's just a cool drink, and to a fish, of course, it's home. So, you see, the way you see things depends a great deal on where you look at them from." From *The Phantom Tollbooth* (Juster, 1961, p. 108)

[3]The actual support for an evocative parenting hypothesis with respect to the association between parental monitoring and adolescent substance use, however, is quite mixed. This is perhaps because many studies rely on measures of parental monitoring that confound adolescent self-disclosure with parental monitoring behaviors. In these studies, when adolescents use substances, parental monitoring is more likely to decrease perhaps because adolescents are simply less likely to disclose their use (relative to their non-use). However, when adolescents do use substances and parents find out about that use, harsh and inconsistent parenting is more likely to occur (Conger & Rueter, 1996).

Unlike many other areas of psychopathology, the study of addictions has a long history of multi-disciplinarity, though the study of addictions within a clinical psychology perspective is relatively recent (So, 2005; Waldron & Turner, 2008). This divide between psychopathology and addictions is not simply historic and extends well beyond fields of research study to include policy, prevention, treatment, training, and federal grants administration. As others have noted, this separation is at best ironic given significant comorbidity between substance use disorders and a range of psychiatric disorders, particularly in treatment seeking samples (Zucker, 2006). Nonetheless, this divide remains largely entrenched in our research studies where, for example, often well-justified criteria continue to exclude those with substance use disorders from clinical trials focused on other psychiatric disorders and studies of substance use often do not take significant comorbidities into account. Clearly a future direction for research is reaching over this divide. Complexity, however, remains a stumbling block.

One approach to reaching over this divide has been to focus on patterns of comorbidity to distinguish subgroups of substance users. This subtyping approach has a long history in studies of alcoholism (Babor, 1996; Zucker, 2006) though less so for other types of substance use. Comorbidity-based subtyping has the goal of forming more homogenous subgroups within the heterogeneous group of individuals who receive the diagnosis of a substance use disorder. However, this approach has other challenges. Although studies of alcoholism subtypes often differentiate a subgroup of individuals with alcoholism who have predicted patterns of comorbidity, hypothesized correlates and characteristics of this subgroup are less consistently supported in the literature (Babor, 1996). An alternative approach is to use patterns of comorbidities as a guide for identifying underlying deficits that may define subtypes of substance use disorders. This approach mirrors that of the RDoC movement embraced by NIMH (Sanislow et al., 2010), in which the study of psychiatric disorder is refocused on underlying deficits (i.e., observable behaviors and neurobiological measures) that cut-across traditional diagnostic categories (e.g., working memory and acute threat) rather than on diagnostic categories considered in isolation or in tandem (e.g., anxiety and depressive disorders). This unpacking of diagnostic categories highlights the similarities across psychiatric disorders but also the heterogeneity within them.

An example of how this approach has been useful in understanding addictions is the study of alcohol use and disorder as a form of disinhibited behavior. The focus on addictive behaviors as a form of disinhibited behavior, and not simply a pattern of consumption and related consequences and dependency symptoms, provides a bridge for thinking about the developmental course of the disorder.[4] Alternatively termed the disinhibitory, antisocial, and externalizing pathway (Sher, 1991; Zucker, Heitzeg, & Nigg, 2011) to alcohol use disorder, this pathway is often posited to first emerge as difficult temperament in infancy which is followed in childhood by externalizing symptoms (e.g., aggression and conduct problems), an early onset of substance use, escalations in antisocial behavior, and the eventual onset of alcohol and substance use disorders (Tarter et al., 1999; Zucker, 2006). The core problem of

[4]This is an important point of potential divergence between some public health approaches to understanding and preventing substance use as a form of risk behaviors, which may have limited contextual and intrapersonal precursors, and a developmental science approach which may view early risk factors for substance use as a heterotypic form of a shared underlying deficit.

this pathway thus typically reflects behavioral disinhibition, “an inability to inhibit socially undesirable or restricted actions” (Iacono, Malone & McGue, 2008, p. 326). Although multiple factors may propel youth down this trajectory, current models emphasize interactions between an underlying liability for behavioral disinhibition (due to genetic and neurobiological factors; see Dick, 2011; Iacono et al., 2008) and a high-risk environment (due to the impact of parental antisociality on impaired parenting, disruptive or impoverished contexts, and deviant peer networks) as core to risk formation (e.g., Zucker et al., 2011). This pathway has been particularly useful in integrating research findings that link neurogenetic and behavioral risk frameworks to specific forms of substance use and addiction and in looking for continuities across such psychiatric disorders as conduct disorder, attention deficit disorder, and substance use disorders.

Little attention, however, has focused on understanding other early emerging deficits that may also underlie addictions. As we have argued elsewhere (Hussong, Jones , Stein, Baucom, & Boeding, 2011), emotion regulation may be a second deficit that acts in isolation or in tandem with behavioral disinhibition to form an early emerging risk pathway for substance use and addictions. Emotion regulation, whose various definitions include the “extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one’s goal” (Thompson, 1994, pp. 27-28), is the focus of significantly less research attention as a predictor of substance use and evidence for this pathway is not as consistent or conceptually integrated as that for a disinhibitory pathway. However, existing studies are consistent with a model in which risk emerges in early childhood as a difficult, behaviorally inhibited temperament followed by elevated internalizing symptoms and social skills deficits that manifest most clearly at school entry. Prolonged internalizing symptoms and challenges in social functioning may fuel a search for alternative coping strategies, increasing the likelihood that youth will acquire coping expectancies and motives. These cognitions in turn are linked with the initiation and escalation of substance use in adolescence (either with the goal of self-medication by drinking alone and/or with the goal of peer acceptance by drinking with deviant peers), with internalizing symptoms and substance use potentiating one another to the point of addiction with the approach of young adulthood. The predictive framework of the internalizing pathway takes into account different manifestations of failures to meet developmental expectations for emotion regulation relative to risk for substance use and addiction over time. In addition, this framework provides a way of conceptualizing and measuring what that risk looks like at different ages and, in turn, of integrating explanatory models from different levels of analysis (i.e., genetic, neural, socioemotional, cognitive, environmental factors associated with emotion regulation and substance use) across maturation as defined in the pathway model. Rather than try to map a single ‘reality’ for the development of addictions, the internalizing pathway, like the externalizing pathway, attempts to simplify that complex reality with the goal of offering a useful framework for understanding, predicting and intervening in substance use within more homogenous groups of individuals.

The study of addictive behaviors as resulting from early emerging risk pathways is clearly still a young field. Importantly, not all addictive behaviors may emerge from early discernible risk pathways; but for those that do, the identification of the underlying deficits

that drive progression along the pathway has substantial potential for informing prevention and treatment. This is particularly important if addictions associated with these early risk pathways are indeed more pernicious as evidenced by greater recurrence and resistance to treatment, incurring higher societal costs and investment of resources, and inflicting more damage and suffering on individuals and their families. Although the jury is still out on this score, evidence from other areas of prevention science indicates that the possibility is a good one (see Ialongo et al., 2006 for a discussion of the advantages of early risk pathways).

A challenge in the developmental study of addictions is the need for methods that capture the changing experiences of smaller subgroups of individuals over time. Translated into methodological terms, the study of such developmental pathways requires large sample sizes to examine low base rate behaviors over longer periods of development, attention to heterotypic continuity in measurement (i.e., the changing expression of a construct over development), and a means for greater integration of results across a wide set of explanatory models and age span. Several current trends in “big data” or “big science” are aligned with meeting this need including the creation of national and local data archives, the development of data management and mining tools linked most closely with the goals of discovery science, and, though lagging behind, the emergence of statistical analysis tools for hypothesis testing using pooled datasets.

One example of a methodological approach that we have found particularly useful for studying developmental pathways for addiction is integrative data analysis (IDA; Curran & Hussong, 2009; Hussong, Curran, & Bauer, 2013). Rather than a single analytic tool, IDA is a methodological framework to guide model building and decision-making in conducting the simultaneous analysis of raw data from two or more studies. IDA both introduces novel analytic approaches and draws on existing analytic tools. We developed and used IDA in our own work studying the internalizing pathway to substance use and disorder. Among data-pooling techniques, relatively unique advantages of IDA primarily result from the level of data pooling; in IDA, pooling is based on raw data (e.g., item responses) from individual participants rather than summary statistics at the level of completed studies (as in meta-analysis). This approach yields larger sample sizes than typical single-study designs, a particularly important advantage for examining low-base rate behaviors that are commonly of interest in addictions.

Several approaches are emerging for studies of developmental pathways that may address the challenge of taking into account heterotypic continuity in measurement. For example, in our work, we have used an extension of traditional factor analytic and item response theory methodology referred to as moderated nonlinear factor analysis (MNLFA; Bauer & Hussong, 2009).[5] The goal of this model is to examine the relationships between the factor (e.g., externalizing symptoms) and the items (i.e., hitting, screaming, stealing, vandalism) of a given measure permitting (a) different item sets to be included over time to capture changes in factor expression (i.e., tantrums in childhood and vandalism in adolescence) in addition to core items (i.e., getting into fights) and (b) different weighting of how items

[5]Although developed in the context of IDA, MNLFA may be used to address issues of heterotypic continuity in single study designs as well.

contribute to the underlying factor across development (i.e., getting into fights may be a stronger indicator of externalizing problems at older than at younger ages) or subgroups of individuals (i.e., getting into fights may also be a stronger indicator for girls than for boys). We can then derive scores based on these measurement models that can be used in traditional analyses allowing for broad utility of the approach and a tool for addressing the challenges of capturing heterotypic continuity in measurement across a variety of research contexts.

Addressing a third methodological challenge, IDA also facilitates the comparison of findings across multiple pooled studies and permits the higher-level integration of results from studies of developmental pathways. Specifically, IDA permits tests of whether these associations differ in magnitude or form over study, a direct evaluation of replication across the pooled studies. Depending on the application, this approach may be extended to explicitly model factors that may account for between-study differences in findings, with potential factors spanning multiple levels of design such as study differences in sampling, geographic region, history, and assessment protocol. Thus, IDA permits an exploration of between-study differences that helps mitigate the need for creating new studies designed to resolve conflicting findings among existing studies posited to result from between-study design differences.

In sum, there remains a significant gap between the study of other forms of psychopathology and addictions. Emerging trends in the literature are reaching over this divide; with one example being the identification of a disinhibitory pathway to substance use and disorder. However, given significant heterogeneity in substance use disorders and the likelihood that multiple developmental pathways may lead to addiction, greater attention to other early emerging developmental pathways is also needed. These developmental pathways have the potential to reshape our understanding of addictive behaviors, connect explanatory frameworks across different levels of analysis (e.g., neurogenetics to neighborhoods), and place these mechanisms within the context of development. However, these models introduce significant methodological challenges which will also require greater attention to advance the study of addictions.

Recommendations

Rather than recommend a set of questions that should guide the future use of developmental science in the study of addictions, we offer a set of guidelines to consider in how to conceptualize those questions, which we argue has a broader research impact. Below are three of the most pertinent to addressing issues of timing and heterogeneity in the development of addictions as raised here.

To repeat Rutter (1987) among others, our first recommendation is to *study processes not associations among variables*. All too often we label variables as either risk or protective factors, rather than focusing on how a set of variables together capture (or serve as a proxy for) an unfolding process over time. The nature of any given variable, risk or protective, is defined in relation to that process and the outcome of interest for a given investigation, which in itself is most often an arbitrary endpoint in the unfolding process. A somewhat

whimsical illustration of this point can be found in the retelling of an old proverb in Jon Muth's (2005) book *Zen Shorts*.

> "There was once a farmer who had worked his crops for many years. One day, his horse ran away. Upon hearing the news, his neighbors came to visit. "Such bad luck," they said sympathetically. "Maybe," the farmer replied. The next morning the horse returned, bringing with it two other wild horses. "Such good luck!" the neighbors exclaimed. "Maybe," replied the farmer. The following day, his son tried to ride one of the untamed horses, was thrown off, and broke his leg. Again, the neighbors came to offer their sympathy on his misfortune. "Such bad luck," they said. "Maybe," answered the farmer. The day after that, military officials came to the village to draft young men into the army to fight in a war. Seeing that the son's leg was broken, they passed him by. "Such good luck!" cried the neighbors. "Maybe," said the farmer."

The take home point is quite simple. Defining variables as risk or protective in a developmental pathway may be relative to the outcome of interest as well as to the point in time along that pathway where we look.

Our second recommendation is to conceptualize the operationalization of variables, and not just their association with one another, as dynamic and open to change over time. When taken seriously, the challenges are daunting to both taking into account as well as ignoring the potential for heterotypic continuity (i.e., the changing manifestation of a constant underlying construct over time). Fortunately, some emerging tools can allow researchers to test for heterotypic continuity in their constructs over time. As noted earlier, Bauer and colleagues introduced a novel measurement approach to examine even nonlinear relations between the factor structure of a measure and age, and creating scores that take into account these dynamic relations over time (Bauer & Hussong, 2009). This approach reflects one way of conceiving the effects of heterotypic continuity in measurement. As usual, such analytic tools, however, are most useful when paired with developmental theory that guides the item pool used to measure heterotypic continuity in constructs over time and to define where one construct begins and another ends for a given application, perhaps the greater challenge presented by the presence of heterotypic continuity.

Our third recommendation is to *consider novel uses of existing data.* Our age of science is populated by many high quality longitudinal studies of adolescent substance use. Effectively tapping into these resources to answer new questions is both art and science and often requires creativity to see what was never meant to be there in the original design of the study. Increasingly, the field is seeing the benefits of this approach to methodology through the creation of novel data structures from existing data achieved through data pooling (combining existing data sets of like structure, such as individuals assessed repeatedly over time), data augmentation (combining existing data sets of different structures, such as combining historical record data with individual assessment data), and structuring data along different time metrics than those assessed (e.g., realigning data points to predict time from drinking onset to disorder, examining trajectories based on pubertal stage rather than age). Analytic tools that guide the appropriateness of data pooling and augmentation will be an important part of this landscape, allowing us to thoughtfully test assumptions that underlie

these approaches for any given application. These analytic tools continue to emerge, often adopted from other fields. For example, although approaches such as Integrative Data Analysis and other data pooling techniques focus on creating 'longer' data sets (adding more people with similar constructs to one another) other techniques focus on creating 'wider' data sets (e.g., Rässler's (2002) approach to creating synthetic data through statistical matching by, conceptually, adding more variables given met assumptions of having similar people across data sets). These methodological advances are exciting but require thoughtful application to capture the complex developmental processes of interest in addictions.

Conclusions

> "Why did you know that if a beaver two feet long with a tail a foot and a half long can build a dam twelve feet high and six feet wide in two days, all you need to build Boulder Dam is a beaver sixty-eight feet long with a fifty-one-foot tail?" … "That's absurd," objected Milo, whose head was spinning from all the numbers and questions. "That may be true," he acknowledged, "but it's completely accurate, and as long as the answer is right, who cares if the question is wrong? If you want sense, you'll have to make it yourself." From *The Phantom Tollbooth* (Juster, 1961, p. 175)

Good theory is that which is useful, consonant with the literature, and above all, specific enough to permit empirical evaluation through a body of research. Complex models of human behavior based on such developmental perspectives as Developmental Science and Developmental Psychopathology guide us in deriving focused hypotheses about the processes that underlie the development of specific outcomes of interest, like addictions. The complex models based on these derived hypotheses are then the foundation for a cumulative science that proceeds through the validation, falsification, and tests of utility of these models that in turn shape our understanding of how addictions develop over time. The push for simplified theory and methods is certainly a simpler science, but the resulting body of knowledge is severely limited in scope and utility when the subject of study is not so simple.

As an echo of Occam's Razor through the centuries, scientific methods caution against the development of overly complex models, arguing for the simplest explanation as best. Indeed, complexity for complexity's sake is a fool's errand but perhaps so too is oversimplication for the sake of simplicity. In this regard, one of the best examples of the danger of oversimplification for simplicity's sake emerges from the development of the Bohr model of atomic structure. In 1913, Niels Bohr proposed a model of the atom which postulated that electrons orbited the nucleus of an atom in a series of orbital rings. The Bohr model was more complex than contemporary theories which hypothesized that atoms did not have constituent parts or an orbital structure (Kragh, 2012). Many scientists argued that the level of complexity added by the Bohr model was unnecessary and unrealistic (Kragh, 2012). However, Bohr's model soon revolutionized the field, becoming a foundational paradigm for atomic and quantum physics (Kragh, 2012). Notably, it has since been proven that electrons do not circle the nucleus of an atom in orbitals as Bohr suggested (Kragh, 2012). Yet, the Bohr model's complex depiction of atomic 'reality' proved to be

significantly more informative than contemporary “simple” theories of atomic behavior. Just as Bohr’s model provided invaluable insight into the complexity of atomic behavior without perfectly capturing reality, developmental science perspectives have the potential to capture the complexity of human behavior, even if those models do not depict reality “perfectly”. Humans have not proven themselves to be so easily captured by science, and it is the complexity of human experience and development that requires a science able to acknowledge and embrace complexity in its theory and methods. Understanding the development of addictions will be no exception.

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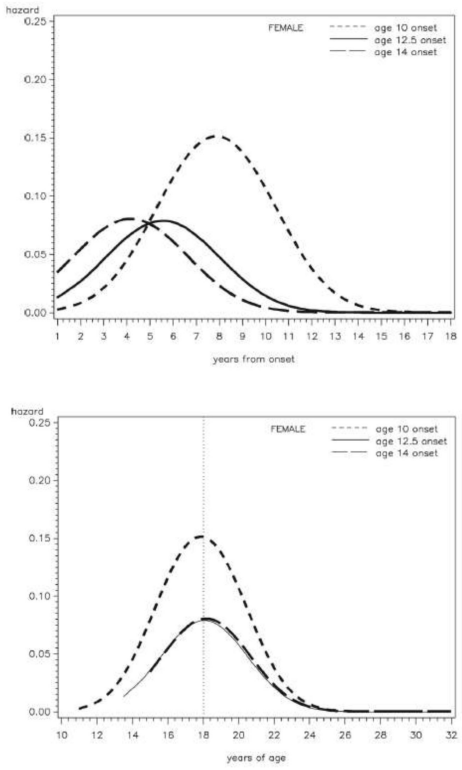

Figure 1.

Hazard functions from point of drinking initiation to alcohol use disorder first onset for girls plotted by years from onset (top panel) and girls' age (bottom panel)

Note: Reprinted from Hussong, A., Bauer, D., & Chassin, L. (2008). Telescoped trajectories from alcohol initiation to disorder in children of alcoholic parents. *Journal of Abnormal Psychology*, *117*(1), 63-78.

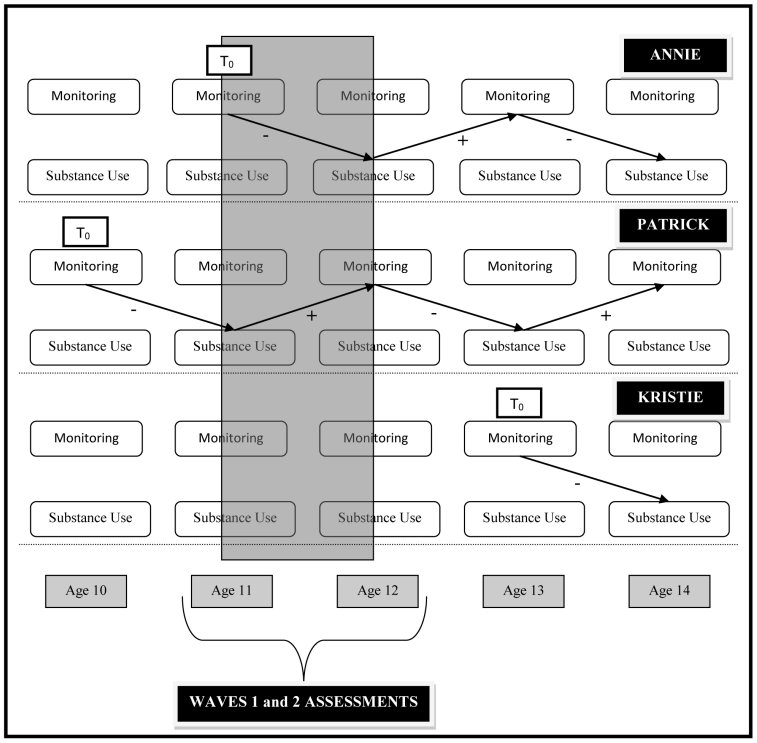

Figure 2.

Emerging Monitoring-Substance Use Associations in Three Participants

Note: Shaded area indicates period when assessment occur; T_0 denotes when process begins to emerge for any given participant.