Modeling Early Sexual Initiation among Young Adolescents Using Quantum and Continuous Behavior Change Methods: Implications for HIV Prevention

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Abstract: Behavioral research and prevention intervention science efforts have largely been based on hypotheses of linear or rational behavior change. Additional advances in the field may result from the integration of quantum behavior change and catastrophe models. Longitudinal data from a randomized trial for 1241 pre-adolescents 9-12 years old who self-described as virgin were analyzed. Data for 469 virgins in the control group were included for linear and cusp catastrophe models to describe sexual initiation; data for the rest in the intervention group were added for program effect assessment. Self-reported likelihood to have sex was positively associated with actual initiation of sex (OR=1.72, 95% CI: 1.43-2.06, $R^2 = 0.13$). Receipt of a behavioral prevention intervention based on a cognitive model prevented 15.6% (33.0% vs. 48.6%, OR = 0.52, 95% CI: 0.24-1.11) of the participants from initiating sex among only those who reported "very likely to have sex." The beta coefficients for the cubic term of the cusp assessing three bifurcating variables (planning to have sex, intrinsic rewards from sex and self-efficacy for abstinence) were 0.0726, 0.1116

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and 0.1069 respectively; R^2 varied from 0.49 to 0.54 (p<0.001 for all). Although an intervention based on a model of continuous behavior change did produce a modest impact on sexual initiation, quantum change has contributed more than continuous change in describing sexual initiation among young adolescents, suggesting the need for quantum change and chaotic models to advance behavioral prevention of HIV/AIDS.

INTRODUCTION

Theory-driven paradigms serve as the foundation of contemporary health behavior research. Guided by these paradigms, behavioral researchers assess relationships between a group of putatively influential factors (e.g., attitudes, perceived risk and benefit, motivation, and intention) and a behavior (e.g., early sexual initiation, multiple sex partners, unprotected sex, etc). Several theories and models, including the Theory of Reasoned Action and Planned Behavior (Ajzen, 1991; Fishbein & Ajzen, 1975), Information-Motivation-Behavior Skills model (Fisher & Fisher, 1993), the Transtheoretical/Stages of Change Model (DiClemente et al., 1991; Prochaska & DiClemente, 1983), and Protection Motivation Theory (Rogers, 1983) have been demonstrated in multiple contexts to predict both preventive and risk behaviors. Common to these theories and models is their implicit or explicit assumption that human behaviors are logical and involve cognitive processes such as premeditation. Therefore, the relationship between an influential factor and a behavior can be predicted using linear causal or "continuous behavior change" (CBC) models. To date, the health behavior literature reflects primarily the assumption of CBC, including studies on HIV risk behaviors such as substance use (Boer & Mashamba, 2005; Wu, Stanton, Li, Galbraith, & Cole, 2005), sexual risk behaviors and condom use (Boer & Mashamba, 2005; Chen et al, 2009; Gong et al., 2009; Kaljee et al., 2005).

While much progress has been made in our understanding of behavior and purposeful behavioral change based on these models, data from some qualitative studies has challenged the significance of a rational decision making framework when applied to some early adolescent behaviors (Steinberg, 2003). Further, data from etiological studies have shown that CBC model-based research can usually explain only 15- 25% of the variances of a risk behavior (Godin & Kok, 1996; Kaljee et al., 2005; Wu et al., 2005), and data from randomized controlled trials indicate that CBC-based behavior interventions often achieve only a small or moderate effect size (Cohen-D ranging from 0.2 to 0.8 and odds ratio from 0.4 to 0.7) (Johnson et al., 2002; Mullen, Ramirez, Strouse, Hedges, & Sogolow, 2002; Noar, Black, & Pierce, 2009).

In response to the apparent limitations of CBC models, some researchers have explored the use of models that incorporate sudden and non-continuous change, such as the occurrence of an argument between two persons,

the appearance of a new idea, the conversion to a religion, and the occurrence of a car accident (Flay, 1978; James, 1902; Thom, 1975; Zeeman, 1973). This type of behavior changes is termed "quantum behavior change" (QBC) (Miller, 2004). In behavioral research, QBC can be referred to as "sudden, dramatic, and enduring behavioral transformations that affect a broad range of personal emotion, cognition, and behavior" (Miller, 2004, p.453). Compared to CBC, the process of QBC is nonlinear and hardly predictable. Analysis of QBC therefore requires different methodological approaches from CBC, such as "catastrophe models."

Catastrophe Theory is a general systems theory describing and predicting discontinuous changes of events through a topological form (Cobb & Zacks, 1985; Guastello, 1989; Thom, 1975). It has been used in physical, biological, social, psychological and behavioral sciences (Cobb & Zacks, 1985; Guastello, Aruka, Doyle, & Smerz, 2008; Lanza, 1999; Tesser, 1980). Instead of tackling multiple factors for a complex system, catastrophe models focus on a few key factors called "control variables" that are presumed to govern the status of a system. Depending on the number of control variables, a series of catastrophe models have been established, including fold (one control variable), cusp (two control variables), swallowtail (three control variables), and butterfly (four control variables). Among these models, the cusp model has been identified as appropriate for describing many health behaviors (Clair, 2004; Guastello, 1982; Mazanov & Byrne, 2006; West & Sohal, 2006).

Since the pioneering work of Thom on catastrophe theory (Thom, 1975), mathematical and statistical methods have been established to study human behaviors using QBC-based models (Cobb, 1981; Guastello, 1982). Guided by QBC-based paradigms, researchers have examined attitude change (Flay, 1978; Florack, Piontkowski, Knocks, Rottmann, & Thiemann, 2002), substance use (Mazanov & Byrne, 2006), alcohol use and abuse (Clair, 2004; Guastello et al., 2008; Smerz & Guastello, 2008), adolescent smoking (Mazanov & Byrne, 2008), and tobacco cessation (Larabie, 2005; West & Sohal, 2006). For example, with longitudinal data collected among 918 smokers, West and colleagues reported that approximately half (48.6%) of the smokers quit smoking suddenly without a prior planning step (West & Sohal, 2006). Findings from multiple modeling studies indicate that QBC-based catastrophic models can better predict certain health risk behaviors (e.g., alcohol abuse, tobacco use, and job-related injury) than traditional CBC-based linear regression models (Clair, 2004; S. J. Guastello, 1982; Mazanov & Byrne, 2008). However, to date studies examining sexual risk behavior using QBC-based models have not been reported.

Sexual initiation (defined as the first engagement in anal or vaginal sexual intercourse in an individual's life) is a critical event in the development of healthy and/or risky sexual behavior. Younger age at the time of sexual initiation has been recognized as a significant predictor of consequent sexual behaviors leading to increased risk of HIV infection (Locke & Newcomb, 2008). Understanding the process of sexual initiation is therefore essential for HIV prevention. The process of sexual initiation among adolescents may contain both

rational and catastrophic components. Previous studies based on CBC models have documented a number of important factors related to early sexual initiation, such as familial and educational factors (Fatusi & Blum, 2008; Felton & Bartoces, 2002; Rosenthal et al., 2001), social norms and personal attitudes regarding sex (Fatusi & Blum, 2008; Lakshmi, Gupta, & Kumar, 2007), peer influences (Kirby, 2002; Rosenthal et al., 2001), and parental and teachers' communication on sex related issues (Kawai et al., 2008). However, intervention studies targeting these factors have demonstrated limited effect in delaying sexual initiation (Chen et al., 2009), with most studies showing no effect on delay or a very short-term effect (DiCenso, Guyatt, Willan, & Griffith, 2002; Ott & Santelli, 2007; Robin et al., 2004).

   To better explain early sexual initiation among adolescents for HIV prevention, we propose a cusp catastrophic model assuming that sexual initiation contains a QBC component (see Fig. 1). In this model, the likelihood of sexual initiation is expressed using a "folding" surface Y as illustrated in Fig. 1:

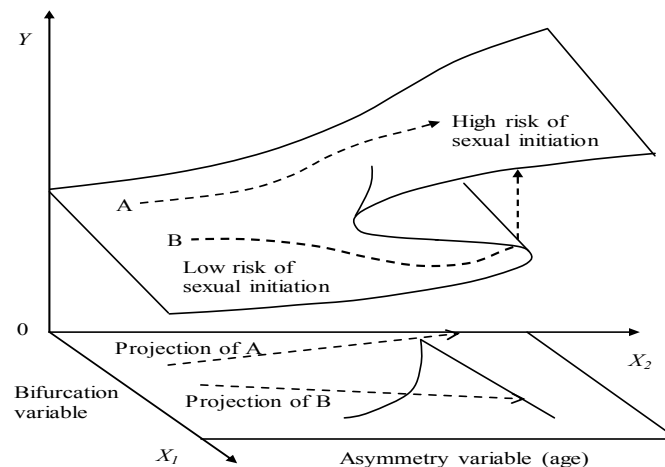$$df(y)/dy = Y^3 - X_1 Y - X_2 = 0 \tag{1}$$

Fig. 1. Cusp catastrophe model of adolescent sexual initiation.

   Two control variables determine the risk levels (or locations on the folding surface) of sexual initiation: a bifurcating variable X_1 (an influential factor) and an asymmetry variable X_2 (age of the subjects in this study). At lower levels of X_1, Y increases continuously as age X_2 increases (Path A in the figure on the surface and its projection on the X_1-X_2 plane), similar to CBC models. However, at higher levels of X_1, the change in Y becomes non-continuous as age

X_2 increases (Path B and its projection), it suddenly leaps from the bottom lower risk surface to the upper high risk surface when age X_2 increases to reach a critical point or a threshold. At either lower levels (prior to or early adolescence) or higher levels (later or post adolescence) of X_2, Y is relatively stable as X_1 changes; however, changes in Y become dramatic during the middle of X_1 (e.g., the adolescent period). In addition, during the adolescence of X_1, the risk level Y can be located either at the upper (high risk) or the bottom (low risk) plane for the same value of X_2.

With the guidance of CBC- and QBC-based paradigms, in this study, we report the findings regarding sexual initiation from longitudinal data among 1241 adolescent virgins. We hypothesize that for some adolescents, initiation of sex is planned in advance, following the CBC-based rationale behavior model. Consequently, the process of sexual initiation among these adolescents can be predicted using traditional linear models. However, we hypothesize that for most early adolescents, the process of sexual initiation does not follow a CBC model but instead is likely to occur without clear planning in advance. Modeling of the process would therefore benefit from application of the QBC paradigm.

MATERIALS AND METHODS

Data Sources and Participants

Data used for this analysis were derived from an NIH-funded randomized controlled trial to evaluate the HIV prevention program "Focus on Youth in Caribbean" (FOYC). This prevention program was guided by the Protection Motivation Theory (Rogers, 1983), a CBC-based social cognitive model. The protocol for the intervention trial was approved by the Human Investigation Committees at Wayne State University, United States and at the Ministry of Health, The Bahamas. The intervention program has been described in detail elsewhere (Chen et al., 2009; Deveaux et al., 2007; Gong et al., 2009).

To conduct the intervention trial, 1360 participants in 15 of the total 26 government schools from New Providence of The Bahamas were randomly assigned to a control group (5 schools, $N= 497$) and two intervention groups (10 schools, $N=863$). The participants were predominantly African descents, 53% girls, and aged 9-12 years when entering the trial. Youth in the control group received an environmental/ecology intervention (the parents received a career planning intervention); youth in the two intervention groups received an HIV risk reduction intervention (the parents received either the career planning intervention or a parental monitoring intervention). To assess sexual initiation, we included only participants who were self-described as virgin ($N=1241$) upon entering the study, the 469 in the control group were used for modeling sexual initiation and the 772 in the intervention group were used for program effect evaluation. Data were collected using questionnaires in classrooms at the baseline and every 6 months through the 24 months follow-up.

Demographic Variables

Demographic variables included in this analysis were: age (in years) at baseline, age at the time of sexual initiation (in years), gender (male/female), and school performance (average, above average and best). In addition, the variable age was used as the asymmetry variable in catastrophe modeling (see description in more detail later in this article).

Initiation of Sex

Sexual initiation was the dependent variable for both the CBC-based and the QBC-based modeling. We defined sexual initiation as the first time an adolescent virgin was involved in sexual intercourse (including vaginal and anal sex). In the baseline and all follow-up surveys, the participants were asked two questions: "Have you ever had sex that is when a boy or man put his penis into a girl's vagina?" (Yes/no) and "Have you had anal sex, where a man or a boy put his penis in a boy's or girl's anus or butt?" (Yes/no). A participant was considered as having initiated sex if he or she responded negatively to both questions in prior waves of the survey and responded positively for the first time to either of two questions in the subsequent survey.

Three Bifurcation Variables for Catastrophe Modeling

Planning for sex: This variable was assessed according to the self-reported likelihood of having sex in the next 6 months. In each wave of data collection, all participants including those who reported never having had sex were asked "How likely is it that you will have sex in the next 6 months"? A five-point Likert scale was used to assess responses to this question varying from "very unlikely" (coded as 1), to "unlikely" (coded as 2), "don't know/not sure" (coded as 3, "likely" (coded as 4) and "very likely" (coded as 5).

Intrinsic rewards from sex: This variable was assessed using the question, "How would you feel if you were to have sex in the next six months?" Answer options to this question included "Very bad" (coded as 1), "Somewhat bad" (coded as 2), "Neither good nor bad" (coded as 3), "Good" (coded as 4) and "Very good" (coded as 5).

Self-efficacy regarding abstinence: This variable was assessed based on the responses (varying from "Strongly agree" to "Strongly disagree" and coded as 1 to 5) of participants to the following three statements (Cronbach $\alpha = 0.87$): (a) "Even if all my friends were having sex, I would not feel I would have to have sex"; (b) "I would be able to say no to someone I am going with if I didn't want to have sex" and (c) "I could go with a person for a long time and not have sex with him/her." The average score of the three items was computed and used for analysis.

Sexual Progression Index

To conduct QBC-based catastrophe modeling, we used a four-level sex progression index (SPI). SPI was defined using self-reported data regarding ever

having had sexual intercourse and the perceived likelihood of having sex in the next 6 months. SPI was set to "1" for participants who reported never having had sexual intercourse and who indicated no possibilities they would have sex in the next six months (e.g., responded "very unlikely" to the question "how likely is it you will have sex in the next 6 months"); SPI was set to "2" for participants who reported never having had sex but who were unsure if they were going to have sex in the next 6 months (e.g., responded "likely," "neutral," and "unlikely"); SPI was set to "3" for participants who never had sex and claimed that they were going to have sex in the next 6 months (e.g., responded "very likely"); and lastly SPI was set to "4" for participants who initiated sexual intercourse regardless of their planning to have sex in the future.

Incidence Rate of Sexual Initiation

Rate of sexual initiation was estimated using the incidence rate method (Rothman, Greenland, & Lash, 2009). The five waves of data collection from the baseline through the 24 months follow-up created four periods for assessing sexual initiation: (a) from the baseline to the first follow-up at six months post intervention, (b) from the first follow-up to the second follow-up at 12 months post intervention, (c) from the second follow-up to the third follow-up at 18 months post intervention, and (d) from the third follow-up to the fourth follow-up at 24 months post intervention. To compute the incidence rate, we counted and summed the number of participants who initiated sex during each of the four periods as the numerator. We then counted and summed the numbers of virgins at the beginning of each of the four periods as the denominator. The six-month incidence rate was thus computed as the ratio of the two. Since each of the four follow-up intervals covered only six months, we then estimated the annual incidence rate of sexual initiation by converting the six-month basis into person-years at risk for sexual initiation as the denominator to estimate the initiation rate.

CBC-Based Statistical Analysis

To test the CBC-based hypothesis that sexual initiation is a rational choice made by young adolescents, we first compared the incidence rate of sexual initiation among the 469 virgins across the five categories of the self-reported likelihood of having sex. χ^2 test was conducted to compare differences in the incidence rate across the five levels of self-reported likelihood and Cochran-Armitage Trend Test was conducted to assess the relationship between the self-reported likelihood and the actual sexual initiation. In addition to the incidence rate, the proportions of subjects who initiated sex were compared across the five categories of self-reported likelihood of having sex to illustrate the importance of CBC-based model in predicting sexual initiation. Finally, the incidence rates of sexual initiation by self-reported likelihood of having sex were compared between the control youth and the intervention youth to assess program effect.

QBC-Based Catastrophe Modeling Analysis

The following polynomial equation (Guastello, 1989) was used to assess if sexual initiation of the 469 adolescent sample followed the cusp catastrophe model as presented in Fig. 1.

$$Y_2 - Y_1 = \beta_0 + \beta_1 Y_1^3 + \beta_2 Y_1^2 + \beta_3 X_1 Y_1 + \beta_4 X_1 + \beta_5 X_2 \qquad (2)$$

In this model, Y_1 and Y_2 were sexual progression indexes (SPI) assessed at the baseline and the last follow-up; X_1 = one of the three influential factors (likelihood to have sex, intrinsic rewards from sex, and self-efficacy of abstinence) used as a bifurcation variable and X_2 = age, used as the asymmetry variable. The three influential factors were selected as bifurcation variables because none of them showed a strong linear association with the dependent variable SPI, although such relationship was assumed according to the Theory of Reasoned Action and Planned Behavior (Ajzen, 1991; Fishbein & Ajzen, 1975). This suggests a bimodal distribution of the SPI along with these bifurcation variables. Age is used as the symmetry variable because: in theory as age advances, everyone will initiate sex; our analysis showed a significant and independent (from the bifurcation variables) cross-sectional association between age and the dependent variable SPI ($\beta = 0.1095$, $p = 0.018$) but a weak or non-significant longitudinal association between age and SPI; and as age advanced, SPI did not increase monotonically but spread in the range from the minimum of 1 to the maximum of 4.

To fit the polynomial model of Eq. 2, data for all variables in the model were transformed individually by subtracting the minimum and then dividing by the standard deviation of each variable as developed by catastrophe modeling specialists (Cobb, 1981; Guastello, 1989). With this transformation, the measurement of all the variables was started at zero with a standard deviation of 1.00. The β_i (i = 1, 2, 3…5) are model coefficients to be estimated with data. Three polynomial equation models were constructed to assess the three bifurcation variables. A significant β_1 of the cubic term Y_1, plus a significant β_4 of the bifurcation term or a significant β_5 of the asymmetry term at $p<.05$ level were used as evidence supporting the notion that the process of progression from virgin to sexual initiation can be described by the cusp catastrophe.

To compare efficiency of a cusp model in describing the process of progression from virgin to first sexual intercourse, results from Eq. 2 were compared with results from the following four alternative linear multiple regression models:

$$Y_2 = \beta_0 + \beta_1 Y_1 + \beta4 X_1 + \beta_5 X_2 \ldots \qquad (3)$$

$$Y_2 = \beta_0 + \beta_1 Y_1 + \beta3 X_1 Y1 + \beta4 X_1 + \beta_5 X_2 \ldots \qquad (4)$$

$$Y_2 - Y_1 = \beta_0 + \beta_1 Y_1 + \beta4 X_1 + \beta_5 X_2 \ldots \qquad (5)$$

$$Y_2 - Y_1 = \beta_0 + \beta_1 Y_1 + \beta_3 X_1 Y_1 + \beta_4 X_1 + \beta_5 X_2 \ldots \qquad (6)$$

Equations 3 and 4 are models for pre- and post-association analysis and Eqs. 5 and 6 are models based on difference equation. These models contain the same predictor variables Y_1, Y_2, X_1 and X_2 as in Eq. 2, but are based on CBC paradigm.

After model fitting, R^2 of the cusp model was computed and compared with those for the four alternative models. Models with higher R^2 values were considered as more effective in describing the process of progression to sexual initiation. Particularly, a greater R^2 for model (2) than for the other models was used as evidence supporting the superiority of the QBC-based cusp model over the CBC-based linear models.

Data used for this analysis were manually entered into the computer. Double entry protocol was imposed to minimize data entry errors. Logic checks were conducted after data entry and discrepancies from the double entry and illogic errors were resolved by referring to the originally completed questionnaires. All statistical analyses described above were completed using the commercial software SAS version 9.2 (SAS Institute Inc, Cary, NC).

RESULTS

Sample Characteristics and Sexual initiation

Among the 1360 subjects, data for 1,241 youth who were self-described as virgin at baseline were included in the analysis, including 469 in the control group and 772 in the intervention group. The participants were 9-12 years old when entering the study. The 24-month follow-up rate was 86.2%. The number and percentage of participants who initiated sex at the four follow-up periods are summarized in the lower panel of Table 1. Overall, 260 participants (21.5%) initiated sex during the 24 months period, including 86 (19.8%) control youth and 174 (22.5%) intervention youth. The estimated annual incidence rate of sexual initiation was 11.8% for control youth and 13.3% for the intervention youth, the difference between these two groups was not statistically significant ($\chi^2 = 0.96$, $p=0.327$). The participants of the study were predominantly African descendants and person-year of exposure was computed as the sum of virgins counted at all four follow-ups divided by two, because each participant contributed to 6 months or 0.5 years of exposure (e.g., with potentials to initiate sex).

Sexual Initiation Associated with Self-Reported Likelihood of Having Sex

Data for youth in the control group in Fig. 2 shows a positive relation between self-reported likelihood to have sex and incidence rate of sexual initiation. The incidence rate of sexual initiation differed significantly for participants who reported different likelihoods of having sex at two time points: at the baseline ($\chi^2 = 6.90$, $p<0.05$) and at the 6 months prior to sexual initiation ($\chi^2 = 83.97$, $p<0.01$). There was a significant positive association between the self-reported likelihood of having sex in the next 6 months and sexual initiation

during the subsequent 6 months ($Z = 7.79$ and $p <0.01$ from the Cochran-Armitage Trend Test). Logistic regression analysis indicated that the odds ratio (OR) for the reported likelihood of having sex in the next 6 months on sexual initiation in the subsequent 6 months was 1.72 (95% CI: 1.43-2.06, $R^2 = 0.13$).

Table 1. Youth Who Initiated Sex at Various Follow-up Periods, Total Sample and Stratified by HIV Prevention Education Condition**.**

Item	Control Youth	Intervention Youth	Total
Total sample (N)	497	863	1360
Gender			
Boys	228(45.9%)	411 (47.6%)	639 (47.0%)
Girls	269(54.1%)	452 (52.4%)	721 (53.0%)
Age (years) at baseline			
Range	9-12	9-12	9-12
Mean (SD)	10.4 (0.6)	10. (0.7)	10.5 (0.7)
School performance			
One of the best	237(47.8%)	429 (50.0%)	666 (49.2%)
Above average	252(50.8%)	402 (46.8%)	654 (48.3%)
Average or poor	7(1.4%)	27 (3.2%)	34 (2.5%)
Participants at follow up			
6 Months	464(93.3%)	826 (95.7%)	1290(95.0%)
12 Months	432(86.9%)	780 (90.4%)	1182(86.9%)
18 Months	416(83.7%)	734 (85.1%)	1150(84.6%)
24 Months	417(83.9%)	755 (87.5%)	1172(86.2%)
Sexual initiation			
Virgins at baseline	469 (100%)	772 (100%)	1241 (100%)
Initiated sex in 0-6 months	21 (4.5%)	40 (5.2%)	61 (4.9%)
Virgin at 6 months	364(83.7%)	683 (88.5%)	1047(86.7%)
Initiated sex in 6-12	20 (5.5%)	44 (6.4%)	64 (6.1%)
Virgin at 12 months	337(92.6%)	600 (87.9%)	937 (89.5%)
Initiated sex 12-18 months	16 (4.7%)	39 (6.1%)	55 (5.9%)
Virgin at 18 months	31 (94.7%)	554 (87.0%)	873 (93.2%)
Initiated sex 18-24 months	29 (9.1%)	51 (9.2%)	80 (9.2%)
Total initiated sex	86 (19.8%)	174(22.5%)	260 (21.5%)
Person-year of exposure	727.5	1304.5	2032
Annual incidence rate	11.8%	13.3%	12.8%

Consistent with CBC theory, data in Fig. 2 indicate that as the reported likelihood to have sex in the next six months varied from "very unlikely" to "very likely, the incidence rate of sexual initiation within the subsequent six months increased from 8.9% to 48.6%. However, when the intervention and control youth were compared, data in Fig. 3 indicate that only youth in the group who thought themselves "very likely" to have sex showed evidence of responding to the CBC-based intervention FOYC, with 33% of those who received FOYC initiating sex compared to 49% of those who received the control

condition (χ^2 = 2.89, *p*=0.089). Among other youths, there was no response to the intervention (e.g. 10.9% of control youth and 12.5% of FOYC youth initiated sex, χ^2 = 0.012 *p*=0.921).
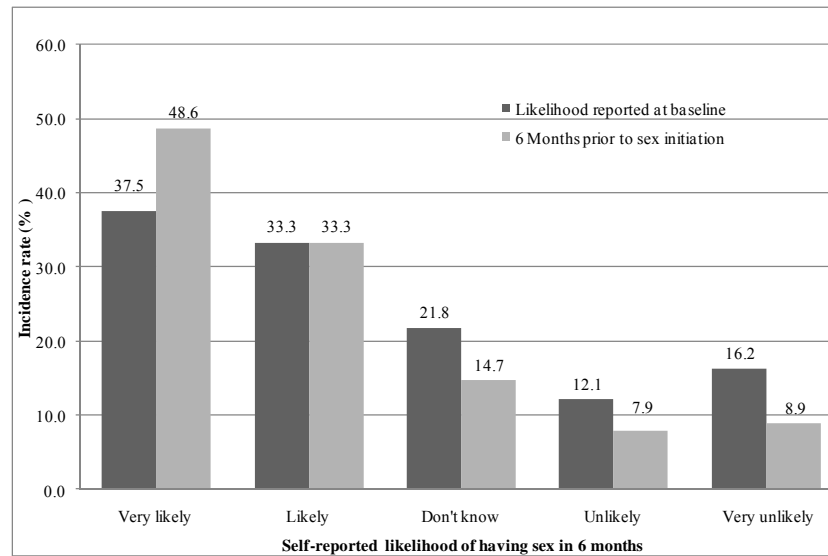

Fig. 2. Relationship between self-reported likelihood of having sex and annual incidence rate of sex initiation (*N*=435).
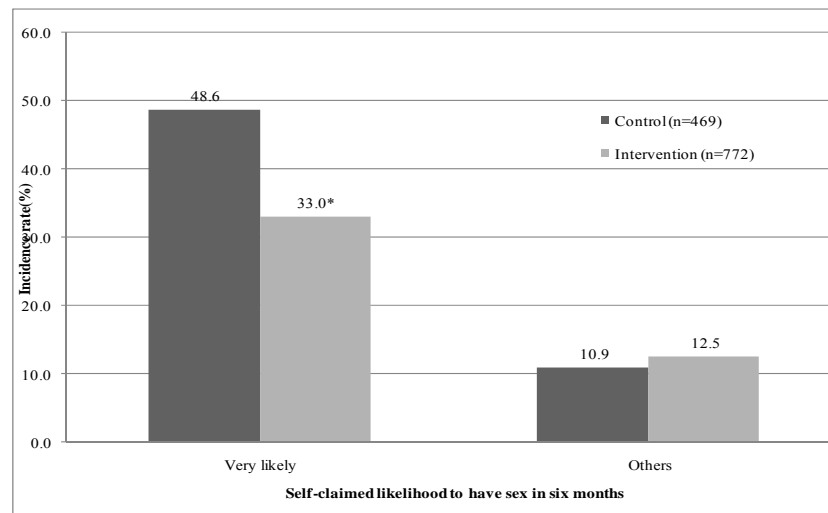

Fig. 3. Incidence rate of sexual initiation among intervention and control adolescents by self-claimed likelihood of having sex.

Table 2. Results of Cusp Catastrophe Modeling for Three Bifurcation Variables (*N*= 469 Virgins, 84 Initiated Sex During a Two-Year Period).

Analytical Cusp Model *(DV = Y_2-Y_1)*	*B*	*t (p-value)*	R^2
Self-reported likelihood			
Y_1^3 (baseline index)	0.0726	2.51(.012)	0.54
Y_1^2 (baseline index)	-0.4819	3.73(.000)	
X_1Y_1 (cross term)	-0.1236	2.58(.010)	
X_1 (likely having sex)	-0.2693	3.62(.000)	
X_2 (age at baseline)	0.0613	1.22(.222)	
Intrinsic rewards			
Y_1^3 (baseline index)	0.1116	6.00(.000)	0.51
Y_1^2 (baseline index)	-0.7319	12.10(.000)	
X_1Y_1 (cross term)	0.0824	1.80(.073)	
X_1 (reward of sex)	0.2767	3.94(.000)	
X_2 (age at baseline)	0.0613	1.20(.231)	
Self efficacy			
Y_1^3 (baseline index)	0.1069	3.58(.000)	0.49
Y_1^2 (baseline index)	-0.6397	4.56(.000)	
X_1Y_1 (cross term)	-0.0385	0.77(.444)	
X_1 (no-sex self-efficacy)	-0.2752	4.23(.000)	
X_2 (age at baseline)	0.0736	1.42(.156)	

Note: All variables in the models were transformed statistically by subtracting the minimum and then divided by the standard deviation.

Table 3. Results from Alternative Linear Models for Three Predictor Variables.

Predictor Variables	Pre- and Post Model (DV = Y_2)		Difference Equation Model (DV = Y_2 - Y_1)	
	β estimate t (p-value)	β estimate t (p-value)	β estimate t (p-value)	β estimate t (p-value)
Test for self-reported likelihood				
Y_1 (baseline index)	-0.0654	0.8740	-1.0654	-0.1260
	0.54(.589)	2.13(.034)	8.82(.000)	0.31(.759)
X_1 (likely having sex)	-0.4280	-0.0739	-0.4280	-0.0739
	7.85(.000)	0.47(.640)	7.85(.000)	0.47(.640)
X_1Y_1 (cross term)		-0.2247		-0.2247
		2.39(.017)		2.39(.017)
X_2 (age at baseline)	0.1239	0.1233	0.1239	0.1233
	1.23(.218)	1.24(.217)	1.23(.218)	1.24(.217)
R^2	0.16	0.18	0.23	0.24
Test for intrinsic rewards				
Y_1 (baseline index)	0.0625	-0.1720	-0.9375	-1.1720
	0.52(.602)	0.85(.395)	7.82(.000)	5.80(.000)
X_1 (reward of sex)	0.3772	0.1789	0.3772	0.1789
	7.06(.000)	1.21(.226)	7.06(.000)	1.21(.226)
X_1Y_1 (cross term)		0.1275		0.1275
		1.44(.150)		1.44(.150)
X_2 (age at baseline)	0.1272	0.1250	0.1272	0.1250
	1.25(.214)	1.23(.221)	1.25(.214)	1.23(.221)
R^2	0.14	0.14	0.20	0.21
Test for self-efficacy				
Y_1 (baseline index)	0.0805	0.4421	-0.9195	-0.5579
	0.66(.507)	0.87(.383)	7.58(.000)	1.10(.271)
X_1 (no-sex efficacy)	-0.4078	-0.2748	-0.4078	-0.2748
	5.91(.000)	1.42(.156)	5.91(.000)	1.42(.156)
X_1Y_1 (cross term)		-0.0950		-0.0950
		0.74(.462)		0.74(.462)
X_2 (age at baseline)	0.1440	0.1468	0.1440	0.1468
	1.40(.163)	1.42(.155)	1.40(.163)	1.42(.155)
R^2	0.11	0.11	0.17	0.17

Note**:** DV: Dependent variable.

Further analysis indicated that among the 86 participants in the control group who initiated sex, only 9 (10.5%) were among those who reported "very likely" to have sex while 45 (52.3%) had reported that they were "very unlikely" to have sex, suggesting the potentials for using QBC-based catastrophic models.

Sexual initiation as a Catastrophic Process

During the 24-month period, 33.5% of the participants experienced increases in SPI, 48.9% experienced no change in SPI, and 17.6% experienced a backward change in SPI. Data in Table 2 presents results from the cusp catastrophe modeling of these changes in SPI during the 24-month follow-up period. The three cusp models fitted the data well ($p<0.001$ from F-test) and the R^2 was 0.54, 0.51 and 0.49 for the three cusp models respectively. The estimated β_1 coefficients for the cubic term of the three cusp models and the β_4 coefficients for the three bifurcation variables (reported likely to have sex, perceived intrinsic rewards from sex and self-efficacy for not having sex) were all statistically significant ($p=0.012$ for the cubic term that assessed reported likely to have sex and $p<0.001$ for the other two cubic terms and all three bifurcation variables), indicating the validity of cusp catastrophe in describing the process of sexual initiation from a virgin without any intention to have sex up to eventually having the first sexual intercourse.

Results in Table 3 indicate that the four alternative linear models with the same predictor variables were not as satisfactory as the corresponding cusp models in predicting SPI, no matter the pre- and post-association models or the difference equation models were used. Although the R^2 for the difference equation models (from 0.17 to 0.24) appeared to be greater than that for the pre- and post-association models (from 0.11 to 0.18), they were much smaller than 0.49 to 0.54, the R^2 for the corresponding cusp models. In addition, the three bifurcation variables X_1 that significantly predicted SPI in the cusp model were no long significant in the alternative linear models in which the cross term X_1Y_1 was included ($p > 0.05$ for all).

DISCUSSION AND CONCLUSIONS

The results from our analysis of five waves, twenty-four months of longitudinal follow-up of youth indicate that the process of sexual initiation among young adolescents follows the cusp catastrophe model. The beta coefficients of the key variables for the three proposed models were all statistically significant, particularly the ones for both the cubic and the bifurcation terms that support the cusp catastrophe. The greater R^2 values from the cusp model than from the corresponding alternative linear models indicate the superiority of quantum behavior change than continuous behavior change in characterizing the process of sexual initiation among young adolescents. The improvement in model-data fitting could be that the QBC-based cusp model also contains a continuous component at the lower bifurcation variable levels that can capture much of the variance of SPI as in the linear models. In addition, there was a substantial number of participants in each of the three progression groups (approximately, 20% progressed backward, 30% progressed forward, and 50% no change). Such a distribution may have also contributed to the higher R^2 for the cusp modeling than for linear modeling.

Findings from this research expand the range of health risk behaviors for which catastrophic modeling is appropriate. In addition to drug use behavior

(Mazanov & Byrne, 2006), alcohol use and abuse (Clair, 2004; Guastello et al., 2008; Smerz & Guastello, 2008), and tobacco smoking and cessation (Larabie, 2005; Mazanov & Byrne, 2008; West & Sohal, 2006), this study indicates that catastrophe models can also be applied to sexual initiation among early adolescents.

Finally, our findings supporting the utility of a QBC-based paradigm do not negate the role of CBC-based paradigm in studying sexual initiation. There is a longitudinal positive relationship between self-reported likelihood of having sex (either at baseline or at six months prior to sexual initiation) and the actual incidence rate of sexual initiation. However, comparatively, the variances explained by a CBC-based paradigm is about 20% to 45% of that explained by a QBC-based paradigm.

Embracing QBC Paradigm in Behavioral Research

The data presented in this analysis and findings from early studies summarized in the Introduction indicate the utility of QBC-based paradigm in examining behavior change. Although the potential contribution of quantum behavior change and catastrophic modeling has long been recognized for at least a quarter century (Byrne, Mazanov & Gregson, 2001; Clair, 2004; Dockens, 1979; Resnicow & Page, 2008; West & Sohal, 2006), a search of the published literature indicates that few behavioral intervention programs and evaluations have been built on a QBC-based paradigm.

In addition to more QBC-based research, findings from this study suggest the importance of integrating a QBC paradigm with one or more CBC paradigms in approaching adolescent behavioral changes; the former is appropriate for describing spontaneous, circumstantial and impulsive components of behavior change while the latter is appropriate for describing continuous and premeditated components of behavior change. Additional research is needed to integrate the two approaches for a better understanding of sexual initiation, as well as changes in other health behaviors. In this study, we have demonstrated that variables assessing continuous behavior change (e.g., planning for having sex, intrinsic rewards from sex and self-efficacy for abstinence) can also act as control variables affecting quantum behavior change, suggesting the use of shared variables as one method to bridge the two distinct paradigms.

Enhancing Intervention Effect Using QBC models

Early initiation of sex is of great significance because of its association with increased rates of health risk behaviors, including teenage pregnancy (Nebot & Rohlfs, 1994; Vundule, Maforah, Jewkes, & Jordaan, 2001), sexually transmitted diseases (Bukusi et al., 2006; Cleghorn et al., 1995; Davies et al., 2007; Gonzales et al., 1999), and HIV risk behaviors (Cleghorn et al., 1995; Gonzales et al., 1999). A vast research experience underscores the limited success of behavioral interventions in successfully postponing sexual initiation among a high proportion of youth for an extended period of time (Ott 2007;

Dicenso 2002; Robin 2004). The data from our study suggest that QBC paradigms might inform behavioral interventions to better address factors which are less cognitive and premeditated. The incorporation of QBC paradigms into CBC-based interventions could also well serve other adolescent behavior interventions such as alcohol and tobacco prevention (Clair, 2004; Guastello et al., 2008; Smerz & Guastello, 2008; West & Sohal, 2006).

There are some limitations to this research. In this analysis, we only examined a few factors related to sexual initiation. Furthermore, the R^2 values for the cusp models, although much higher than those for the linear models, indicate that the variables we included can explain 49-54% of the variance of sexual initiation. Additional data are needed to include a broader array of contextual factors, either predisposing or situational, to further explain or confirm how the factors identified in this study and others may affect early sexual initiation among adolescents. In addition, the follow-up period of 6-months may be too long to assess "planning" for sex among youth who are undergoing rapid biological, psychological, developmental, and environmental changes occurring during early adolescence. Had the follow-up periods been shorter (one , two or three months between the surveys), perhaps there would have been greater indication of pre-meditation consistent with a CBC paradigm.

Despite these limitations, in this study, we contrasted both rational and chaotic models in describing sexual initiation among young adolescents. Research findings of this study add new empirical data supporting the importance of integrating the traditional linear and rational paradigm with the quantum and chaotic paradigm to advance health behavior research and prevention to curb the global epidemic of HIV/AIDS in the 21st Century.

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REFERENCES

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50,* 179-211.

Boer, H., & Mashamba, M. T. (2005). Psychosocial correlates of HIV protection motivation among black adolescents in Venda, South Africa. *AIDS Education and Prevention, 17,* 590-602.

Bukusi, E. A., Cohen, C. R., Meier, A. S., Waiyaki, P. G., Nguti, R., Njeri, J. N. et al. (2006). Bacterial vaginosis: risk factors among Kenyan women and their male partners. *Sex Transmitted Diseases, 33,* 361-367.

Byrne, D. G., Mazanov, J., & Gregson R. A. M. (2001). A cusp catastrophe analysis of changes to adolescent smoking behaviour in response to smoking prevention programs. *Nonlinear Dynamics, Psychology, and Life Sciences, 5,* 115-137.

Chen, X., Lunn, S., Deveaux, L., Li, X., Brathwaite, N., Cottrell, L. et al. (2009). A cluster randomized controlled trial of an adolescent HIV prevention program among Bahamian youth: Effect at 12 months post-intervention. *AIDS and Behavior, 13,* 499-508.

Clair, S. (2004). A cusp catastrophe model for adolescent alcohol use: An empirical test. *Nonlinear Dynamics, Psychology, and Life Sciences, 2,* 217-241.

Cleghorn, F. R., Jack, N., Murphy, J. R., Edwards, J., Mahabir, B., Paul, R. et al. (1995). HIV-1 prevalence and risk factors among sexually transmitted disease clinic attenders in Trinidad. *AIDS, 9,* 389-394.

Cobb, L. (1981). Parameter estimation for the cusp catastraphe model. *Behavioral Science, 26,* 75-78.

Cobb, L. & Zacks, S. (1985). Applications of statistical catastrophe theory for statistical modeling in the biosciences*. Journal of the American Statistical Association, 78,* 124–130.

Davies, S. C., Taylor, J. A., Sedyaningsih-Mamahit, E. R., Gunawan, S., Cunningham, A. L., & Mindel, A. (2007). Prevalence and risk factors for herpes simplex virus type 2 antibodies among low- and high-risk populations in Indonesia. *Sexually Transmitted Diseases, 34,* 132-138.

Deveaux, L., Stanton, B., Lunn, S., Cottrell, L., Yu, S., Brathwaite, N. et al. (2007). Reduction in human immunodeficiency virus risk among youth in developing countries. *Archives of Pediatric and Adolescent Medicine, 161,* 1130-1139.

DiCenso, A., Guyatt, G., Willan, A., & Griffith, L. (2002). Interventions to reduce unintended pregnancies among adolescents: systematic review of randomised controlled trials. *British Medical Journal, 324*(7351), 1426.

DiClemente, C. C., Prochaska, J. O., Fairhurst, S. K., Velicer, W. F., Velasquez, M. M., & Rossi, J. S. (1991). The process of smoking cessation: an analysis of precontemplation, contemplation, and preparation stages of change. *Journal of Consulting and Clinical Psychology, 59,* 295-304.

Dockens, W. S., 3rd. (1979). Induction/catastrophe theory: a behavioral ecological approach to cognition in human individuals. *Behavioral Science, 24,* 94-111.

Fatusi, A. O., & Blum, R. W. (2008). Predictors of early sexual initiation among a nationally representative sample of Nigerian adolescents. *British Medical Central-Public Health, 8,* 136. DOI#: 10.1186/1471-2458-8-136.

Felton, G. M., & Bartoces, M. (2002). Predictors of initiation of early sex in black and white adolescent females. *Public Health Nursing, 19,* 59-67.

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research.* Reading, MA: Addison-Wesley.

Fisher, W. A., & Fisher, J. D. (1993). A general social psychological model for changing AIDS risk behavior. In J. P. G. Reeder (Ed.), *The social psychology of HIV infection* (pp. 127-153). Hillsdale, NJ: Erlbaum.

Flay, B. R. (1978). Catastrophe theory in social psychology: Some applications to attitudes and social behavior. *Behavioral Science, 23,* 335-350.

Florack, A., Piontkowski, U., Knocks, I., Rottmann, J., & Thiemann, P. (2002). When perceived communicator bias leads to enduring attitude change: The case of attitudes towards the "green card" in Germany. *Current Research in Social Psychology, 8,* 39-50.

Godin, G., & Kok, G. (1996). The theory of planned behavior: a review of its applications to health-related behaviors. *American Journal of Health Promotion, 11,* 87-98.

Gong, J., Stanton, B., Lunn, S., Deveaux, L., Li, X., Marshall, S., et al. (2009). Effects through 24 months of an HIV/AIDS prevention intervention program based on protection motivation theory among preadolescents in the Bahamas. *Pediatrics, 123,* 917-928.

Gonzales, V., Washienko, K. M., Krone, M. R., Chapman, L. I., Arredondo, E. M., Huckeba, H. J. et al. (1999). Sexual and drug-use risk factors for HIV and STDs: a comparison of women with and without bisexual experiences. *American Journal of Public Health, 89,* 1841-1846.

Guastello, S. J. (1989). Catastrophe modeling of the accident processes: Evaluation of an accident reduction program using the occupational hazards survey. *Accident Analysis and Prevention, 21,* 17-28.

Guastello, S. J. (1982). Moderator regression and the cusp catastrophe: Application of two-stage personnel selection, training, therapy and program evaluation. *Behavioral Science, 27,* 259-272.

Guastello, S. J. (1984). Cusp and butterfly catastrophe modeling of two opponent process models: drug addiction and work performance. *Behavioral Science, 29,* 258-262.

Guastello, S. J., Aruka, Y., Doyle, M., & Smerz, K. E. (2008). Cross-cultural generalizability of a cusp catastrophe model for binge drinking among college students. *Nonlinear Dynamics, Psychology, and Life Sciences, 12,* 397-407.

James, W. (1902). *The Varieties of Religious Experience.* New York: Simon & Schuster.

Johnson, W. D., Hedges, L. V., Ramirez, G., Semaan, S., Norman, L. R., Sogolow, E., et al. (2002). HIV prevention research for men who have sex with men: A systematic review and meta-analysis. *Journal of Acquired Immune Deficiciency Syndrome, 30 Suppl 1,* S118-129.

Kaljee, L. M., Genberg, B., Riel, R., Cole, M., Tho le, H., Thoa le, T. K. et al. (2005). Effectiveness of a theory-based risk reduction HIV prevention program for rural Vietnamese adolescents. *AIDS Education and Prevention, 17,* 185-199.

Kawai, K., Kaaya, S. F., Kajula, L., Mbwambo, J., Kilonzo, G. P., & Fawzi, W. W. (2008). Parents' and teachers' communication about HIV and sex in relation to the timing of sexual initiation among young adolescents in Tanzania. *Scandinavian Journal of Public Health, 36,* 879-888.

Kirby, D. (2002). Antecedents of adolescent initiation of sex, contraceptive use, and pregnancy. *American Journal of Health Behavior, 26,* 473-485.

Lakshmi, P. V., Gupta, N., & Kumar, R. (2007). Psychosocial predictors of adolescent sexual behavior. *Indian Journal of Pediatrics, 74,* 923-926.

Lanza. (1999). Catastrophe theory: Application of nonlinear dynamics to assault victim responses. *Journal of the American Psychiatric Nurses Association, 5,* 117-121.

Larabie, L. C. (2005). To what extent do smokers plan quit attempts? *Tobacco Control, 14,* 425-428.

Locke, T. F., & Newcomb, M. D. (2008). Correlates and predictors of HIV risk among inner-city African American female teenagers. *Health Psychology, 27,* 337-348.

Mazanov, J., & Byrne, D. G. (2006). A cusp catastrophe model analysis of changes in adolescent substance use: assessment of behavioural intention as a bifurcation variable. *Nonlinear Dynamics, Psychology, and Life Sciences, 10,* 445-470.

Mazanov, J., & Byrne, D. G. (2008). Modelling change in adolescent smoking behaviour: stability of predictors across analytic models. *British Journal of Health Psychology, 13*(Pt 3), 361-379.

Miller, W. R. (2004). The phenomenon of quantum change. *Journal of Clinical Psychology, 60,* 453-460.

Mullen, P. D., Ramirez, G., Strouse, D., Hedges, L. V., & Sogolow, E. (2002). Meta-analysis of the effects of behavioral HIV prevention interventions on the sexual risk behavior of sexually experienced adolescents in controlled studies in the United States. *Journal of Acquired Immune Deficiency Syndrome, 30* Suppl 1, S94-S105.

Nebot, M., & Rohlfs, I. (1994). Risk factors of pregnancy in teenagers using family planning. Work Group on Sexuality and Adolescence. *Medicina Clinica, 103*, 366-370.

Noar, S. M., Black, H. G., & Pierce, L. B. (2009). Efficacy of computer technology-based HIV prevention interventions: a meta-analysis. *AIDS, 23,* 107-115.

Ott, M. A., & Santelli, J. S. (2007). Abstinence and abstinence-only education. *Current Opinions in Obstetrics and Gynecology, 19,* 446-452.

Prochaska, J. O., & DiClemente, C. C. (1983). Stages and processes of self-change of smoking: toward an integrative model of change. *Journal of Consulting and Clinical Psychology, 51,* 390-395.

Resnicow, K., & Page, S. E. (2008). Embracing chaos and complexity: a quantum change for public health. *American Journal of Public Health, 98,* 1382-1389.

Robin, L., Dittus, P., Whitaker, D., Crosby, R., Ethier, K., Mezoff, J. et al. (2004). Behavioral interventions to reduce incidence of HIV, STD, and pregnancy among adolescents: a decade in review. *Journal of Adolescent Health, 34,* 3-26.

Rogers, R. W. (1983). Cognitive and physiological processes in fear appeals and attitude change: A revised theory of protection motivation. In J. T. Cacioppo & R. E. Petty (Eds.), *Social psychology: A source book* (pp. 153-176). New York: Guilford Press.

Rosenthal, S. L., Von Ranson, K. M., Cotton, S., Biro, F. M., Mills, L., & Succop, P. A. (2001). Sexual initiation: predictors and developmental trends. *Sexually Transmitted Diseases, 28,* 527-532.

Rothman, K. J., Greenland, S., & Lash, T. (2009). *Modern Epidemiology* (3rd edition). Philadephia/Baltimore/New York: Wolters Kluer/Lippincott & Wilkins.

Smerz, K. E., & Guastello, S. J. (2008). Cusp catastrophe model for binge drinking in a college population. *Nonlinear Dynamics, Psychology, and Life Sciences, 12,* 205-224.

Steinberg, L. (2003). Is decision making the right framework for research on adolescent risk taking? In D. Romer (Ed.), *Reducing adolescent risk: Toward an integrated approach* (pp. 18-24). Thousand Oaks, CA: Sage Publications.

Tesser, A. (1980). When individual dispositions and social pressure conflict: A catastrophe. *Human Relations, 33,* 393-407.

Thom, R. (1975). *Structural stability and morphogenesis*. NY: Benjamin-Addison-Wesley.

Vundule, C., Maforah, F., Jewkes, R., & Jordaan, E. (2001). Risk factors for teenage pregnancy among sexually active black adolescents in Cape Town: A case control study. *South African Medical Journal, 91,* 73-80.

West, R., & Sohal, T. (2006). "Catastrophic" pathways to smoking cessation: findings from national survey. *British Medical Journal, 332,* 458-460.

Wu, Y., Stanton, B. F., Li, X., Galbraith, J., & Cole, M. L. (2005). Protection motivation theory and adolescent drug trafficking: relationship between health motivation and longitudinal risk involvement. *Journal of Pediatric Psychology, 30,* 127-137.

Zeeman, E. C. (1973). Catastrophe theory in brain modelling. *International Journal of Neuroscience, 6,* 39-41.