In Vivo Studies of Transdisciplinary Scientific Collaboration

Lessons Learned and Implications for Active Living Research

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Abstract: The past 2 decades have witnessed a surge of interest and investment in transdisciplinary research teams and centers. Only recently, however, have efforts been made to evaluate the collaborative processes and scientific and public policy outcomes of these endeavors. This paper offers a conceptual framework for understanding and evaluating transdisciplinary research, and describes a large-scale national initiative, the National Institutes of Health Transdisciplinary Tobacco Use Research Centers (TTURCs) program, undertaken to promote cross-disciplinary scientific collaboration in the field of tobacco use science and prevention. A 5-year evaluation of collaborative processes and outcomes observed across multiple TTURC centers conducted during 1999 to 2004 is described. The findings highlight key contextual circumstances faced by participating centers (i.e., the breadth of disciplines and departments represented by each center, the extent to which members had worked together on prior projects, spatial proximity among researchers' offices, and frequency of their face-to-face interaction) that influenced their readiness for collaboration and prompted them to follow different pathways toward transdisciplinary integration. Implications of these findings for developing and evaluating future transdisciplinary research initiatives in the field of active living research are discussed.

(Am J Prev Med 2005;28(2S2):202–213)

Overview

The field of active living research (ALR), as it has evolved in recent years, emphasizes certain core principles. First, ALR researchers generally assume that an individual's tendency to engage in physical activity is influenced by both personal and situational factors including his or her motivation and commitment to exercise regularly, availability of leisure time for recreational physical activities, and access to environments that support physically active lifestyles.[1–3]

Second, the capacity of an environment to promote physical activity is determined by multiple physical and social circumstances including its hygienic and aesthetic qualities, perceived safety, and sociability.[4–6] Considering the great variety of personal and environmental factors that influence physical activity patterns among individuals and aggregates, it is clear that a broad interdisciplinary perspective spanning multiple fields (e.g., psychology, sociology, geography, urban planning, public policy) is required for gaining a comprehensive understanding of these phenomena.[7,8]

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The contemporary enthusiasm for interdisciplinary approaches to active living research reflects a shift over the past 2 decades from individually focused and behaviorally oriented strategies of health promotion toward more holistic environmental and community approaches encompassing multidisciplinary views of health and illness.[9–11] This paradigm shift from unidisciplinary to interdisciplinary approaches, and from individualized projects toward collaborative team research, is evident across many areas of science.[12–14] The growing interest and investment in promoting interdisciplinary collaboration is reflected in several large-scale research initiatives, including the establishment of the MacArthur Foundation Networks in Mental Health and Human Development during the 1980s,[15] the National Institutes of Health (NIH) Transdisciplinary Tobacco Use Research Centers (TTURCs) during the 1990s,[16–18] and more recently, the Robert Wood Johnson Foundation's (RWJF) Active Living, Obesity, and Nutrition Program,[19] the NIH Roadmap Initiative,[20,21] and the National Academy of Sciences/Keck Foundation's 15-year Initiative to Transform Interdisciplinary Research.[12] Collectively, these programs represent an investment of several hundred million dollars in interdisciplinary research by federal agencies and private foundations.

Despite this substantial outlay of funds to establish interdisciplinary research networks and centers, few efforts have been made to calibrate and empirically

0749-3797/05/$–see front matter
doi:10.1016/j.amepre.2004.10.016

assess the relative advantages and cost-effectiveness of these initiatives as compared to unidisciplinary single-investigator grants.[15,22,23] The dearth of prior efforts to evaluate the tangible benefits of interdisciplinary research may be attributable to the now widespread belief, both within and outside academia, that integrative cross-disciplinary approaches to scientific and community problems afford greater explanatory power and societal value than unidisciplinary studies.[14,24–26] Although many scientists take for granted the presumed benefits of interdisciplinarity as a framework for organizing research, important questions can be raised about the relative effectiveness of alternative strategies for conducting interdisciplinary investigations. It is not clear that these different implementation strategies are equally effective in achieving the potential benefits of interdisciplinary research. For instance, an individual scientist may choose to work on his or her own in developing an interdisciplinary approach to a particular research question, without joining a collaborative research team. Alternatively, multiple researchers trained in different fields may decide to combine their efforts as members of a collaborative team focusing on a particular topic. Little is known about the relative advantages and disadvantages of these noncollaborative and collaborative forms of interdisciplinary research. Moreover, for collaborative ventures it is important to distinguish between geographically dispersed research teams (e.g., as exemplified by the MacArthur Foundation Networks and many RWJF active living research projects) and place-based research centers (such as the NIH TTURCs and Comprehensive Cancer Centers), since the scientific processes and outcomes generated by these alternative arrangements may be quite different.[27,28]

Evaluating the scientific, public policy, and health outcomes of various forms of interdisciplinary research has become increasingly important as government agencies and private foundations continue to allocate substantial resources toward such initiatives. As a basis for evaluating the cost-effectiveness of these expenditures, a comprehensive science of interdisciplinarity is needed. The science of interdisciplinarity as we envision it would (1) address fundamental conceptual issues, including the defining features and differences between unidisciplinary versus cross-disciplinary research[29] (encompasses the subcategories of multidisciplinary, interdisciplinary, and transdisciplinary research, each of which is described in the next section); (2) offer a typology of alternative strategies for conducting cross-disciplinary research; (3) provide a set of methodologic tools for recording the processes and products of cross-disciplinary research, encompassing both quantitative and qualitative measures, and prospective as well as cross-sectional research designs; and (4) posit theoretically derived, testable hypotheses regarding the key organizational, interpersonal, institutional, and environmental circumstances that facilitate or hinder the success of cross-disciplinary research efforts.

A detailed discussion of the science of interdisciplinarity is beyond the scope of this paper. This newly emerging field is at such an early stage in its development that neither longitudinal comparative studies of unidisciplinary and cross-disciplinary research initiatives, nor evidence-based algorithms for modeling their respective near- and long-term outcomes, are yet available. A span of 2 to 3 decades may be required for evaluating the cumulative scientific, public policy and health outcomes of a particular interdisciplinary initiative such as the NIH TTURC Centers, the RWJF Active Living, Obesity, and Nutrition Program, or the NAS/Keck Initiative to Transform Interdisciplinary Research.

The above caveats notwithstanding, it is important that we begin to take initial steps toward conceptualizing and measuring the ongoing processes and near-term outcomes of interdisciplinary research projects. These initial efforts will establish a preliminary database that eventually can be linked to more distal scientific, policy, and health outcomes as those longer-term consequences of interdisciplinary research take shape in the coming years. The remaining sections of this paper describe the methodologic approaches and empirical findings of one such effort, namely, a cross-center comparative study of multiple NIH TTURC centers.[27,30] This ongoing investigation focuses on the day-to-day activities of place-based collaborative research teams rather than on geographically dispersed networks or on sole-investigator interdisciplinary projects. Moreover, it employs a participant-observation comparative case study methodology[31–33] to examine collaborative activities among TTURC scientists as they occur in vivo, that is, in the context of their everyday research environments. The emphasis here is on grounded theory development rather than on hypothesis testing and validation.[34,35] This single investigation does not represent all facets of the science of transdisciplinarity, but it has generated new insights and provocative findings about collaborative research processes and outcomes, nonetheless. We believe that these findings have important implications for the organization of interdisciplinary initiatives in the field of active living research and beyond. These implications are discussed in the concluding section of the paper.

Evaluating the Collaborative Processes and Outcomes of Transdisciplinary Research Centers

In 1999, the NIH established seven TTURCs at Brown University, Yale University, and Georgetown University, and the Universities of Wisconsin, Minnesota, California–Irvine (UCI) and Southern California (USC). The initial phase of this 5-year, $70-million initiative con-

cluded in August 2004, and several TTURC centers have been approved for funding over the next five years.[36] A distinguishing feature of the TTURC initiative is its explicit emphasis on the goal of promoting transdisciplinary intellectual integration in the field of tobacco science. The TTURC requests for applications incorporate Rosenfield's[29] conceptualization of transdisciplinary collaborative research as distinct from multidisciplinary and interdisciplinary research. According to Rosenfield,[29] transdisciplinarity is a process by which researchers work together to develop a shared conceptual framework that integrates and extends discipline-specific theories, concepts, and methods to address a common research problem. By contrast, multidisciplinarity is a process whereby researchers in different disciplines work independently or sequentially, each from his or her own disciplinary perspective, to address a particular research topic. Interdisciplinary collaborations involve greater sharing of information and closer coordination among researchers from different fields than occur in multidisciplinary projects, but the participants remain anchored in their respective disciplinary perspectives and stop short of achieving the novel and integrative conceptual models that are the hallmark of transdisciplinary research. Rosenfield[29] suggests that the creative potential of cross-disciplinary collaboration increases as scientists move from multidisciplinary and interdisciplinary projects toward transdisciplinary research, since the latter entails more extensive collaborative dialogue among co-investigators, and thus, is more likely to yield conceptual integrations of broader scope and societal impact than those associated with multidisciplinary and interdisciplinary strategies.

One component of the TTURC established at UC Irvine is the Transdisciplinary Core Research Project (TD Core Study), the major goal of which is to gain an understanding of key factors that enhance or impede the success of transdisciplinary scientific research on tobacco use and control.[37] To achieve that goal, the TD Core research team developed (1) measurement criteria for distinguishing among multidisciplinary, interdisciplinary, and transdisciplinary scientific collaborations; (2) a working conceptual model that identifies antecedents, intermediate processes, and near-term outcomes of team research as an initial step toward developing a grounded theory of transdisciplinary scientific collaboration (TDSC); and (3) a 5-year participant observation case study to document the processes and outcomes of TDSC at multiple TTURC centers. The conceptual model underlying the TD Core study, as well as the methods and findings of this research, are summarized below as a basis for understanding its implications for organizing future transdisciplinary research initiatives focusing on active living, obesity, and other public health issues. A more detailed discussion of the research design, methods, and findings of the TD Core Study can be found in earlier articles.[27,38]

Conceptual and Methodologic Strategies of TD Core Study

The TD Core Study, from its inception, has been guided by a working model of scientific collaboration that incorporates antecedent conditions (intrapersonal, social, physical environmental, organizational, and institutional factors) that influence the collaborative "readiness" of research teams and centers, as well as intervening processes (e.g., behavioral, affective, and interpersonal experiences of team members, and their intellectual efforts to create and integrate new scientific ideas) that contribute directly or indirectly to the development of short- and longer-term collaborative research products and outcomes (e.g., the development of new concepts, integrative models, new training programs, institutional changes to support transdisciplinary collaboration, and innovative public health policies and programs). The conceptual model is shown in Figure 1.

The specific antecedent factors, processes, and outcomes shown in Figure 1 are included in the proposed model based on both previous analyses of scientific collaboration and the authors' conceptualization of the dynamics of transdisciplinary research.[13,15,27,29] The top arrows in Figure 1 depict the influence of antecedent factors on collaborative processes, and the influence of those processes on transdisciplinary research outcomes. The bottom arrows indicate that the outcomes of collaboration (e.g., achievement of novel and integrative theories, institutional changes to better support transdisciplinary research) can, in turn, influence subsequent collaborative processes (e.g., feelings of satisfaction among team members resulting from the development of novel ideas and conceptual frameworks), and also modify an institution's or organization's readiness for undertaking subsequent collaborative projects (e.g., through the allocation of shared research space to support future transdisciplinary endeavors).

Over the course of the 5-year TD Core Study, several methods and measures have been used to record the antecedents, processes, and outcomes of transdisciplinary collaboration including (1) face-to-face interviews with all investigators and research staff at a particular TTURC; (2) structured surveys of TTURC members regarding their experiences of scientific collaboration and their feelings and beliefs regarding the effectiveness of their center in achieving the goals of transdisciplinary scientific collaboration and integration; (3) behavioral observations of centerwide meetings and events to discover and record circumstances that facilitate or hinder scientific collaboration; (4) focus groups conducted with graduate student researchers and postdoctoral fellows to gauge the extent to which a transdisciplinary orientation is conveyed by faculty members to their trainees; and (5) archival

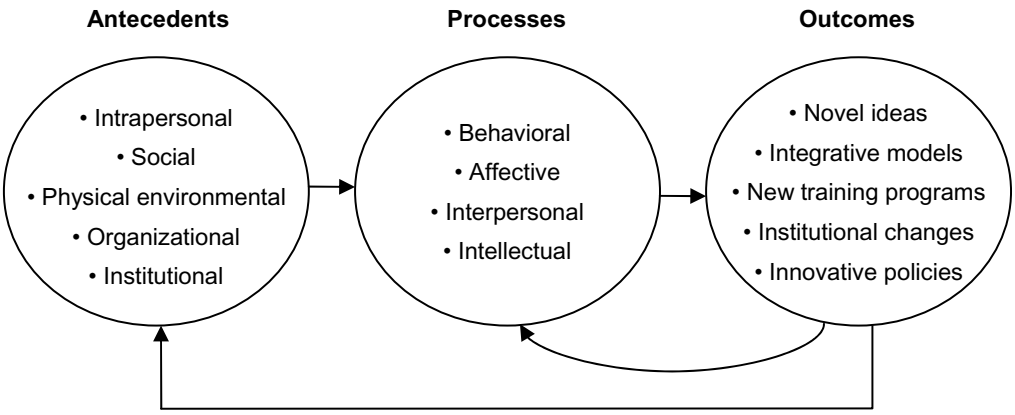

Figure 1. Conceptual model of transdisciplinary scientific collaboration. Adapted from Stokols et al.[27]

measures of research products such as collaborative publications, research and training proposals, new scientific and community initiatives spanning multiple TTURC centers, and steps taken by a host university to support the transdisciplinary activities of the TTURC located on its campus. (The interviews and surveys of investigators and research staff are conducted semiannually. The focus groups are convened on an annual basis, while behavioral observations of multiple centerwide meetings and archival data are gathered cumulatively each year. Copies of the interview and survey protocols used in the TD Core Study are available at www.tturc.uci.edu/about/CoreTransdisciplinary.html, and are described in greater detail in Stokols et al.[27].)

Although the 1999 proposal to establish the UCI TTURC incorporated a budget and plan for assessing scientific collaboration at only one center (UCI), the six other TTURCs subsequently were invited informally (at the NIH TTURC National Retreat held in San Diego during January 2001) to join the TD Core Study by completing the requisite survey, interview, and meeting observation protocols. Participants at four of the seven centers noted that the additional time required for completing the protocols was too great, but the Brown and USC TTURCs decided that the additional time required was manageable and agreed to participate. Thus, the findings discussed below are derived from data provided by three of the seven TTURC centers between 1999 and 2004. Some of the reported findings are based on data provided by all three of the participating centers, whereas in other cases, they are derived from the data provided by only one or two of the three centers. The most complete survey, interview, observational, and archival data were obtained from the UCI and USC TTURCs due to their geographic proximity in the Los Angeles/Orange County CA region. The TD Core Study team based at UCI was able to make frequent visits to the USC TTURC during each year of the project to conduct interviews and focus groups, and to gather survey, observational, and archival data. A smaller subset of survey and interview data was obtained from members of the Brown TTURC through mailed questionnaires and interviews with project leaders conducted by the TD Core staff at national TTURC retreats during years 2 to 4 of the Initiative.[27] Thus, the three participating TTURCs constitute a convenience sample. Because we did not obtain data from the nonparticipating centers, we were unable to perform comparative analyses across all seven TTURCs to identify possible dimensions on which the participating and nonparticipating centers might have differed from each other.

Given the participant observation case study design of the TD Core project, the reported findings from the first 5 years of the TTURC Initiative must be viewed as exploratory and suggestive rather than conclusive. The TD Core team is comprised of TTURC investigators, trainees, and staff, all of whom are subjectively involved in, rather than objectively detached from, the TTURC Initiative. Thus, team members' interpretations of the data necessarily are influenced by their membership in the TTURC in ways that are not fully known. In an effort to minimize the influence of membership bias on the results, steps were taken to corroborate data gathered using one instrument [e.g., TTURC members' responses to TD Core surveys] with those obtained via other protocols (e.g., comments made during face-to-face interviews and informal conversations with research staff, behavioral observations recorded at centerwide meetings). Over the course of the TD Core Study, team members also made efforts to corroborate each other's interpretations of the data and to maximize inter-rater reliability when gathering observational data. However, an important strength of participant-observation case studies is that they afford a fine-grained analysis of the day-to-day activities of research center members. Thus, they offer fertile ground for generating theoretical insights and hypotheses about the processes and outcomes of scientific collaboration that can be subjected to quasi-experimental tests in

later studies. Given the exploratory nature of this research, we focus on descriptive rather than inferential statistics in our presentation of the findings.

Findings from First 5 Years of TD Core Study

In this section, we summarize key observations and findings derived from the initial 5 years of the TD Core Study. By using multiple methods and measures to probe different facets of scientific collaboration at transdisciplinary research centers (e.g., including affective, behavioral, social, and intellectual dimensions of members' experiences over a 5-year period), the TD Core Study opens different "windows" or vantage points on the collaborative climate, productivity, and effectiveness of these organizations. One finding emerging from the data is that each TTURC is characterized by a unique set of institutional and organizational circumstances that exert important contextual influences on collaborative processes and outcomes. In 1999, the three TTURCs were established within qualitatively distinct contexts or "starting points" for intellectual collaboration, and appear to have followed alternative rather than identical "pathways" in their efforts to achieve transdisciplinary integration over the past 5 years.

Antecedents of Transdisciplinary Collaboration

A striking difference between the USC, UCI, and Brown TTURCs is the dissimilarity of their organizational structures. At USC, the TTURC was established within a pre-existing organized research unit, the Institute for Prevention Research, situated within the Department of Preventive Medicine. The majority of USC TTURC members have overlapping affiliations with the same Institute, university department, and TTURC center. By contrast, members of the Brown and UCI TTURCs are spread across multiple university departments and schools rather than belonging to a common administrative unit. Additionally, USC TTURC members had worked together on collaborative research projects in the years preceding their center's establishment in 1999, whereas investigators at Brown and UCI had less shared history of collaboration prior to the TTURC Initiative. Moreover, members of the USC TTURC share two floors of the same building, whereas offices of the Brown and UCI TTURC participants are dispersed across multiple laboratory and departmental facilities at those campuses. One similarity between the Brown and USC TTURCs is that investigators at those centers work largely from a shared methodologic framework and empirical database, whereas the UCI scientists associated with four major research projects rely for the most part on different research methods and separate data sets.

The common departmental affiliations of participants in the USC TTURC, their history of collaboration on previous projects, and shared research space within the same building enabled them to achieve a smoother and more rapid launch of TTURC projects and core activities than was possible at the Brown and UCI centers. Unlike participants in the USC TTURC, members of the Brown and UCI centers reported that they spent substantial amounts of time during the first 2 years of the Initiative resolving differences in scientific terminology and research strategy, and negotiating collaborative agreements (including formal memoranda of understanding) among themselves and between administrators from their respective campus departments. Another circumstance that facilitated a fast start-up of collaborative activities at the USC center is the relatively narrower scope of disciplines represented among the core and project leaders there (drawn largely from the social and behavioral sciences, with a shared focus on the links among culture, ethnicity, and smoking), as compared to the TTURCs at both Brown and UCI, where participants represent a broad "molecules to society" spectrum of disciplines spanning neuroanatomy, pharmacology, psychiatry, epidemiology, developmental and health psychology, communications, and public policy.

Analyses of TD Core interview, survey, and behavioral observation data over the past 5 years suggest that certain contextual factors, including shared departmental identities among center members, streamlined versus complex administrative arrangements, a history of collaboration among participants on previous research projects, spatial proximity among their offices and laboratory space, and a narrow versus broad scope of disciplines represented among team members enhance their readiness for transdisciplinary collaboration. At the same time, non-overlapping departmental identities, complex administrative structures, little or no history of previous collaboration among team members, geographic separation of their offices and laboratory facilities, and a wide spectrum of disciplinary perspectives among team members reduce their initial preparedness for intellectual collaboration and slow the pace of collaborative activities, especially during the start-up phase of a transdisciplinary research center. Additional contextual factors that have been found in other studies to enhance the collaboration readiness of geographically dispersed research teams and place-based centers are the leadership skills of team directors,[15] the design of organizational incentive structures to encourage collaborative behaviors,[39] and small versus large size of networks and centers.[23] Rhoten,[23] for example, suggests that small (<20 investigators) and medium-sized (21 to 50 members) centers are more conducive to the generation of interdisciplinary knowledge than large centers [with ≥ 50 investigators]. Each of the TTURCs participating in the TD Core Study have

between 11 and 18 investigators, co-investigators, and core leaders, combined.

Processes of Transdisciplinary Collaboration

The conceptual model shown in Figure 1 suggests that certain antecedent conditions (including the organizational, institutional, and environmental circumstances mentioned above) influence collaborative processes and products of research teams in important ways. The links between these contextual factors and the behavioral, affective, interpersonal, and intellectual processes observed among TTURC members are described below.

Behavioral processes. At the Brown and UCI TTURCs, where nonoverlapping departmental affiliations, lack of shared space, and multidisciplinary diversity placed greater constraints on initial collaboration than at USC, TTURC leaders and members organized a series of brainstorming sessions and off-campus retreats to address cross-disciplinary tensions and to facilitate progress toward intellectual integration. Interviews with members of the Brown and UCI TTURCs indicate that these efforts to improve communications and mutual understanding of divergent disciplinary perspectives have been helpful in promoting sustained collaboration around shared research interests. Moreover, data from the Behavior Change Index administered at UCI as part of the TD Core Study's semiannual survey of investigators reveal cumulative increases in the frequency of transdisciplinary activities during years 3 to 5 of the Initiative. This questionnaire asks respondents to indicate on a seven-point scale (ranging from −3 to +3) the degree to which various transdisciplinary behaviors increased, decreased, or remained the same over the course of their involvement with the TTURC (from its inception to the present time). Examples of transdisciplinary activities include reading journals or attending conferences outside one's major field, participating in TTURC working groups to integrate members' ideas, and modifying one's research plans as a result of discussions with TTURC colleagues. As shown in Figure 2, data averaged over three different time points reveal that UCI TTURC investigators spend more time collaborating with TTURC colleagues in working groups for the purpose of integrating each other's ideas and more time reading journals and attending conferences outside their major field than they did during earlier years of the Initiative.

The reports of increased transdisciplinary activities among UCI TTURC members shown in Figure 2 are corroborated by archival records of the number of integrative research meetings organized annually at that center, including monthly (or more frequent) scientific meetings of the Tobacco Research Network, Basic Mechanisms of Addiction Workgroup, and the Public Health Workgroup; as well as the twice yearly centerwide retreats and annual meetings with the members of other TTURCs. Also, interviews with TTURC investigators indicate that they particularly value centerwide retreats and other scientific meetings that afford opportunities for integrative discussion with each other.

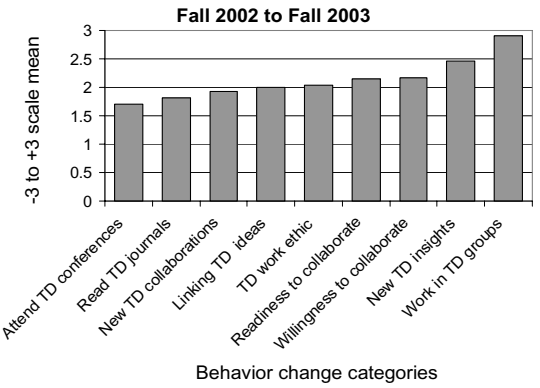

Figure 2. Reported increases in transdisciplinary behaviors among UCI TTURC members over the 5-year Initiative. TD, transdisciplinary; TTURC, Transdisciplinary Tobacco Use Research Center; UCI, University of California–Irvine.

Affective processes. Survey data regarding the subjective beliefs and feelings of TTURC members provide additional insight into the collaborative climate and effectiveness of transdisciplinary research centers. For instance, on a semantic differential item asking investigators to rate their TTURC along a 7-point scale (where 1="scientifically fragmented" and 7="scientifically integrated"), the responses from UCI investigators over five measurement intervals (from fall 2001 to fall 2003) reflect a modest linear increase in perceived integration from 3.57 during fall 2001 to 4.90 during fall 2003. These data shown in Figure 3 (top left) suggest that efforts made by TTURC leaders to organize several integrative research meetings and retreats resulted not only in the higher incidence of reported and observed transdisciplinary behaviors noted earlier, but also prompted a parallel shift in investigators' belief that their center had progressed over successive years from scientific fragmentation toward a moderate level of integration. On the other hand, when the UCI investigators were asked to rate their feelings about the TTURC along the dimensions of "frustrating/satisfying," "unenjoyable/enjoyable," and the extent to which they feel "unappreciated" or "appreciated," their responses (summarized in Figure 3) reflect nonlinear shifts in both positive and negative directions over successive periods, with the lowest ratings on each scale registered during fall 2002 followed by a positive upswing during spring and fall 2003. Interviews with the UCI investigators conducted during late fall 2002 and the end of fall 2003 suggested at least two circumstances that might have contributed to the affective downswing during fall 2002 and upswing during fall 2003. First, an NIH site visit of the UCI TTURC

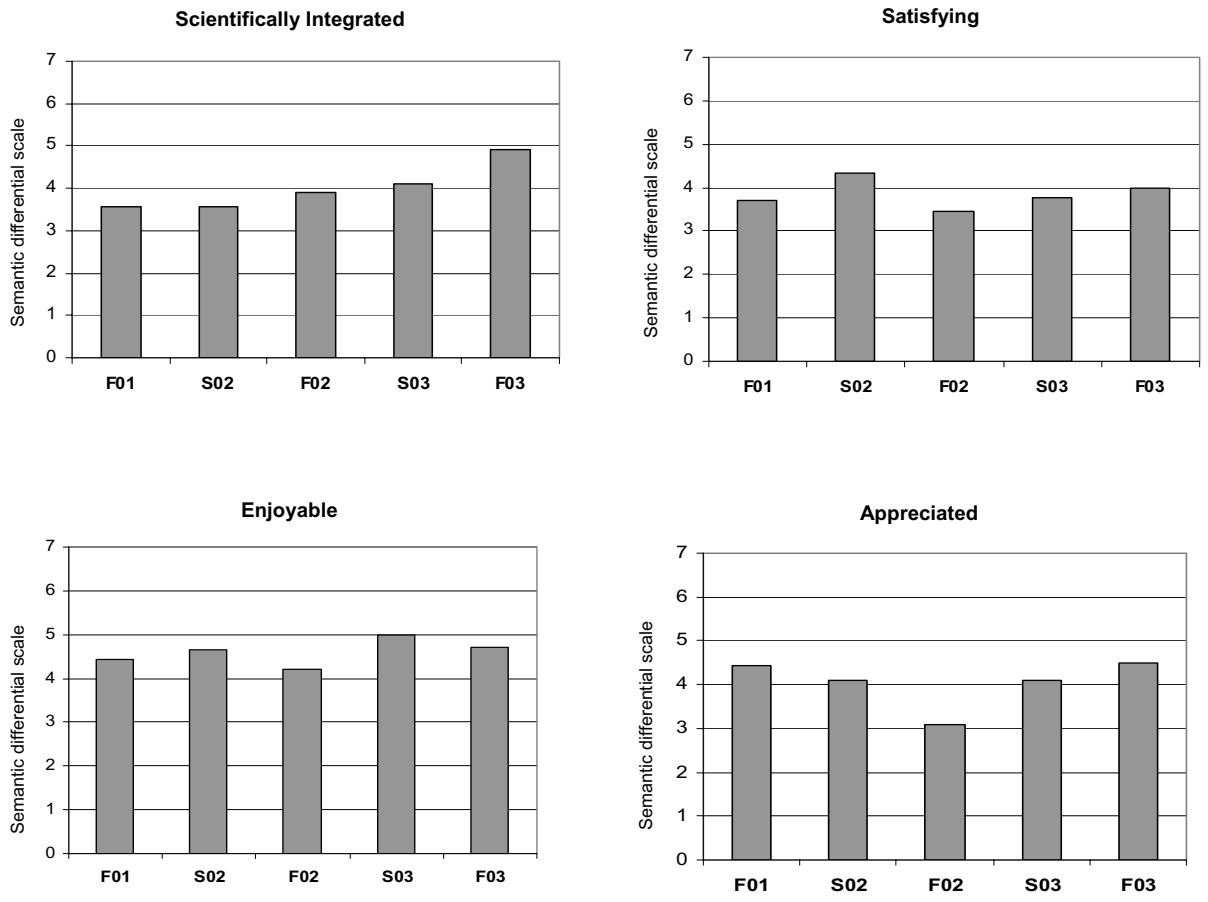

Figure 3. Investigators' semantic differential ratings of the UCI TTURC between fall 2002 and fall 2003. F, fall; S, spring; TTURC, Transdisciplinary Tobacco Use Research Center; UCI, University of California–Irvine.

completed during November 2002 prompted self-critical scrutiny and some feelings of discouragement among investigators about the incremental rather than rapid rate of transdisciplinary progress during the first 2 years of the Initiative. On the other hand, subsequent notification during early fall 2003 that a continuation request for applications for the TTURC Initiative had been approved by the NIH Board of Scientific Affairs was viewed as encouraging news by TTURC members.

The affective responses summarized in Figure 3 reveal emotional "ups and downs" experienced by UCI TTURC members over the course of their collaboration. This cyclical pattern of affective experiences may be a common feature of transdisciplinary scientific collaboration, at least among the members of place-based research centers who work together closely over a period of several years.

Interpersonal processes. Interpersonal processes and levels of social organization exert an important influence on scientists' efforts to achieve transdisciplinary integration. For instance, interpersonal tensions can evoke negative affect, thereby undermining intellectual collaboration, whereas high levels of social support and shared scientific values typically enhance the effectiveness of collaborative endeavors.[15,27,40] As noted earlier, the multidisciplinary diversity, nonoverlapping departmental affiliations, and lack of shared research space among investigators at the Brown and UCI TTURCs constrained initial collaborative efforts at those centers. At UCI, for example, ten TTURC investigators trained in widely different fields are affiliated with two major academic units, the College of Medicine and the School of Social Ecology. From the TTURCs' inception in 1999, behavioral observations of centerwide meetings and interviews with investigators highlighted recurring differences in scientific terminology and strategy among participants from the two schools. These linguistic and epistemologic differences observed among TTURC scholars from multiple fields are consistent with previous discussions of the divergent scientific world views found within the physical, biological, behavioral, social, and policy sciences.[41–43]

The emergence of two distinctly different perspectives on collaborative processes and outcomes at the UCI TTURC is reflected in analyses of survey data, disaggregated by investigators' primary departmental affiliation. When researchers from the College of Medicine and the School of Social Ecology are grouped

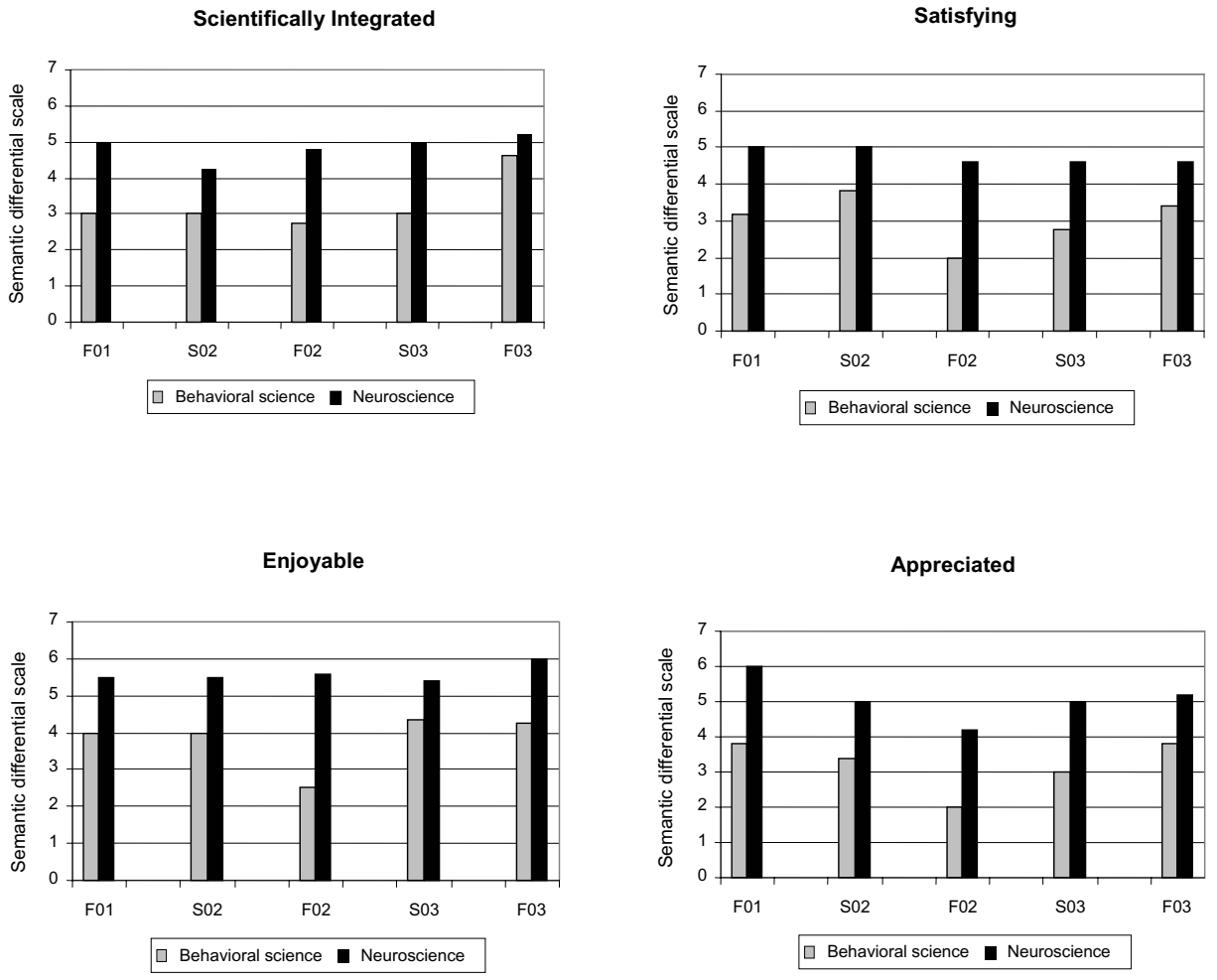

Figure 4. Neuroscientists' and behavioral scientists' semantic differential ratings of the UCI TTURC between fall 2002 and fall 2003. F, fall; S, spring; TTURC, Transdisciplinary Tobacco Use Research Center; UCI, University of California–Irvine.

separately and compared with each other, their ratings of how integrated, satisfying, and enjoyable their TTURC is, and the degree to which they feel appreciated by fellow members, reveal strikingly different patterns. The neuroscience investigators (from the College of Medicine in which the Administrative Core of the TTURC also is based) report consistently higher ratings of scientific integration (M=4.85 across five time points), satisfaction (M=4.71), enjoyment (M=5.61), and appreciation (M=4.95) than their behavioral science counterparts (from the School of Social Ecology), whose mean scores on the same variables averaged over five measurement periods are 3.30, 3.08, 3.80, and 3.20, respectively. These data, summarized in Figure 4, reflect what we have come to refer to as the "Mars–Venus effect" (extrapolating from the title of Gray's[44] widely known book about gender differences), in which distinct subgroups of investigators coalesce within the same research organization. In this case, the groups are characterized by divergent scientific perspectives, collaborative orientations, and experiences (rather than by gender differences, the focus of Gray's book). For example, the neuroscience investigators at UCI (the "Martians") consistently provide more positive ratings of the TTURC than the behavioral scientists ("Venusians"). Whether these discrepant patterns of response reflect social desirability bias or other response sets is not known, but the same patterns emerge from analyses of interview and observational data across multiple time points.

Additional evidence for the emergence of two distinct groupings of researchers at UCI was obtained from the Collaborative Relations Survey completed by ten investigators during spring 2003. (Data from the Collaborative Relations Survey were not available for the Brown and USC TTURCs.) This questionnaire assesses network relationships among the scientists and includes an item that measures the extent to which each person is working to integrate ideas with each other investigator. Each respondent rated his or her relationship with each other investigator on this item using a 7-point scale where 1="not at all" and 7="very

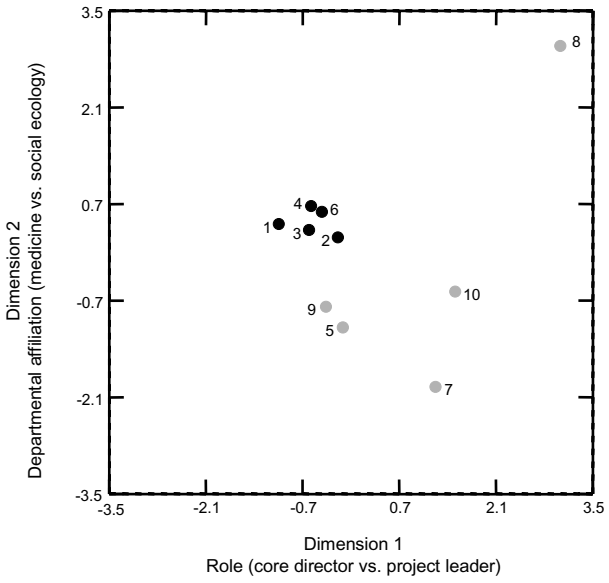

Figure 5. Correspondence analysis of the degree to which UCI TTURC investigators work closely with each other to integrate ideas. TTURC, Transdisciplinary Tobacco Use Research Center; UCI, University of California–Irvine.

much." Correspondence analysis[45] was used to represent graphically the relationships among investigators. Correspondence analysis provides a visual representation of the relationship between two or more variables—in this case, individual scientists. Applied to data such as respondents' scores on the Collaborative Relations Survey, the analysis produces column and row vectors which, when plotted graphically, reveal how each variable relates to the others in Euclidean space. The column and row vectors are then re-scaled to provide optimal scores, which are the coordinates for the data points in normalized Euclidean space. The data are displayed primarily in two dimensions, one horizontally along the x-axis and the other vertically along the y-axis. Once the data points are arrayed spatially, it is up to the researcher to interpret what the first and second dimensions represent and what explains the interpoint distances. Based on additional data [e.g., from interviews, meeting observations, and other surveys] gathered as part of the TD Core Study, it appears that the first dimension captures a scientist's role within the center such that project leaders [cases 1, 2, 3, 4, 5, 6, 9] are located on the left side of the figure and core directors [7, 10] are located on the right. The second dimension, arrayed vertically, appears to represent a scientist's departmental affiliation such that scientists from the College of Medicine [1, 2, 3, 4, 6] are clustered together and located higher on the plot, whereas scientists from the School of Social Ecology [5, 7, 9, 10] are located at some distance below them. Case 8 is an outlier and, as such, it is difficult to interpret its position. Figure 5 shows the network of relations among UCI investigators based on the extent to which they work with each other to integrate ideas. Each numbered circle represents an investigator, and the distance between each point reflects how closely each person reported working with the others. For instance, investigators 1 and 6 work more closely than 1 and 10. Overall, the data reveal a cohesive subgroup among investigators 1, 2, 3, 4, and 6. These individuals (collectively referred to as "Martians") are all neuroscientists based within the College of Medicine. Investigators 5, 7, 8, 9, and 10, by contrast, appear to be less cohesively organized as a group and are relatively untethered with respect to integrating ideas with other members of the center. The latter group (collectively referred to as "Venusians") is comprised of behavioral and social scientists affiliated with the School of Social Ecology.

Together, the findings shown in Figures 4 and 5 suggest that in some instances transdisciplinary research centers encompassing a wide array of fields must confront the challenges of balancing "centrifugal" social forces—those that result in greater divergence and fragmentation—with "centripetal" tendencies toward convergence and integration (e.g., organizing frequent brainstorming sessions to overcome collaborative constraints and promote opportunities for informal face-to-face interaction). These countervailing forces are to be expected in research settings characterized by high levels of multidisciplinary diversity and geographic dispersion among participants but must be managed effectively so that they do not undermine progress toward transdisciplinary collaboration.

Intellectual processes. The intellectual processes of transdisciplinary scientific collaboration include team members' efforts to generate novel ideas, methods, and integrative conceptual frameworks. Interviews, surveys, and meeting observations revealed that certain settings and events, including centerwide retreats and smaller working group meetings, were especially useful in facilitating conceptual brainstorming and collaborative theory development among center members. The outcomes of these intellectual efforts are summarized below.

Outcomes of Transdisciplinary Collaboration

An important question raised by the emergence of different worldviews and distinct groups of researchers at UCI is whether the members of that TTURC, or any collaborative venture that encounters centrifugal tendencies toward fragmentation, can successfully achieve transdisciplinary collaborative outcomes. To address that question, the TD Core Study team examined various indicators of potential outcomes and products of transdisciplinary collaboration. One challenge inherent in evaluating transdisciplinary scientific ventures is that their outcomes emerge gradually and may not become evident for several years or even decades. The societal impacts of a transdisciplinary research initiative

such as the TTURC program (e.g., its influence on public policy or population health) require a broad historical timeframe (spanning ≥ decades) for their assessment.

These methodologic challenges notwithstanding, it is possible to identify and assess near-term outcomes of scientific collaboration that may emerge during the initial phase (e.g., first 5 years) of a transdisciplinary research program. For instance, the "building blocks" of transdisciplinary intellectual collaboration are the integrative ideas and conceptual themes that arise through informal discussions and exchanges among two or more researchers from different fields. These novel ideas represent the intellectual capital generated by a transdisciplinary network or center. Accordingly, TTURC investigators were asked to identify any new ideas and conceptual themes they had developed through discussions with TTURC colleagues from the inception of the TTURC in 1999 onward. By compiling this inventory of novel ideas at the UCI and USC TTURCs through periodic interviews with investigators, we were able to trace in effect the intellectual history of those centers.

A detailed discussion of the intellectual themes developed by TTURC investigators is beyond the scope of this paper. It is apparent from the TD Core Study data, however, that each of the participating centers made considerable strides toward transdisciplinary integration over the course of the 5-year initiative. At Brown, a TTURC-based team of psychologists, economists, statisticians, and health policy researchers developed a shared economic model to assess the costs of smoking. At USC, TTURC members generated four new transdisciplinary research center proposals, one of which was funded (for an NIH Transdisciplinary Substance Abuse Prevention Center), and submitted a TTURC renewal proposal in 2004 that integrated USC's initial focus on culture and smoking with a genetics component. And at UCI, investigators identified new directions for transdisciplinary collaboration across multiple research projects (some involving partnerships with TTURCs at other universities), including the measurement of the effects of tobacco advertising on brain response and addiction circuits; and a study of the links among ethnicity, personality, and adolescent smoking patterns in the United States and China undertaken jointly by members of the UCI and USC TTURCs. The TD Core data, thus, suggest that investigators at all three TTURCs made tangible progress toward transdisciplinary conceptual integration over a 5-year period, despite the collaborative constraints encountered at some of the centers. It is unlikely that these new avenues of transdisciplinary collaboration would have occurred in the absence of the NIH TTURC Initiative.

Lessons Learned from TD Core Study of Transdisciplinary Collaboration and Implications for Active Living Research

The benefits of transdisciplinary collaboration are widely heralded by scientists in many fields, yet the effectiveness of alternative strategies for promoting such collaboration is not well understood. The TD Core Study was undertaken to better understand the circumstances that enhance or hinder scientific collaboration at research centers in the field of tobacco science and beyond. The reported findings are qualified by the interpretive constraints on participant observation case studies mentioned earlier. They are useful, nonetheless, in illuminating certain collaborative processes and outcomes that can occur in the context of place-based transdisciplinary research centers. In that respect, they provide a basis for targeting and refining future organizational efforts to promote transdisciplinary collaboration in rapidly developing multidisciplinary fields such as active living research.

The diverse contextual circumstances faced by the USC, Brown, and UCI TTURCs influenced their readiness for collaboration, and led these centers to follow different pathways toward transdisciplinary integration. Whereas each of the TTURCs made valuable progress toward transdisciplinary integration, the pace and scope of this progress was slowed at certain centers by recurring disagreements over scientific and administrative matters especially during the early years of the Initiative. At UCI, these tensions apparently led to an organizational "filtering" process in which the most committed members of the center (and those with the greatest affinity among their disciplinary perspectives and departmental affiliations) continued to collaborate closely over the course of the Initiative, whereas other investigators working more independently on projects further removed from the neuroscience core of the TTURC became increasingly peripheral over time. A key question posed by these findings for future transdisciplinary initiatives is whether the centrifugal tendencies sometimes observed at large, highly diverse research centers are sufficiently powerful to undermine their long-term success and cost-effectiveness.

The findings from at least one other study of collaboration at an interdisciplinary research center suggest that too much "closeness" among team members and similarity among their scientific perspectives can foster "groupthink" and suppress innovation.[23] Some degree of scientific debate and collaborative tension may actually catalyze transdisciplinary discoveries and offset tendencies toward conventional thinking and excessive agreement among investigators. On the other hand, the TD Core data suggest that when investigators with widely different disciplinary backgrounds and spatially separate offices and laboratories undertake collaborative projects, the potential for group fragmentation and

polarization is strong. According to Festinger's[46] theory of social comparison, individuals generally seek others who are similar to themselves for purposes of validating their own attitudes, values, and opinions. Neuroscientists who share interests in genetic mechanisms of addiction, for example, are more likely to affiliate with each other than with social scientists at the same center whose interests are more distant from their own. Furthermore, the physical separation of neuroscientists' offices and laboratories from those of social scientists at the center only reinforce these centrifugal tendencies toward fragmentation.[47] Thus, a major challenge facing future transdisciplinary research initiatives is to achieve an appropriate balance between diversity and debate among investigators on the one hand, and intellectual integration and social support on the other. If collaborative tensions and debates become too strident and distracting, they can inhibit spontaneity and creativity and undermine the long-term success of transdisciplinary research. Yet, a modicum of debate among proponents of different scientific worldviews may be useful in prompting conceptual integration in the short run and more substantial contributions to science and society in later years.

Taken together, findings from the TD Core Study suggest certain guidelines for organizing transdisciplinary research initiatives in the field of tobacco science, active living research, and beyond. When reviewing proposals for transdisciplinary programs and centers, audits of collaboration readiness should be performed by funding organizations and university administrators to identify contextual constraints on teamwork and integration. The audit should include a checklist of potential impediments to scientific collaboration including physical separation of investigators' research facilities, their lack of experience working together on prior projects, and the absence of formal or informal agreements among campus administrators who represent participating departments and schools. Prospective co-investigators should be required to address these issues as part of the proposal development process. It is especially important to ensure, before a transdisciplinary project begins, that participants will have ample opportunities for face-to-face interaction on a regular basis as well as convenient access to electronic communications technologies (e.g., wireless laptop or handheld computers, intranet sites, electronic bulletin boards). Also, to the extent possible, center directors and project leaders should have a track record of proven effectiveness in facilitating transdisciplinary collaboration. Low scores on these dimensions would signal the need to implement preparatory or remedial actions aimed at enhancing the prospects for collaborative success. The funding of scientifically meritorious proposals could be made contingent on the completion of these actions, including investigators' participation in workshops that explicitly address the challenges of transdisciplinary collaboration (and the steps that they can take to improve their chances for success); assignment of shared research space by campus administrators for use by center members; and negotiation of administrative agreements between participating departments before the center is formally established.

As new initiatives to create transdisciplinary centers are implemented in the field of active living research and other scientific arenas, prospective efforts should be made to evaluate their effectiveness in promoting collaboration, intellectual integration, and contributions to science and society. The accumulation of evidence concerning the processes and outcomes of transdisciplinary collaboration is essential for developing a comprehensive science of interdisciplinarity. This emerging area of science studies[32,48–50] would build on the findings from exploratory case studies of transdisciplinary collaboration[15,18,23,27] by providing prospective evaluations of specific strategies implemented in some centers (but not in comparison sites) aimed at enhancing the effectiveness of team research. Accordingly, federal agencies and private foundations should incorporate funding for transdisciplinary program evaluations when new grants for collaborative research programs and centers are awarded. These prospective evaluations would help assess the generalizability of findings from the TD Core Study to other research settings and shed light on the best ways to achieve an appropriate balance between spontaneity versus routinization of centerwide activities, transdisciplinary debate versus integration, and organizational cohesion versus fragmentation. Moreover, they would provide a basis for linking the early products of transdisciplinary collaboration at research centers (e.g., emergence of shared conceptual models) with longer-term outcomes at scientific, institutional, and societal levels.

The TD Core Study focused on contextual antecedents, collaborative processes, and outcomes associated with place-based centers rather than geographically dispersed research teams. Until prospective evaluations of these different strategies for organizing transdisciplinary research are completed, it is impossible to gauge their relative effectiveness. However, considering the sizable proportion of research center grant awards that must be allocated toward administrative infrastructure and operations, and the incremental rather than rapid returns on these investments at scientific and societal levels, the long term cost-effectiveness of place-based centers (e.g., over a 10- to 15-year period) cannot be taken for granted. Thus, new initiatives to establish transdisciplinary centers in the field of active living research should be supplemented by a diversified portfolio of funding strategies, including short-term grants for collaborative studies undertaken by geographically dispersed teams and national collaborations among university scientists working closely with researchers and professionals based in government agencies and nonprofit organizations. These diversified investments

in transdisciplinary research on active living are likely to facilitate significant scientific advances and improved public health outcomes in the coming decades.

This paper was presented at the Active Living Research Annual Conference at Del Mar, CA on January 30–31, 2004. We thank the members of the Brown University, UCI, and USC TTURCs for their participation in this study. Development of the manuscript was supported by a grant from the National Institutes of Health (NIDA/NCI) to establish the UCI TTURC (NIH award DA-13332).

No financial conflict of interest was reported by the authors of this paper.

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