# Toward a Better Understanding of the Influences on Physical Activity

## The Role of Determinants, Correlates, Causal Variables, Mediators, Moderators, and Confounders

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**Background:** For research on physical activity interventions to progress systematically, the mechanisms of action must be studied. In doing so, the research methods and their associated concepts and terminology become more complex. It is particularly important to clearly distinguish among determinants, correlates, mediators, moderators, and confounder variables used in physical activity research. This article examines the factors that are correlated with and that may have a causal relationship to physical activity.

**Methods and Results:** We propose that the term "correlate" be used, instead of "determinant," to describe statistical associations or correlations between measured variables and physical activity. Studies of the correlates of physical activity are reviewed. The findings of these studies can help to critique existing theories of health behavior change and can provide hypotheses to be tested in intervention studies from which it is possible to draw causal inferences. Mediator, moderator, and confounder variables can act to influence measured changes in physical activity. Intervening causal variables that are necessary to complete a cause–effect pathway between an intervention and physical activity are termed "mediators." The relationship between an intervention and physical activity behaviors may vary for different groups; the strata by which they vary are levels of "moderators" of the relationship. Other factors may distort or affect the observed relationships between program exposure and physical activity, and are known as "confounders."

**Conclusions:** Consistent use of terms and additional research on mediators and moderators of intervention effects will improve our ability to understand and influence physical activity.

**Medical Subject Headings (MeSH):** behavior, causality, confounding factors, exercise, physical fitness, research design (Am J Prev Med 2002;23(2S):5–14) 

### Introduction

A range of theories and models has been used to specify variables that are believed to influence physical activity and other behaviors. Researchers test hypotheses derived from theories by (1) examining associations among theoretically derived variables with behavior that help to "understand and predict" the behavior, and (2) evaluating interventions that are designed to modify the influences that are believed to lead to behavior change. There are hundreds of behavioral studies on physical activity, with great diversity in research designs, measurement approaches, populations studied, theories used, variables tested, and physical activity outcomes. This diversity makes it difficult to integrate the findings and summarize the status of the field, thus limiting the ability of subsequent research to build on previous findings.

This paper is divided into several sections, the first describing the criteria for causal relationships, which draws mainly from epidemiologic methods. Definitions are then provided for the key terms and examples are used to illustrate them. The third section deals with correlates of physical activity and how well they are linked to theories of behavior change. The fourth section reflects on these terms from a behavioral science perspective.

It is particularly difficult to integrate the results from associational and intervention studies. Part of this dif-

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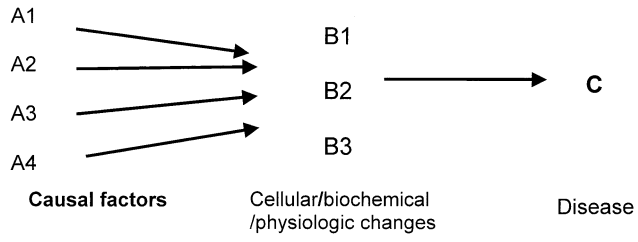



**Figure 1.** Causal pathways in health and disease

ficulty is due to the inconsistent use of terms and misuse of logical and empiric guidelines for ascertaining and describing causality. The primary aim of this paper is to recommend more standardized use of selected terms related to understanding the causation of physical activity behavior. It is hoped that clarification of terms will contribute to improvements in behavioral research on physical activity, with the explicit goal of enhancing the effectiveness of interventions.

## The Logic of Causality: Defining Correlates and Determinants

Identifying factors that are associated with physical activity is a basic research concern. Many studies have attempted to explain and predict behavior, as well as to test hypotheses derived from specific theories. The research literature on physical activity is replete with findings of significant cross-sectional associations between a range of personal, social, and environmental variables and levels of physical activity. These are usually correlational studies, and might, for example, report that socioeconomic status or social supports are associated with physical activity behavior. Such relationships do not support causal inferences, but may generate hypotheses for further study. This section is concerned with clarifying and defining the logical criteria for causal relationships, and distinguishing these from evidence of association or correlation.

The logic of causality is fundamental to any study of factors that act to substantially increase the probability of an outcome. This kind of thinking is applied in disease-based epidemiologic studies. For example, what causes coronary heart disease? There is a constellation of probable causal variables that include physical inactivity, high cholesterol levels, tobacco use, and genetic factors. This group of factors in turn may contribute to microphysiologic changes. For example, physical activity may reduce coronary heart disease risk through improvements in cardiac endothelial cell function, collateral circulatory changes, or through improved oxygen uptake.[1,2] These cellular and biochemical changes are shown as B1, B2, B3 in Figure 1, and in turn these cause or prevent coronary heart disease occurrence. This is a causal pathway, where a behavioral change makes an impact on physiology, that in turn causes a reduction in disease occurrence. Note that a behavioral change could also have a negative causal impact on health: Adopting a sedentary lifestyle or poor diet could be causal factors for ill health.

The causal pathways and methods of studying them in public health and behavioral interventions are less clearly identified. The causal or etiologic factor(s) may be public health interventions that are deliberate efforts at achieving change. Alternatively, causal factors may be naturalistic changes in policy or in physical or social environments that are not necessarily planned, but do induce (cause) changes in the outcomes of interest. The outcome might be a measurable change in health-related behavior, health system access, service utilization, or other outcomes of relevance to improving public health.

There are few examples of absolute causal factors that "cause" the outcome in 100% of cases, but none in the behavioral realm. In behavioral research, there is also the possibility of multiple causal factors (which might "cause" physical activity) and also reciprocal determinism, where the causal relationships are bidirectional—this makes discussion of traditional "causal" pathways more complex. Further, exposure to a factor does not "inevitably" lead to the behavioral outcome. Thus, etiologic variables in behavioral sciences are probabilistic factors that substantially increase the likelihood of the outcomes subsequently occurring, but do not "guarantee" them.

The term "determinant," as it has most typically been used in the physical activity research literature, is a misnomer. The majority of studies have used the term "determinant" in the context of findings that demonstrate reproducible associations or predictive relationships (correlates), rather than the more appropriate use of the term as a cause-and-effect relationship.[3] It is recommended that the term "determinant" be used with greater precision and not be used to describe correlates of physical activity.

Determinants are most appropriately defined as causal factors, and variations in these factors are followed systematically by variations in physical activity behavior. When researchers have the purpose of identifying strategies that can be influenced to modify the outcome of interest, the proposed causal factor is generally referred to as the "independent variable" (or study factor) and the outcome or effect as the "dependent variable."[4] The relationship is more likely to be causal when variation in physical activity (dependent variable) has been produced by changes in level or intensity of external influences (independent contributory variables), such as exposure to an intervention.

The discipline of epidemiology has developed criteria against which to assess the evidence for a causal relationship.[5] The first is study design, with greatest scientific weight being given to experimental evidence, where a randomized controlled trial design is used.

Next would be evidence from interventions that use quasi-experimental designs,[6] with the next levels of evidence emanating from observational studies, such as cohort (panel) designs. The weakest designs for causal evidence are cross-sectional analytic studies (typically surveys) that "generate hypotheses" and provide measures of association, rather than defining "causal" factors.

Apart from the research design, there are other important factors that need to be considered in assessing the causal nature of any relationship.[5] These factors include:

1. The strength of the association—stronger statistical associations, replicated across studies, tend to point in a causal direction.
2. A temporal sequence is necessary, with exposure to the causal factors preceding the outcome.
3. Stronger causal evidence includes demonstrating a dose–response relationship, with increments in exposure associated with greater outcomes. For example, if single-session advice from a physician impacts positively on physical activity levels among patients, multisession counseling is expected to produce greater effects.
4. Finally, the causal model needs to be conceptually plausible. In disease-oriented epidemiology, biological mechanisms are necessary to explain relationships.[1,2] In the behavioral domain, frameworks or models that describe why and how a program might be efficacious may be necessary.[3]

The logic of causality is fundamental to improving research to understand and influence physical activity. Having defined the concepts of correlation and causation, the next section discusses the influence of other factors that are not directly causal, but may influence observed relationships in physical activity data sets.

## Definitions of Mediators, Moderators, and Confounders: An Epidemiologic Perspective

This section proposes definitions for understanding the factors that intervene between interventions and physical activity behavior change and the factors that can moderate or confound such relationships. The overall logic and elements of causal relationships are important in appraising the evidence on the effects of interventions to increase physical activity. However, it is important to further examine any observed program effects.[7] Are they direct effects, with the intervention program directly producing the changes in physical activity outcome, or are there other influencing variables that need to be considered in better understanding and interpreting any apparent causal relationships? Could the observed associations in the data be due to factors other than exposure to the intervention or identified primary study factor? Could this be an observed association, but not a true causal relationship? These questions underpin the quest for understanding the mechanisms by which physical activity interventions are, or are not, effective. Three conceptually related methodologic ideas are central here: the concept of a mediator, or intervening causal variable; the concept of a moderator or effect-modifier, also known as a statistical interaction; and finally, the concept of a confounder. These terms are defined in the caption of Figure 2.

**Mediators.** A mediator, or intervening causal variable, is on the causal pathway between exposure to the intervention (A, in Figure 2) and program effects or outcomes (shown as C in each panel of Figure 2). There may be a single mediator between the program and the outcome (M1), or a series of cascading mediators (M2, M3) that intervene and are causally related in sequence, between the program and outcome. This does not imply that the entire "causal pathway" requires explanation through B, the mediator, as some of the effect may be direct (from A to C, bypassing any mediator, in Figure 2). However, substantive mediators should be shown to be significant mechanisms through which the program exerts its effects. Relevant statistical approaches include path analytic methods[7] and sequential regression techniques.[8] For example, hypothesized mediators might include social support, perceived physical competence, or use of behavior change strategies.

**Confounders.** A confounder is a predictor of the outcome, but is also associated with exposure. For example, age may confound the relationship between a program and its outcome. Age may be related to the outcome—older people may be less likely to be physically active and thus age is associated with exposure—as older people may be less likely to participate in a program. The confounder will influence the observed association between program and outcomes and distort the true magnitude of effects. Methods for dealing with confounders include matching, stratified analyses, and controlling for them using multivariable analytic techniques.[5] Note that the direction of the "causal arrows" in Figure 2 are important. The proposed confounder needs to be a causal factor for the outcome (B→C), and a factor associated with the program (B→A). Note that if the program "causes" the confounder (the causal direction A→B), then this is not confounding, but a mediator, as A→B→C.

**Moderators ("effect modifiers").** Sometimes the strength of the relationship between a program and outcomes varies according to a third variable. This third variable is known as an effect modifier (or moderator). This is analogous to the concept of statistical interaction, with the association A→C varying across levels of the moderator, B (lower panel, Figure 2). For

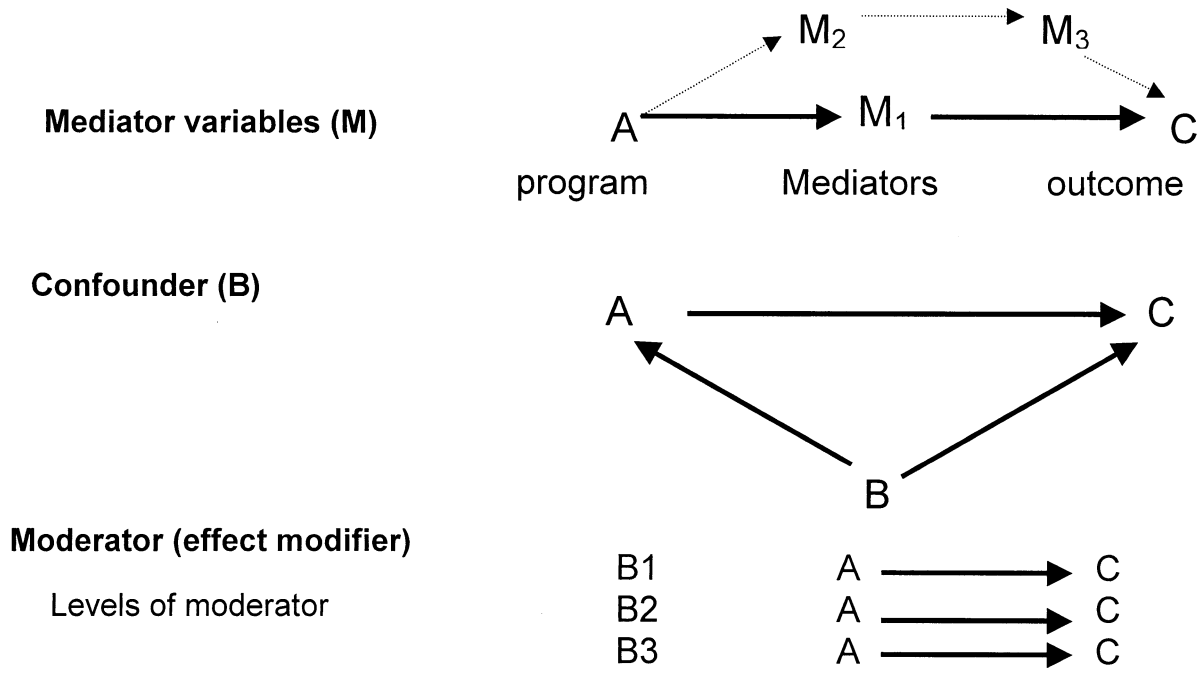



**Figure 2.** Definition of terms. Mediator—an intervening variable that is necessary to complete a cause–effect link between an intervention program and physical activity. Confounder—a confounding variable is associated with the outcome, physical activity, but is also associated with exposure to the program, and will influence the strength of the observed association between program and physical activity. Moderator—an interaction variable that affects the direction, strength, or both of the relationship between an intervention and mediator or mediator and physical activity; stratification by the moderator variable will show different strength relationships between the program and physical activity behavior.

example, the effects of a program may be much greater for men than for women, so that gender-specific effect sizes may be very different from each other, and also different from the overall effect size This is well recognized as an interaction in statistical methods, and is dealt with by including interaction terms in statistical models used to assess program effects, or by stratifying the data by the levels of the moderator, and re-examining effects. In the hypothetical example above, there will be an interaction between gender and the intervention—this is important as it has policy implications for subsequent program use, as the program will be of different effectiveness for men and women. The concept of a moderator is quite different for a confounder: The confounder distorts the observed association, but the associations are similar when stratified at each level of the confounder. On the other hand, a moderator produces different estimates of the association at different levels of the variable.

A hypothetical worked example showing the difference between confounders and moderators is provided in Figure 3. The top three panels demonstrate confounding, where the presence of a third variable, gender, distorts the association between an intervention and the outcome, physical activity levels. For all participants, there appears to be a significant effect favoring the intervention (panel A); when stratified by gender, the effect is no longer present. Furthermore, gender is associated with both the outcome (males are less likely to increase physical activity) and with program exposure (males are half as likely to have attended the program, panel B). Overall, the criteria for confounding are summarized in panel C. The last frame, panel D, shows another hypothetical example, with gender as a potential *moderator*; here the effect of the intervention is different at the two levels of the moderator. For all participants, intervention attendees appear 2.8 times as likely as controls to increase physical activity; however, these effects are different when stratified by gender (the moderator variable), with an even greater effect for males, but a nonsignificant intervention effect for females.

**More complex situations.** Sometimes theoretical variables can operate in different ways in different situations. It may be conceptually easy, for example, in physiologic studies to understand an intervening causal variable or mediator, because it is a biological change leading to disease. For example, it is clear that changes in physiologic mediators are essential in order to explain the protective benefit linking physical activity and reduced heart disease risk. However, mediating pathways are less clear in behavioral research, due to the complex bi-directional relationships among psychosocial variables, environmental variables, and physical activity. For example, if self-efficacy is a mediator in one

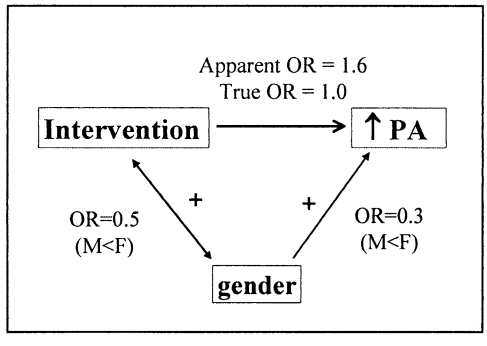
**Panel A: CONFOUNDING I : Is there a different intervention effect on physical activity (PA) observed when stratified by potential confounder ?**

| Group | Allocation | Increase PA (n) | No change (n) | Significance (odds ratio ±95% CI) |
|---|---|---|---|---|
| All participants | Intervention | 514 | 400 | 1.6 (1.3 - 1.9) |
| | Controls | 486 | 600 | |
| Stratify by gender | | | | |
| Males | Intervention | 114 | 200 | 1.0 (0.7 - 1.3) |
| | Controls | 286 | 500 | |
| Females | Intervention | 400 | 200 | 1.0 (0.7 - 1.4) |
| | Controls | 200 | 100 | |

**Panel B. CONFOUNDING II: Is the confounder associated with exposure and with the outcome ?**

| Is potential confounder (gender) associated with the outcome (increased PA) | Increase PA (n) | No change (n) | Significance (odds ratio ±95% CI) |
|---|---|---|---|
| Males | 400 | 700 | 0.3 (0.2 – 0.4) |
| Females | 600 | 300 | |
| Is potential confounder (gender) associated with the exposure (the intervention) | Intervention (n) | Controls (n) | |
| Males | 550 | 550 | |
| Females | 600 | 300 | 0.5 (0.4 – 0.6) |

**Panel C. CONFOUNDING III. Summary of evidence for confounding (diagram)**




**Panel D. MODERATOR EXAMPLE: A hypothetical study with gender as a moderator**

| Group | Allocation | Increase PA (n) | No change (n) | Significance (odds ratio ±95% CI) |
|---|---|---|---|---|
| All participants | Intervention | 130 | 70 | 2.8 (1.8 – 4.2) |
| | Controls | 80 | 120 | |
| Stratify by gender | | | | |
| Males | Intervention | 70 | 30 | 3.5 (1.9 - 6.6) |
| | Controls | 40 | 60 | |
| Females | Intervention | 50 | 50 | 1.5 (0.8 – 2.7) |
| | Controls | 40 | 60 | |

**Figure 3.** Examples of hypothetical intervention results: gender as a confounder (panels A, B, and C) and as a moderator (panel D)

situation, it implies that an exposure to the physical activity program results in a change in self-efficacy that itself results in increases in physical activity. In other situations, self-efficacy could be a moderator (effect modifier). Here, exposure to the intervention program for people at different levels of self-efficacy would produce different effects. For example, those with high self-efficacy may be more likely to change their physical

activity compared to those with low self-efficacy. It would also be possible for self-efficacy to have some confounding aspects, as it could be related to the outcome, physical activity participation, but could also be associated with program participation such that people with high self-efficacy are more likely to participate in the intervention. Thus, in different contexts, self-efficacy could be a mediator, moderator, or confounder.

The process of identifying mechanisms of action is a common part of biological research but is less common in health behavior research.[9] An increased understanding of the mediators of physical activity interventions will provide feedback that can lead to systematic improvements in intervention efficacy. Better understanding of moderators can help tailor interventions to the needs of specific subgroups of people. Greater examination of data for potential confounders can lead to more accurate interpretations about the causal effects of interventions.

## The Role of Studies on the Correlates of Physical Activity

This section reviews the literature on the correlates of physical activity. These should not be considered as causal factors. Nonetheless, research to identify correlates has both practical and theoretical uses. Practically, correlational studies generate hypotheses about possible causal relationships and about potential mediators that can be targeted in intervention studies. Theoretically, correlational studies could test predictions derived from theory and produce results that eventually lead to modifications in theories.

Consistent correlates of physical activity that are identified in cross-sectional or longitudinal studies can then become hypothesized mediating or moderating variables. Cross-sectional studies are an efficient and empirical means of screening many potential correlates.[10] Variables that are consistently uncorrelated with physical activity seem to be poorer choices to target in studies designed to understand or increase physical activity levels.

The literature describing factors that are associated with physical activity in children, adolescents, and adults is large and has been reviewed several times. Sallis et al.[11] recently reviewed about 100 studies of child and adolescent physical activity correlates. The most recent review of adult physical activity correlates reflects the results of approximately 300 studies.[12,13] Both of these reviews provide a critique of the literature and recommend research priorities, so those points are not repeated here.

Table 1 is adapted from the recent literature review[13] and shows the pattern of findings on studies of the correlates of physical activity among adults. For each variable that has been evaluated in multiple studies, the theory or theories connected with the variable have been specified. The main theories used in physical activity research have been the health belief model, theory of planned behavior, social cognitive theory, and the transtheoretical model. For background on these theories, see Glanz et al.[14]

As has been noted previously,[3,12] the fact that there are multiple correlates within each category of variables strongly suggests a very complex causal web. The documentation of intrapersonal, interpersonal, social/cultural, and physical environmental correlates seems to demand a multilevel ecologic approach to understanding physical activity.[12] Only multilevel models may be able to account for the existing data.

The literature on physical activity correlates also can be used to examine the utility of behavioral theories as applied to physical activity. Although several theories have been explicitly used in the design of correlates studies, many studies have been atheoretical. Thus, the literature can be used to both evaluate the extent to which major behavioral theories are empirically supported and to examine the contribution made by variables not connected with any major theory.

Based on Table 1, the number of variables associated with each theory and the number of variables with consistent evidence of association with physical activity were tallied. The percentage of variables supported ranged the health belief model (25%) to the transtheoretical model (100%). The theory of planned behavior (67%) and social cognitive theory (70%) were also highly supported. Thus, only the health belief model failed to receive clear support in the literature on adult physical activity correlates.

The most remarkable finding was the large number of variables that were not associated with a specific theory but were still found to be consistently related to physical activity. No current theory, or even a combination of theories, accounted for 15 variables that were associated with physical activity. This pattern presents a major challenge to behavioral theories. There are several interpretations of this finding. One perspective is that new behavioral theories need to be developed that account for the existing data. Existing theories that do not incorporate so many of these documented correlates seem to be an inadequate basis for understanding the behavior and guiding intervention design. They do provide much of the current framework for understanding physical activity, but theories need to evolve to incorporate emerging empirical data.

There have been previous calls for physical activity-specific theories and models.[13,15] From another perspective, it seems unrealistic to create a theory with dozens of variables, even if they all have empirical support. Even if such a complicated theory could be created, it would be virtually impossible to simultaneously measure all its testable components. Yet a

**Table 1.** Correlates of physical activity in adults and theories associated with each variable[a]

| Determinant | Theory or model associated with each variable | Associations with overall physical activity |
|---|---|---|
| **Demographic and biological factors** | | |
| Age | — | −− |
| Blue-collar occupation | — | − |
| Childlessness | — | + |
| Education | — | ++ |
| Gender (male) | — | ++ |
| Genetic factors | — | ++ |
| High risk for heart disease | — | − |
| Income/socioeconomic status | — | ++ |
| Injury history | — | + |
| Marital status | — | − |
| Overweight/obesity | — | 00 |
| Race/ethnicity (nonwhite) | — | −− |
| **Psychological, cognitive, and emotional factors** | | |
| Attitudes | HBM, TPB | 0 |
| Barriers to exercise/cons | HBM, TPB, TTM | −− |
| Control over exercise | TPB | + |
| Enjoyment of exercise | — | ++ |
| Expect benefits/outcome expectations/pros | SCT, TTM | ++ |
| Health locus of control | — | 0 |
| Intention to exercise | TPB | ++ |
| Knowledge of health and exercise | HBM | 00 |
| Lack of time | — | − |
| Mood disturbance | — | −− |
| Normative beliefs | TPB | 00 |
| Perceived health or fitness | — | ++ |
| Personality variables | — | + |
| Poor body image | — | − |
| Psychological health | — | + |
| Self-efficacy | SCT, TPB, TTM | ++ |
| Self-motivation | — | ++ |
| Self-schemata for exercise | — | ++ |
| Stage of change | TTM | ++ |
| Stress | — | 0 |
| Susceptibility to illness/seriousness of illness | HBM | 00 |
| Value of exercise outcomes | TPB | 0 |
| **Behavioral attributes and skills** | | |
| Activity history during childhood/youth | — | 00 |
| Activity history during adulthood | SCT | ++ |
| Alcohol | — | 0 |
| Contemporary exercise program | — | /0 |
| Dietary habits (quality) | — | ++ |
| Past exercise program | — | + |
| Processes of change | TTM | ++ |
| School sports | — | 00 |
| Skills for coping with barriers | SCT, TTM | + |
| Smoking | — | 00 |
| Sports media use | — | 0 |
| Type A behavior pattern | — | + |
| Decision balance sheet | TTM | + |
| **Social and cultural factors** | | |
| Exercise models | SCT | 0 |
| Past family influences | SCT | 0 |
| Physician influence | SCT | ++ |
| Social isolation | — | − |
| Social support from friends/peers | SCT | ++ |
| Social support from spouse/family | SCT | ++ |
| **Physical environment factors** | | |
| Access to facilities: actual | Eco | + |
| Access to facilities: perceived | Eco | 00 |
| Climate/season | Eco | −− |
| Cost of programs | SCT, Eco | 0 |

*(continued on next page)*

**Table 1.** Correlates of physical activity in adults and theories associated with each variable[a] (continued)

| Determinant | Theory or model associated with each variable | Associations with overall physical activity |
|---|---|---|
| Home equipment | Eco | 0 |
| **Physical activity characteristics** | | |
| Intensity | — | − |
| Perceived effort | — | −− |

++, repeatedly documented positive association with physical activity; +, weak or mixed evidence of positive association with physical activity; 00, repeatedly documented lack of association with physical activity; 0, weak or mixed evidence of no association with physical activity; −−, repeatedly documented negative association with physical activity; −, weak or mixed evidence of negative association with physical activity; —, no data available; HBM, health belief model; TPB, theory of planned behavior; TTM, transtheoretical model; SCT, social cognitive theory; Eco, ecological models.
Note: "Support" is defined as a code of −, −−, +, and ++. Demographic and biological variables are not included in this summary.
[a]Adapted from Sallis and Owen.[13]

different perspective is that physical activity is too complex a behavior to be encompassed by a single theory. Perhaps progress at the current stage of understanding would best be served by a continued application of existing theories supplemented by creative thinking to evaluate influencing variables that are outside of current theories. Consolidation of knowledge into a multidimensional model or set of unified principles may not be possible until sometime in the future.

## Application of Mediator and Moderator Concepts: A Behavioral Science Perspective

This section presents reflections from a behavioral science perspective. The consistent application of mediator and moderator concepts provides a logic to evaluate influencing variables that are not defined within current theories. There are some limitations to studying only the direct outcomes of interventions or naturally occurring variations in environmental or social conditions on behavior.[16] First, if no intervention effect was established, then little knowledge was acquired regarding why a particular strategy was not effective. Second, there was no way to identify which components of the program were efficacious and which were ineffective or possibly harmful. Third, many behavioral interventions may have only indirect effects or produce their effects on proximal or intermediate causal variables.[9] To address these limitations, behavioral scientists studied these "third variables" that define influencing and intervening mechanisms between interventions and physical activity behavior change.

This line of thought is by no means new. In 1928, Woodworth articulated the generic mediation model, or stimulus-organism-response (S-O-R) model, which proposed that the effects of stimuli (environment factors) on behavior are mediated by various processes internal to the organism.[17] More recently, a mediator in behavioral research was defined as a third variable that is necessary to complete the causal process that links physical activity interventions and behavior (see Baron and Kenny[8]). Some cognitive-behavioral researchers have advocated mediator research, arguing that physical activity intervention research "operates predominantly through psychosocial mediating processes or indirect effects."[9] Other behavioral scientists have not embraced intra-individual mediator processes. For example, operant conditioning models postulate that environmental variables, particularly reinforcing and punishing stimuli, have direct effects on physical activity without the need of internal mediating processes.[18]

In the context of this paper, efforts to understand physical activity may extend beyond these behavioral theories alone, although the development of many current physical activity interventions continue to be, at least in part, guided by existing theory. Studying mediating processes or third variables that influence the relationship between interventions and physical activity should allow for the continued application of existing behavioral theories as well as examining the roles of new environmental factors and less theoretically oriented personal and behavioral variables. The recent development of ecologic models provides an example of this. Ecologic models of physical activity behavior posit that changes in the physical environment can have similarly direct effects on behavior that are not necessarily mediated by psychosocial variables within the individuals.[12]

However, it is likely that physical environment influences can also be mediated.[19] For example, installing a walking trail could directly stimulate physical activity, but knowledge of, and perceptions about, the trail also could mediate the effects of the environmental change.

To understand the role of mediation in intervention development further, it is helpful to think about a one-component strategy that targets one mediator. Consider an intervention that manipulates social support for physical activity. A social cognitive approach[20] would lead the interventionist to implement strategies to change social support, to measure implemented social support among the target group, and to analyze the mediating role of perceived social support. It is hypothesized that if the intervention did not increase a

participant's perceived social support, then the intervention would not have an effect. Furthermore, the mediator could be used as a proximal outcome indicator in the analyses to determine whether the intervention actually changed the chosen mediator. Further analyses could evaluate whether change in social support was related to change in the outcome and whether social support explained the intervention's effects on physical activity.[8] For interventions designed to alter reinforcement contingencies or physical environments, the degree of implementation of behavior change interventions will also affect the observed outcomes. Therefore, environmental variables may be defined as process variables and may best be considered the extent to which the intended changes are actually carried out. For example, the extent to which parents actually reinforce children for decreasing television viewing or the length of walking trails constructed are the interventions. However, measures of these variables are also process variables. It may also be useful to assess the factors that affect the implementation of those variables.[21] If an intervention is not well implemented, it may not affect the mediators, so the outcomes will not be achieved. Although not often studied, "process evaluation" is the measurement and analysis of an intervention as it is being implemented and assessment of factors affecting that implementation.[21] There is growing recognition of the importance of understanding intervention process.[22,23] For example, attendance at sessions, proportion of the intended material covered by the instructor, and use of behavior change materials are important process variables. In community programs, process variables might include participation of gatekeepers in meetings and progress in achieving subgoals leading to the environmental change.

A behavioral perspective can also be used to assess the role of moderators. For example, stage of change is one way to categorize individuals.[24] It may be that stage of change is a moderator of the relationship between interventions and behavior. For example, some cognitive mediators may be important early in the change process at low levels of physical activity readiness, and other mediators may be effective later in the change process at higher levels of physical activity readiness. As another example, self-efficacy may not have a large causal role in intending to be active but may become more important when adopting physical activity.

Baranowski et al.[9] proposed that there can be a range of mediating processes (psychosocial variables, such as outcome expectations, self-efficacy, and modeling). In addition, there can be cascading sequences of mediating processes, such as a child's self-efficacy for asking to be active after school that affects the likelihood that the child will ask to be active after school at home, which increases the likelihood that a parent will play with the child at home[9] (see panel A, Figure 2).

The key issue is how to study behavior change processes across interventions that may be distal from behavior change. The most common occurrence of this problem is in community interventions, when the intervention may be applied at a level of organization higher than the individual, such as schools or work sites or communities. Such community interventions may target organization levels or gatekeepers such as health professionals or teachers. This expresses the hope that a change in physical activity policy (e.g., all middle school students should have daily physical education) and behavior change of gatekeepers will cascade down to where the child in the school is exposed to an environment that promotes five periods of required physical activity weekly.

In the context of multilevel interventions (which is often a reality for physical activity interventions), mediating variables can include implemented environmental changes and personal psychosocial representations intervening between environments and behavior. To understand the effects of multilevel interventions, researchers should map the levels of intervention and then analyze mediators and outcomes that are appropriate at each level.[7,25] For example, in community-based interventions where researchers target changing physical and social environments, the intervention is often applied at the level of community leaders. When the intervention is applied at the community leader level, the mediator of this level is community leader behavior (e.g., social environmental change). The effect of the leader behavior could be studied in relation to psychosocial mediators at the individual level, such as a community resident's perceived social support or access to programs.[26] Thus, interventions at one level (community leader behavior) can cascade to another level (community residents' perceptions) and finally to the individual's physical activity. Although such relations are complex and may be difficult to analyze, multilevel interventions and cascading mediators reflect current conceptualizations of how interventions work.

## Conclusions

This article has focused primarily on definitional issues, with the aim of establishing a clearer conceptual basis for distinguishing between determinants and correlates, and understanding mediators, moderators, confounders, and process variables in physical activity research. We have reviewed the pattern of findings on the relationships with physical activity of variables from the main theories that have been applied to physical activity behavior. In this research literature, the term "determinant" has been used broadly and imprecisely. Thus, simple statistical associations, especially from cross-sectional analyses, should be called "correlates" of physical activity. A mediator was defined as an interven-

ing psychosocial variable that is necessary to complete a cause–effect link between an intervention and physical activity. Process variables are subsets of mediators that describe the extent to which the intervention was actually implemented. A moderator was defined as a variable that affects the direction or strength of the relationship between an intervention and mediator or mediator and physical activity. A confounder is a factor that distorts the observed association between the intervention or study factor and the outcome, but is not an intervening causal variable (mediator). Confounders should be sought and considered in assessing the results of every study, and addressed in the design and analysis phases.[5] One final area for further work is the study of the correlates, determinants, and mediators of physical activity maintenance and adherence. This is beyond the scope of the current paper, but exactly the same concepts and definitions can be applied to this area.

In the previous section, a review of the utility of these concepts of influencing variables was provided from a behavioral science perspective, given that this discipline has led much of the intervention effort in recent decades. Although many behavioral and other theories have been used in the design of correlational and intervention studies, it is apparent that many studies have been atheoretical. There has also been consideration of the extent to which major behavioral theories have been empirically supported by studies of physical activity correlates. The challenge to theorists—that many significant correlates are not connected to any theory—needs to be considered.

The current discussion should help to promote more consistent use of terminology as well as to improve research on the mechanisms through which physical activity interventions exert their effects. Only by understanding the causes of intervention successes and failures can we systematically improve interventions and thus improve public health. This effort is likely to require the development or modification of social-cognitive and behavioral theories, the measurement of additional variables in studies, and the use of unfamiliar statistical techniques (see Mâsse et al.[27]; see also MacKinnon[28] for new approaches to the statistical testing of mediators). Nonetheless, this is a rapidly evolving area of study, and these concepts and methods will continue to improve over time. This article provided some initial definitions and a framework for understanding that will result in better use of theory and explanatory variables; it is hoped that this will lead to more evidence-based and effective physical activity-promoting interventions.

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