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ORIGINAL ARTICLE

Failure of Post-Action Stages of the Transtheoretical Model to Predict Change in Regular Physical Activity: A Multiethnic Cohort Study

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Abstract

Background Predicting variation in meeting recommended levels of physical activity is important for public health evaluation.

Purpose The purpose of this study is to determine the predictive value of stages of the Transtheoretical Model (TTM) for classifying people who meet the US Healthy People 2010 guideline for regular physical activity.

Methods A cohort (N=497) from a random, multiethnic sample of 700 adults living in Hawaii was assessed at 6-month intervals three or more times for 2 years. Latent transition analysis was used to classify people according to TTM stages and separately according to whether they met the guideline. The predictive value of pre- vs. post-action stages was then tested.

Results Stages were more likely to falsely classify people as meeting the guideline than to falsely classify them as not meeting it. Probabilities of predicting 6-month transitions were about 50% for the stable class of meeting the guideline each time and just 25% for transitions between meeting and not meeting the guideline.

Conclusion The TTM post-action stages had limited usefulness in this cohort. Further longitudinal study is needed to determine whether TTM stages can accurately classify transitions from physical inactivity to physical activity below recommended levels.

Keywords Asian American · Native Hawaiian/Pacific Islander · Public health recommendation · Predictive value · Latent transition analysis

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Introduction

The physical activity of many US adults is below levels regarded as sufficient for health promotion. Although three of four adults say they engaged in some form of leisure-time physical activity during the past month [1], less than half participated regularly at the recommended [2] levels of moderate physical activity for at least 30 min five or more days per week or vigorous physical activity for at least 20 min three or more days per week [3, 4]. Insufficient physical activity is more likely among women, minorities, and people having low socio-economic status [5].

These and other estimates of regular physical activity in a population base have been limited to prevalence measures taken at a single point in time. Surveillance systems that estimate point-prevalence can detect group trends in a population, but they do not provide measures of inter- and intra-individual change. Measuring whether and in what way people vary across time in meeting recommended levels of physical activity is a prerequisite to identifying factors that might be modified to increase the rate of meeting physical activity guidelines. We are unaware of studies that have done this in a population base. In this report, we describe periodic (i.e., every 6 months) change across 2 years in the rate of meeting the US Healthy People 2010 recommendation for regular physical activity [2] in a cohort of adults living in Hawaii.

We were especially interested in whether post-action stages of the Transtheoretical Model (TTM) of physical activity behavior change would have positive predictive value for accurately classifying people as meeting or not meeting the physical activity recommendation. The TTM theorizes that people use cognitive and behavioral processes to move between progressive stages of change from building intention to subsequent action (i.e., adoption or current participation) and maintenance (i.e., continued participation for 6 months or more) of regular physical activity [6]. These stages have been widely used to guide observational studies and physical activity interventions but with mixed success [7]. Critical reviews of the usefulness of the TTM for designing physical activity interventions [8, 9] have refocused attention on the need to determine whether the original TTM stages are valid for understanding physical activity [10–12]. Aside from the need to also consider whether TTM processes are valid [7, 10, 13] and useful for understanding change in physical activity [14, 15], much of the controversy about application of the TTM to physical activity has involved conceptual and measurement confusion about: (1) defining and testing transitions within pre-action motivational stages (e.g., awareness and intentions about becoming physically active) and within post-action motivational stages (e.g., starting and then sustaining physical activity) [12, 16] and (2) ensuring congruence between binary stages of vaguely defined physical activity and more direct measures of physical activity, which is an inherently complex behavior.

Physical activity differs widely according to type and intensity of effort [17, 18] and is typically measured as a continuous variable (e.g., even the most sedentary able-bodied people can be ranked according to daily physical activity) [19]. Binary classification of physical activity participation according to a public health standard homogenizes that variation among people in the types and intensities of their participation. Likewise, evidence on stage theory applied to many health behaviors suggests that stage models are most valid when they classify people according to whether the behavior has been performed (i.e., classifying people as being in either a pre- or a post-action stage) [12]. Hence, our purpose here was to classify people into pre- vs. post-action TTM stages and then determine whether that binary classification had value for predicting a binary physical activity outcome, namely, whether people in those stages met or did not meet the Healthy People 2010 guideline for regular moderate or vigorous physical activity.

Tests of the validity of TTM stages for physical activity have been mostly limited to cross-sectional comparisons of mean physical activity scores between stages [18, 20, 21]. A few studies examined the classification agreement between TTM stages and criterion levels of physical activity, but they also used cross-sectional research designs and varying definitions of physical activity levels and stages that were not fully consistent with each other [22–24]. Hence, it is not yet known whether the TTM stages are useful for predicting whether people meet a recommended level of regular physical activity at a single point in time or during transition across time. Accurate prediction of change in behavior is the fundamental assumption behind the usefulness of the TTM stages for understanding adherence (i.e., the post-action stages), rather than merely adoption (i.e., the pre-action stages) of physical activity. As far as we know, however, this assumption has not been tested in a longitudinal population cohort.

The main purposes, therefore, of the study we report here were to determine: (1) the positive predictive value of the post-action stages of the TTM for classifying whether people met the US Healthy People 2010 guideline for regular participation in either moderate or vigorous physical activity [2] and (2) whether transitions across time between the TTM pre- and post-action stages would have positive predictive value for classifying transitions across time between meeting or not meeting the guideline.

To optimize the potential for accurate prediction, we defined regular physical activity to the participants in a similar way for TTM staging as for the primary measure of physical activity behavior. To corroborate the results, we used two validated measures of physical activity that were feasible for administration by interview in a population-based survey and that provided estimates of weekly time spent in moderate or vigorous physical activity during the past 7 days or during a usual week.

Methods

Participants

This longitudinal cohort study used a random sample of 700 adults (18 years or older) from Hawaii who were assessed every 6 months for 2 years. A cohort of 497 participants completed the measures at least three times and was used for analysis; 394 completed all the measures five times. The cohort was not demographically different from the total random sample (see Tables 1 and 2).

Table 1 Participant characteristics at baseline

Characteristic	Sample (*N*=700)	Cohort (N=497)
	Mean (SD)	Mean (SD)
Age	47.0 (17.1)	49.7 (16.7)
BMI	25.9 (5.6)	25.9 (5.8)
Education (years)	14.6 (2.8)	15.0 (2.9)
Median household income	$40–50,000/year	$40–50,000/year
	Frequency (%)	Frequency (%)
Gender		
Male	256 (36.6)	177 (35.6)
Female	438 (62.6)	316 (63.6)
Missing	6 (0.9)	4 (0.8)
Race/Ethnicity		
Caucasian	261 (37.3)	198 (39.8)
Pacific Islanders	155 (22.1)	96 (19.3)
Asian	218 (31.1)	158 (31.8)
Other	60 (8.6)	40 (8.0)
Missing	6 (0.9)	5 (1.0)
Hispanic/Latino	71 (10.1)	41 (8.2)
Marital status		
Married	360 (51.4)	263 (52.9)
Never married	156 (22.3)	94 (18.9)
Widowed	45 (6.4)	40 (8.0)
Divorced/separated	103 (14.7)	72 (14.5)
Living with partner	34 (4.9)	26 (5.2)
Missing	2 (0.2)	2 (0.4)

Procedures

The questionnaire was programmed into a computer-assisted telephone interview system by a local survey firm. Prior to survey administration, the questionnaire was pilot-tested for interpretability and ease of administration. Participants were recruited using random digit dialing procedures with a maximum of three call attempts per household including at least 1 week and one weekend day attempt. A total of 4,392 calls made by random digit dialing resulted in contact, of which 2,785 calls (63.41%) reached eligible households and 1,607 calls reached ineligible households (pagers, nonresidents, non-English speakers). A qualified individual whose birthday was closest to the date of the phone call was asked to participate. Trained interviewers informed potential participants that they would receive a $10 incentive per interview, with $25 for the last one, if they agreed to participate in 30-min interviews regarding their physical activity over 2 years. The survey firm recruited 700 participants (a 25.13% recruitment rate= recruited/eligible households). Informed consent ensuring privacy and confidentially was obtained from participants. The University of Hawaii Institutional Review Board approved all procedures.

Table 2 Physical activity according to TTM stages at baseline

Characteristic	Sample (*N*=700) Mean (SD)	Cohort (*N*=497) Mean (SD)
TTM stages (% of participants)		
IPAQ MET-min×week^{-1}		
Pre-action (28%)		
Moderate	889 (1360)	842 (1294)
Vigorous	744 (1718)	684 (1659)
Action (14%)		
Moderate	895 (1090)	831 (971)
Vigorous	1467 (2176)[a]	1388 (1936)[a]
Maintenance (58%)		
Moderate	1354 (1389)[ab]	1275 (1296)[ab]
Vigorous	2006 (2475)[a]	1693 (2109)[a]
GLTEQ MET×week^{-1}		
Pre-action (28%)		
Moderate	11.7 (11.9)	11.5 (11.7)
Vigorous	8.3 (14.5)	7.1 (13.2)
Action (14%)		
Moderate	17.8 (11.2)[a]	17.7 (11.0)[a]
Vigorous	19.5 (19.5)[a]	17.1 (18.3)[a]
Maintenance (58%)		
Moderate	21.5 (10.7)[ab]	21.5 (10.8)[ab]
Vigorous	28.7 (19.8)[ab]	26.9 (19.9)[ab]

Stage proportions (%) were the same at baseline in the total sample and the cohort

TTM Transtheoretical Model; *BMI* body mass index (weight(kg)/ height (m)^2); *IPAQ* International Physical Activity Questionnaire ; *GLTEQ* Godin Leisure-Time Exercise Questionnaire; *MET* metabolic equivalent

[a] Bonferroni contrasts ($p<.05$)>pre-action

[b] Bonferroni contrasts ($p<.05$)>action

Measures

Self-reported demographics included gender, age, race/ ethnicity, years of education, household income, marital status, height, and weight. Stages were assessed using a standard staging algorithm [25, 26] that defined current participation in regular moderate or vigorous physical activity in a way consistent with the types and level of participation specified by US Healthy People 2010 [2]. The primary measure used to assess physical activity was the International Physical Activity Questionnaire (IPAQ) short form [27]. Because of the imprecision of self-report measures of physical activity, the Godin Leisure-Time Exercise Questionnaire (GLTEQ) [28] was used as a secondary measure to corroborate the results obtained using the IPAQ. See “Appendix 1” for Interview Definitions.

The IPAQ records physical activity as hours and additional minutes of participation during the past 7 days in activities rated according to multiples of metabolic equivalents (METS) expressed as MET-min × week^{-1}. It assesses frequency and duration of moderate (four METS) and vigorous (eight METS) physical activity, appropriate for categorization of individuals as meeting public health guidelines for sufficient regular physical activity. The IPAQ has acceptable measurement properties for monitoring population levels of physical activity among 18- to 65-year-old adults in diverse settings. Studies conducted in 12 countries on six continents using standardized methods indicate that IPAQ questionnaires yield repeatable data (Spearman's rho ~ 0.80). Criterion validity judged against accelerometry is comparable to other self-report measures (a median validity coefficient of rho ~ 0.30) [27, 28]. The “usual week” and “last 7 days” reference periods perform similarly, and the reliability of the self-administered form is similar to the telephone interview [27].

The GLTEQ expresses physical activity as METS × week^{-1}. It was modified for this study to assess the number of days in a usual week spent doing moderate activity (five METS) and strenuous activity (nine METS) for at least 30 min/day total. GLTEQ scores correlate 0.32 with accelerometer counts and have acceptable test–retest reliability (>0.80 across 1 month) for assessing strenuous exercise among adults aged 20 to 59 years old [28, 29].

Reliability and criterion validity for the IPAQ and the GLTEQ are comparable to other self-report measures of physical activity [27, 29, 30]. Results using the IPAQ are presented in detail, while concurrent results using the GLTEQ are summarized for comparison.

Analysis

Latent Transition Analysis

Participants in the cohort were first classified according to pre-action stages (i.e., precontemplation, contemplation, or preparation) or post-action stages (i.e., action or maintenance) from the TTM and then separately classified according to not meeting or meeting the public health guideline for regular (i.e., moderate or vigorous) physical activity [2] at each of the five time points using latent transition analysis (LTA) performed in M*plus* 5.1 [31]. Full information maximum likelihood (FIML) estimation was used to replace missing data. FIML yields accurate fit indices and parameter estimates with up to 25% simulated missing data [32]. LTA provides Bayesian probability estimates of participants' movement between discrete latent classes. At each subsequent 6-month assessment, we tested the probabilities that: (a) those who transitioned positively from pre- to post-action TTM stages would also transition from not meeting the guideline to meeting it and (b) whether those who transitioned negatively from post- to pre-action TTM stages would transition negatively from meeting the guideline to not meeting it.

Sensitivity and Specificity Analyses

Agreement between the stage membership (i.e., action or maintenance vs. pre-action stages) and meeting vs. not meeting the guideline for regular physical activity was described using standard diagnostic estimates [33], including sensitivity (true positives/(true positives + false negatives)) and specificity (true negatives/(true negatives + false positives)) analyses. Because sensitivity and specificity and, thus, the positive likelihood ratio (sensitivity/1−specificity), do not indicate the predictive value of a test when the prevalence of the outcome varies, we used Bayes' theorem to estimate the posttest odds of accurate classification: the likelihood ratio times the pretest odds (i.e., prevalence of meeting the guideline/1−prevalence). The positive predictive value, or probability of accurate classification (odds/1+odds), of stages was then derived (i.e., true positives/true positives+false positives). The negative likelihood ratio (1−sensitivity/specificity) and negative predictive value (true negatives/true negatives+false negatives) were also computed to estimate the probability that pre-action stages would predict not meeting the guideline and the negative posttest probability (1−negative predictive value) that people in the pre-action stages would meet the guideline.

Multinomial Logistic Regression Analysis

Multinomial logistic regression analysis using maximum likelihood estimation was performed with SPSS 15.0 to determine the likelihood that the pattern of TTM stage membership (i.e., action or maintenance vs. pre-action stages) could accurately predict the pattern of meeting or not meeting the physical activity guideline at each 6-month assessment while adjusting for demographic covariates that were associated with classification accuracy. Statistical significance of likelihood ratios and goodness of model fit were tested by χ^2 tests [34]. Strength of association was estimated using the Nagelkerke pseudo R^2 [35].

Based on results of the LTA, participants were placed in one of four stage classes at each transition: (1) pre-action-to-pre-action; (2) post-action-to-pre-action; (3) pre-action-to-post-action; (4) post-action-to-post-action. Participants were similarly placed in one of four discrete LTA classes of meeting or not meeting the physical activity guideline at each 6-month transition period (e.g., from baseline to 6-month assessment, from 6- to 12-month assessment, etc.): (1) not-meeting-to-not-meeting; (2) meeting-to-not-meeting; (3) not-meeting-to-meeting; (4) meeting-to-meeting. The meeting-to-meeting classification (i.e., those who remained in post-action stages) was the reference for all logistic odds ratios.

The following variables were included as covariates in the logistic models: gender, age (<50≥ years); race (Hawaiian/Pacific Islander vs. White; Asian vs. White;

multiethnic vs. White); education (<15≥ years); median annual household income (≤$40,000–50,000>); marital status (married or living with partner vs. widowed, separated/divorced, or never married); BMI (<25≥). All logistic models were adjusted for gender and other significant ($p<.05$) covariates.

Results

Latent Transition Analysis: Stages and Meeting the Physical Activity Guideline

Across the 2-year period of the study, 51% of the cohort was classified in the action or maintenance stages at all five time points, while only 6% were always classified in pre-action stages. In contrast, about 18% of the cohort met the 2010 public health guideline for regular physical activity at all 6-month assessments when physical activity was measured by the IPAQ, while 24% never met the recommended level. The corresponding rates were 24% and 15% when physical activity was measured using the GLTEQ.

Stages

At baseline, 73% of the cohort was in a post-action stage (14% in action and 59% in maintenance). Those proportions were similar at each subsequent 6-month assessment (76–78%: action, 11–14%; maintenance, 59–67%). At the first 6-month transition, there was an 86% probability that people would remain post-action if they had been post-action at baseline and a 47% chance that they would be post-action if they had been pre-action at baseline. Those probabilities were similar at each subsequent 6-month transition, ranging from 86% to 90% and 37% to 47%, respectively. Data are available upon request. On average, the probability was 3.3 times greater that participants would transition from pre- to post-action stages (mean=43%) than from post- to pre-action stages (mean=13%; $z=10.45$, $p<.001$).

IPAQ

Forty-six percent of the cohort met the recommended level of regular physical activity at baseline. That point-prevalence was similar at each subsequent 6-month assessment (40–50%). There was a 61% probability that people would meet the guideline at the 6-month transition if they had met it at baseline and a 24% chance of meeting the guideline at 6 months if they had not met it at baseline. Data are available upon request. Those probabilities were similar at each subsequent 6-month transition, ranging from 68% to 73% and 27% to 32%, respectively. On average, the probability that participants would transition from meeting the guideline to not meeting it (mean=32%) was similar to the probability that they would transition from not meeting the guideline to meeting it (mean=29%).

GLTEQ

Fifty-six percent of the cohort met the recommended level of regular physical activity at baseline. That point-prevalence was similar at each subsequent 6-month assessment (49–60%). There was a 68% probability that people would meet the guideline at the 6-month transition if they had met it at baseline and a 27% chance of meeting the guideline at 6 months if they had not met it at baseline. Data are available upon request. Those probabilities increased to about 74% and 36% to 40%, respectively, at subsequent 6-month transitions. On average, the probability that participants would transition from meeting the guideline to not meeting it (mean=28%) was similar to the probability that they would transition from not meeting the guideline to meeting it (mean=35%).

Diagnostic Analysis: Cross-Sectional Results

The sensitivity and specificity analyses indicated that people were about 40% to 50% more likely to be in either the action or maintenance stages at each 6-month assessment if they met the public health guideline for regular participation in either moderate or vigorous physical activity than if they did not meet the guideline. Likelihood ratios for meeting the guideline (i.e., sensitivity/1−specificity) ranged from 1.35 to 1.50 (mean=1.43) when physical activity was measured by the IPAQ and from 1.43 to 1.62 (mean=1.53) when it was measured by the GLTEQ. In contrast, people were four times more likely to be in a pre-action stage if they did not meet the guideline at each assessment than if they did meet it. Likelihood ratios for not meeting the guideline (i.e., specificity/1−sensitivity) ranged from 2.6 to 5.9 (mean=4.0) when physical activity was measured by the IPAQ and from 3.6 to 5.0 (mean=4.0) when it was measured by the GLTEQ.

Based on the observed point-prevalence of meeting the guideline at each assessment, the probability of an accurate classification (i.e., the positive predictive value) averaged 60% (range was 48% to 71%). Data are available upon request. Probabilities were about 75% to 85% that people who did not meet the guideline at each assessment were in pre-action according to the staging algorithm (negative predictive values ranged from .71 to .79 (mean=.75) and from .75 to .94 (mean=.85)) when physical activity was measured by the GLTEQ or the IPAQ, respectively. Inversely, 15% to 25% of people who were in a pre-action stage met the guideline (i.e., 1−negative predictive value). In contrast, only 55% to 65% of people who met the guideline at each assessment were in the action or maintenance stages. Positive predictive values ranged from .48 to .60 (mean=.55) when physical activity was measured by the IPAQ and .58 to .71 (mean=.65) when it was measured by the GLTEQ.

Diagnostic Analysis: Longitudinal Results

The positive predictive value and the sensitivity of the post-action stages for predicting whether people met the physical activity guideline across the four transition periods were low to medium. Tables 3, 4, 5, and 6 present the results when physical activity was measured by the IPAQ. Positive predictive values for classifying the meeting-to-not-meeting and not-meeting-to-meeting classes ranged from .15 to .35 for the IPAQ and .24 to .43 for the GLTEQ. Ranges for classifying the meeting-to-meeting class were .40 to .48 for the IPAQ and .50 to .61 for the GLTEQ. The positive predictive values of the pre-action stages for classifying the not-meeting-to-not-meeting class ranged from .72 to .82 for the IPAQ and .64 to .73 for the GLTEQ. Likewise, the sensitivities of the pre- and post-action stages were low (range=.13 to .37), except for classification of the meeting-to-meeting class by the post- to post-action stage transition (range=.88 to .92 for IPAQ and .85 to .91 for GLTEQ).

Multinomial Logistic Regression Analysis

Predicting Transitions: IPAQ

The logistic model for the first transition period (i.e., baseline to 6-month assessment) was significant (χ^2 (12)= 104.5, $p<.001$) and had acceptable fit (χ^2 (9)=9.8, $p=.366$; $R^2=.21$). Stage (χ^2 (9)=74.2, p<.001) and gender (χ^2 (3)= 23.7, $p<.001$) contributed to the model. Positive predictive value was higher in men than women (50% vs. 33%, $z=2.9$, $p<.01$) for the meeting-to-meeting class. Based on the adjusted model, the probability of being accurately classified by stage was 50% for people who did not meet the guideline each time and 50% for those who met it both times. None of the cases in the transition classes of meeting-to-not-meeting or not-meeting-to-meeting could be classified by the stage model.

The logistic model for the second transition period (i.e., 6- to 12-month assessment) was significant (χ^2 (12)= 121.6, $p<.001$) and had acceptable fit (χ^2 (9)=9.1, $p=.430$; $R^2=.24$). Stage (χ^2 (9)=93.2, $p<.001$) and gender (χ^2 (3)=23.0, $p<.001$) contributed to the model. Positive predictive value was lower in men than women for predicting the not-meeting-to-not-meeting class (58% vs. 86%, $z=2.49$, $p<.01$). Based on the adjusted model, the probability of being accurately classified by stage was 48% for people who did not meet the guideline each time and 50% for those who met it both times. None of the cases in the transition classes of meeting-to-not-meeting or not-meeting-to-meeting could be classified by the model.

The logistic model for the third transition period (i.e., 12- to 18-month assessment) was significant (χ^2 (15)= 147.7, $p<.001$) and had acceptable fit (χ^2 (30)=33.2, $p=.316$; $R^2=.28$). Stage (χ^2 (9)=119.7, $p<.001$), gender (χ^2 (3)=9.2, $p=.026$), and education level (χ^2 (3)=15.8, $p=.001$) contributed to the model. Positive predictive value was lower in people with less education for the not-meeting-to-not-meeting (16% vs. 83%, $z=1.68$, $p<.01$) and the meeting-to-not-meeting (28% vs. 58%, $z=2.54$, $p<.01$) classes and lower for men (64%) than women (84%) for the not-meeting-to-not-meeting class. Based on the adjusted model, the probability of being accurately classified by stage was 54% for people who did not meet the guideline each time and 56% for those who met it both times. None of the cases in the transition classes of meeting-to-not-meeting or not-meeting-to-meeting could be classified by the model.

The logistic model for the fourth transition period (i.e., 18- to 24-month assessment) was significant (χ^2 (15)= 143.7, $p<.001$) and had acceptable fit (χ^2 (30)=37.3, $p=.169$; $R^2=.28$). Stage (χ^2 (9)=117.4, $p<.001$), gender (χ^2 (3)=9.0, $p=.029$), and education level (χ^2 (3)=14.3, $p=.003$) contributed to the model. Positive predictive value for the not-meeting-to-not-meeting class was lower in people with less education (18% vs. 86%, $z=5.86$ $p<.01$) and for men than women (69% vs. 89%, $z=1.75$, $p<.05$) for predicting the not-meeting-to-not-meeting class. Based on the adjusted model, the probability of being accurately classified by stage was 57% for people who did not meet the guideline each time and 53% for those who met it both times. Probabilities for the transition classes of meeting-to-not-meeting or not-meeting-to-meeting were not good estimates because so few cases could be classified by the model.

Predicting Transitions: GLTEQ

Similar effects of stage and gender, but no effect of education level, were observed across transitions as those that were found when physical activity was measured by the IPAQ. Across the adjusted models and transitions, the probability of being accurately classified by stage ranged from 36% to 64% for people who did not meet the guideline each time, 0% to 27% for those who had met the guideline at the prior assessment but not at the subsequent assessment, 0% to 45% for those who met the guideline at the subsequent but not at the prior assessment, and 51% to 90% for those who met the guideline both times.

Discussion

Post-action TTM stages defined according to the US Healthy People 2010 guideline for regular participation in either moderate or vigorous physical activity had limited

Table 3 Classification agreement (95% CI) between transitions in pre- and post-action stages and transitions in participation at the 2010 public health guideline for regular physical activity measured at baseline and 6-month time point by the International Physical Activity Questionnaire (*N*=497)

Physical activity guideline: baseline to 6-month			
Stages			Predictive accuracy
	Not-met-to-not-met		
Pre-action-to-pre-action	53 True positives	21 False positives	PPV=.72 (.61, .82)
Pre-action-to-post-action	155 False negatives	268 True negatives	NPV=.63 (.59, .68)
	Sensitivity=.26 (.20, .31)	Specificity=.93 (.90, .96)	NLR=.80 (.74, .88)
			PLR=3.51 (2.19, 5.63)
	Met-to-not-met		
Post-action-to-pre-action	13 True positives	33 False positives	PPV=.28 (.15, .41)
Post-action-to-post-action	75 False negatives	376 True negatives	NPV=.83 (.80, .87)
	Sensitivity=.15 (.07, .22)	Specificity=.92 (.89, .95)	NLR=.93 (.85, 1.02)
			PLR=1.83 (1.01, 3.33)
	Not-met-to-met		
Pre-action-to-post-action	9 True positives	53 False positives	PPV=.15 (.06, .23)
Pre-action-to-pre-action	51 False negatives	384 True negatives	NPV=.88 (.85, .91)
	Sensitivity=.15 (.06, .24)	Specificity=.88 (.85, .91)	NLR=.97 (.86, 1.08)
			PLR=1.24 (0.64, 2.38)
	Met-to-met		
Post-action-to-post-action	125 True positives	190 False positives	PPV=.40 (.34, .45)
Post-action-to-pre-action	16 False negatives	166 True negatives	NPV=.91 (.87, .95)
	Sensitivity=.89 (.83, .94)	Specificity=.47 (.41, .52)	NLR=.24 (.15, .39)
			PLR=1.66 (1.48, 1.86)

CI confidence interval; *NPV* negative predictive value; *PPV* positive predictive value; *NLR* negative likelihood ratio (1−sensitivity/specificity); *PLR* positive likelihood ratio (sensitivity/1−specificity)

utility for classifying whether people in the cohort met the guideline at each 6-month interval. The stages were not useful for predicting the 6-month transitions between meeting and not meeting the guideline across 2 years. Sensitivity was acceptably high but specificity was low. Post-action stage membership was more likely to falsely classify people as meeting the guideline when they did not meet it than it was to falsely classify people as not meeting the guideline when they did meet it. Thus, the low predictive value was mainly the case because the post-action TTM stages had poor specificity for accurately classifying whether people met the guideline. Knowing whether someone is in the action or maintenance stage appears to have modest practical or theoretical usefulness for predicting whether the person is currently meeting, or will subsequently meet, the US Healthy People 2010 guideline for regular participation in moderate or vigorous physical activity. Our findings, obtained from longitudinal observations of intra-individual change across 6-month intervals, extend prior cross-sectional findings that people's perceptions of their current stage overestimate their measured physical activity [21].

The positive predictive value of a person's stage was worst when classifying whether people transitioned between meeting the guideline and failing to meet the guideline at each of the 6-month intervals. This observation especially challenges the validity of post-action stages because TTM theory is predicated on transitional change across time. The probabilities of correctly classifying people who failed to meet the guideline at each assessment (mean=78% for IPAQ and 70% for GLTEQ) or met the guideline each time (mean=44% for IPAQ and 56% for GLTEQ) were similar to the cross-sectional analyses. However, probabilities were less than chance of predicting the key transitions which are central to the usefulness of the post-action stages for predicting change in regular physical activity. Probabilities were very low for accurately classifying the negative transition from meeting-to-not-meeting the guideline (mean=23% for IPAQ and 31% for GLTEQ) and the positive transition from not-meeting-to-meeting the guideline (mean=25% for IPAQ and 40% for GLTEQ) across the 2 years. People who stayed in either the post- or the pre-action stages each time had the same odds of transitioning positively or negatively between meeting and

Table 4 Classification agreement (95% CI) between transitions in pre- and post-action stages and transitions in participation at the 2010 public health guideline for regular physical activity measured at 6- and 12-month time points by the International Physical Activity Questionnaire (N=497)

Physical activity guideline: 6- to 12-month			
Stages			Predictive accuracy
	Not-met-to-not-met		
Pre-action-to-pre-action	50 True positives	14 False positives	PPV=.78 (.68, .88)
Pre-action-to-post-action	151 False negatives	282 True negatives	NPV=.65 (.61, .70)
	Sensitivity=.25 (.19, .31)	Specificity=.95 (.93, .98)	NLR=.79 (.73, .85)
			PLR=5.26 (2.99, 9.25)
	Met-to-not-met		
Post-action-to-pre-action	8 True positives	39 False positives	PPV=.17 (.06, .28)
Post-action-to-post-action	41 False negatives	409 True negatives	NPV=.91 (.88, .94)
	Sensitivity=.16 (.07, .13)	Specificity=.91 (.89, .94)	NLR=.92 (.81, 1.04)
			PLR=1.88 (0.93, 3.78)
	Not-Met-to-Met		
Pre-action-to-post-action	15 True positives	41 False positives	PPV=.27 (.15, .38)
Pre-action-to-pre-action	80 False negatives	361 True negatives	NPV=.82 (.78, .86)
	Sensitivity=.16 (.09, .23)	Specificity=.90 (.87, .93)	NLR=.94 (.85, 1.03)
			PLR=1.55 (0.90, 2.68)
	Met-to-met		
Post-action-to-post-action	133 true positives	197 false positives	PPV=.40 (.35, .46)
Post-action-to-pre-action	19 false negatives	148 true negatives	NPV=.89 (.84, .93)
	Sensitivity=.88 (.82, .93)	Specificity=.43 (.38, .48)	NLR=.29 (.18, .45)
			PLR=1.53 (1.38, 1.71)

CI confidence interval; *NPV* negative predictive value; *PPV* positive predictive value; *NLR* negative likelihood ratio (1−sensitivity/specificity); *PLR* positive likelihood ratio (sensitivity/1−specificity)

not meeting the guideline as people who transitioned between pre- and post-action stages.

The probability of accurate classification by a predictive test is dependent upon outcome prevalence. In this cohort, probabilities were each about 30% that people would transition either positively or negatively between meeting and not meeting the guideline at each 6-month assessment. These estimates were based on relatively small numbers of people (i.e., 144–212 each time), though, and might vary in larger population samples. The range in point-prevalence of meeting the guideline was 40% to 50% when physical activity was measured by the IPAQ and 50% to 60% when it was measured by the GLTEQ. These rates are similar to point estimates of the US adult population (i.e., 48% to 49%) based on recent Behavioral Risk Factor Surveillance System surveys [3, 36]. All the rates are higher than a recent estimate from the National Health Interview Survey (i.e., 29%) [4]. We are unaware of comparable longitudinal cohort data on physical activity measured by either self-reports or objective methods. However, because self-reports of physical activity overestimate physical activity levels compared to objective monitoring by accelerometry [37–39], it is likely that the positive predictive value of TTM post-action stages for classifying regular physical activity is even lower than indicated by our results.

Most studies have interpreted cross-sectional differences between TTM stages in mean scores on measures of physical activity as providing evidence for validity of the stages [7, 18, 20, 40, 41]. However, group-level differences do not demonstrate how well the stages perform as predictors of levels of physical activity for an individual. Although mean levels of physical activity in our cohort of adults from Hawaii generally differed according to stages, consistent with past studies, the accuracy of stages for classifying individuals according to whether they met or did not meet public health guidelines for regular physical activity was poor.

Prior studies that examined interpersonal agreement between TTM stages and criterion levels of physical activity reported better classification accuracy than we observed here, but they used cross-sectional research designs and varying definitions of physical activity levels and stages that were not fully consistent with each other [21–23]. None used a staging definition and an equivalent

Table 5 Classification agreement (95% CI) between transitions in pre- and post-action stages and transitions in participation at the 2010 public health guideline for regular physical activity measured at 12- and 18-month time points by the International Physical Activity Questionnaire (N=497)

Physical activity guideline: 12-month to 18-month

Stages			Predictive accuracy
	Not-met-to-not-met		
Pre-action-to-pre-action	58 True positives	16 False positives	PPV=.78 (.69, .88)
Pre-action-to-post-action	139 False negatives	284 True negatives	NPV=.67 (.63, .72)
	Sensitivity=.29 (.23, .36)	Specificity=.95 (.92, .97)	NLR=.75 (.68, .82)
			PLR=5.52 (3.27, 9.32)
	Met-to-Not-met		
Post-action-to-pre-action	11 True positives	31 False positives	PPV=.26 (.13, .40)
Post-action-to-post-action	59 False negatives	396 True negatives	NPV=.87 (.84, .90)
	Sensitivity=.16 (.07, .24)	Specificity=.93 (.90, .95)	NLR=.91 (.82, 1.01)
			PLR=2.17 (1.14, 4.10)
	Not-met-to-met		
Pre-action-to-post-action	9 True positives	28 False positives	PPV=.24 (.11, .38)
Pre-action-to-pre-action	44 False negatives	416 True negatives	NPV=.90 (.88, .93)
	Sensitivity=.17 (.07, .27)	Specificity=.94 (.91, .96)	NLR=.89 (.78, 1.00)
			PLR=2.69 (1.34, 5.40)
	Met-to-Met		
Post-action-to-post-action	164 True positives	180 False positives	PPV=.48 (.42, .53)
Post-action-to-pre-action	13 False negatives	140 True negatives	NPV=.92 (.87, .96)
	Sensitivity=.93 (.89, .97)	Specificity=.44 (.38, .49)	NLR=.17 (.10, .29)
			PLR=1.65 (1.48, 1.83)

CI confidence interval; *NPV* negative predictive value; *PPV* positive predictive value; *NLR* negative likelihood ratio (1−sensitivity/specificity); *PLR* positive likelihood ratio (sensitivity/1−specificity)

criterion level of physical activity that were each consistent with contemporary US public health recommendations for participating in regular moderate or vigorous physical activity [2, 42, 43].

In a telephone survey of a random, cross-sectional multiethnic sample of 2,912 US women aged 40 years or older, Bull and colleagues [22] reported that 20% who were classified as being in one of the post-action TTM stages for vigorous exercise (60% of the sample) did not meet the public health recommendation for regular exercise (i.e., ≥60 min/week). Among women classified in post-action stages for moderate physical activity (86% of the sample), 10% did not meet the recommended level for regular participation in moderate physical activity (i.e., ≥150 min/week). Prevalence of meeting the two criterion levels was about 50% and 80%, respectively. All activities exceeding three METS were aggregated, and regular exercise did not specify vigorous intensity (e.g., ≥6 METS).

In a cross-sectional telephone survey of 346 adults (61.5% female), 18–75 years of age living in a Rhode Island community, stages were defined according to participation in regular exercise performed 3–5 times per week for 20 or more minutes at an intensity that increases breathing and causes sweating [23]. The criterion level of regular physical activity was participation in either mild (i.e., minimal effort, no sweating), moderate (i.e., not exhausting, light sweating), or strenuous (i.e., heart beats rapidly, sweating) exercise ≥3 times in a usual week using the GLTEQ. Fifty-seven percent of the sample was in either the action (7.5%) or maintenance (49.7%) stages. The sensitivity and specificity of the post-action stages for classifying regular participation at mild, moderate, and strenuous levels were 60%, 85%, and 90% and 45%, 60%, and 60%, respectively. Frequencies of true and false positives or prevalence rates of the physical activity levels were not reported. However, if prevalence were estimated at 50%, the positive predictive values would be 52%, 68%, and 69%, respectively.

In a cross-sectional population-based mail survey of Alberta, Canada residents who had Type 1 (N=692) or Type II diabetes (N=1586), action and maintenance stages were referenced to leisure-time activities of a moderate intensity equivalent to a brisk walking pace or faster [24]. Usual weekly moderate and vigorous leisure-time physical activity during the past month was assessed by the GLTEQ.

Table 6 Classification agreement (95% CI) between transitions in membership in pre- and post-action stages and transitions in participation at the 2010 public health guideline for regular physical activity measured at 18- and 24-month time points by the International Physical Activity Questionnaire (*N*=497)

Physical activity guideline: 18- to 24-month

Stages			Predictive Accuracy
	Not-met-to-not-met		
Pre-action-to-pre-action	65 True positives	14 False positives	PPV=.82 (.74, .91)
Pre-action-to-post-action	136 False negatives	282 True negatives	NPV=.68 (.63, .72)
	Sensitivity=.32 (.26, .39)	Specificity=.95 (.93, .98)	NLR=.71 (.64, .78)
			PLR=6.84 (3.95, 11.84)
	Met-to-not-met		
Post-action-to-pre-action	6 True positives	26 False positives	PPV=.19 (.05, .32)
Post-action-to-post-action	41 False negatives	424 True negatives	NPV=.87 (.84, .90)
	Sensitivity=.13 (.03, .22)	Specificity=.94 (.92, .96)	NLR=.93 (.83, 1.04)
			PLR=2.21 (0.96, 5.09)
	Not-met-to-met		
Pre-action-to-post-action	13 True positives	24 False positives	PPV=.35 (.20, .51)
Pre-action-to-pre-action	53 False negatives	407 True negatives	NPV=.88 (.86, .91)
	Sensitivity=.20 (.10, .29)	Specificity=.94 (.92, .97)	NLR=.85 (.75, .96)
			PLR=3.54 (1.90, 6.60)
	Met-to-met		
Post-action-to-post-action	168 True positives	181 False positives	PPV=.48 (.43, .53)
Post-action-to-pre-action	15 False negatives	133 True negatives	NPV=.90 (.85, .95)
	Sensitivity=.92 (.88, .96)	Specificity=.43 (.37, .48)	NLR=.19 (.12, .32)
			PLR=1.59 (1.44, 1.77)

CI confidence interval; *NPV* negative predictive value; *PPV* positive predictive value; *NLR* negative likelihood ratio (1−sensitivity/specificity); *PLR* positive likelihood ratio (sensitivity/1−specificity)

The action and maintenance stages had a sensitivity of 83% to 88% and a specificity of 64% to 69% for classifying whether participants met Canada's physical activity guideline of ≥120 min/week (≥30/day ≥4 days/week) in moderate or vigorous physical activity [24]. About 53% to 54% were in post-action stages (10–11% in action and 43–44% in maintenance), but 42% of the people with Type I diabetes and 36% of those with Type II diabetes met the physical activity guideline. We calculated the respective positive predictive values of the post-action stages as 66% and 58%. Those probabilities are similar to those we observed for meeting the US 2010 public health guideline for moderate or vigorous physical activity at each 6-month assessment in the present cohort when physical activity was measured by the GLTEQ.

Knowing whether the predictive probabilities that we report are good estimates of the true predictive association between TTM stages and meeting US public health recommendations for regular physical activity will require more longitudinal study in other cohorts. Although the sensitivity, specificity, and likelihood ratios for binary tests of association are computationally independent of prevalence, they can vary widely in different populations [44]. That can occur mainly because most binary tests and most outcomes are not truly dichotomous, and their underlying traits can vary in different population segments. Nonetheless, the positive predictive value of the pre- and post-action stages in this cohort did not differ according to socioeconomic characteristics other than gender and education level. The prediction of not meeting the guideline at consecutive 6-month assessments was generally lower in men and in people with less education, but those differences were not consistent across all transitions.

The point prevalence rates of post-action stage membership in this cohort were higher than in the earlier studies and in other population-based estimates [45], whereas the rates of meeting the physical activity criterion varied widely or were not reported in prior cross-sectional studies that used varying definitions and cut-points. The prevalence of action or maintenance stage membership in this cohort varied from about 73% to 78% across the 2 years (Fig. 1). The rate of meeting the public health guideline also differed across time, ranging from 40% to 50% and 49% to 60% depending on the measure of physical activity. Regardless

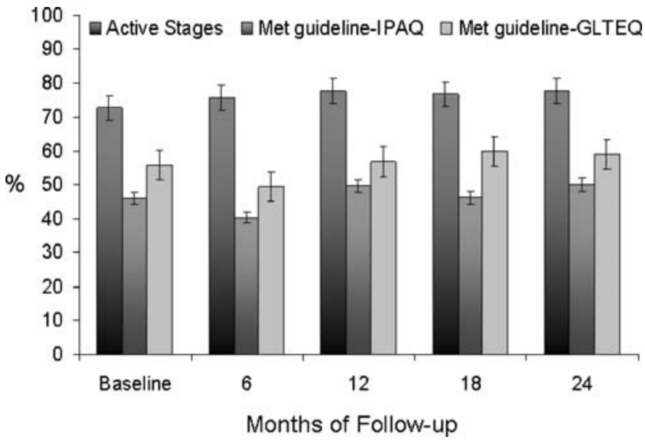

Fig. 1 Point prevalence ±95% CI at each assessment of post-action stages (action or maintenance) and meeting the 2010 public health guideline for regular participation in moderate or vigorous physical activity measured by the *IPAQ* or the *GLTEQ*

of that variation, post-action stage membership systematically overestimated the rate of meeting the guideline. This occurred despite giving clear definitions of regular moderate and vigorous physical activity to the participants, fully consistent with the guidelines, during stage determination.

However, the interview instructions for staging differed in context from the instructions given about physical activity. The staging questions asked for planned physical activity for the purpose of physical fitness, whereas the GLTEQ instructions used exercise examples without specifying their context and the IPAQ instructions specified all physical activity, including work, transportation, recreation, exercise, and sport. Because all physical activity encompasses exercise and planned physical activity for the purpose of fitness, the context of the staging questions might account for pre-action stages falsely classifying people as not meeting the guideline for regular physical activity measured by the IPAQ. However, the differences in context cannot explain why the post-action stages falsely classified people as meeting the guideline, which accounted for the largest misclassification errors (i.e., the low positive predictive value of post-action stages for both IPAQ and GLTEQ measures).

Despite their widespread use in physical activity studies [7, 20], there is virtually no prospective evidence that TTM stages represent true discrete classes rather than an ordinal continuum of physical activity [10, 46–48]. One interpretation of the low predictive values in this cohort is that the action and maintenance stages do not adequately define the distribution of motivational readiness for adherence (e.g., 6-month maintenance) after physical activity is adopted. This interpretation is supported by predictive values that were worse than chance for using stage transitions to classify relatively less prevalent transitions between meeting and not meeting the guideline during the 2-year period of observation.

Another interpretation is that a binary class of meeting or not meeting the guideline for physical activity based on IPAQ or GLTEQ scores obscures graduated transitions from physical inactivity to fully meeting the guideline. Contemporary recommendations for physical activity among US adults vary subtly according to thresholds of intensity (e.g., ≥3 METS [49], three to six METS [42], or four to 5.9 METS [50]), weekly frequency (e.g., most preferably all days per week [49] or ≥5 days per week [2, 42]), and daily duration (e.g., ≥30 min of moderate activity accumulated in one or more sessions each lasting at least 10 min [2, 42, 49] or ≥60 min [51]). These variations permit different interpretations of the recommended total amount of physical activity (i.e., MET-$\min \times \text{week}^{-1}$) and its pattern of accumulation.

For this study, we used the revised recommendation by the US Department of Health and Human Services for Healthy People 2010 [2] (http://www.healthypeople.gov/data/midcourse/pdf/fa22.pdf), estimated by one measure of physical activity that specified sessions of at least 10 min (i.e., the IPAQ) and another measure that specified a 30-min duration (i.e., the GLTEQ). Time reported in moderate or vigorous activities as defined by each measure's instructions was used to classify attainment of the recommended guideline. Agreement between the IPAQ and GLTEQ is moderate-to-substantial (kappa ~ .45 to .70) for cross-sectional comparisons but just fair-to-moderate (kappa ~ .25 to .40) for longitudinal change (R.K. Dishman, unpublished observations, 2009). Therefore, part of the poor performance by TTM stages in this study for accurately classifying people's status of meeting the physical activity guideline or for predicting change in that status across 6-month transitions might be explained by imprecision by the IPAQ and GLTEQ for measuring physical activity [38]. Nonetheless, classification by stages was poor in each case, corroborating that pre- and post-action TTM stages had poor predictive validity regardless of which measure of physical activity was used. These two measures of physical activity use standard methods common to quantitative surveys, but further research is needed to determine the predictive value of the TTM stages for predicting change in physical activity assessed by an objective measure.

Given its prominence in US public health policy [2, 52], binary classification of physical activity participation will continue to have public health importance and require investigation using prospective cohort designs and methods such as latent transition analysis that model intra- and interpersonal change. Because the minimal amount of physical activity needed to increase health and well-being is not yet known [52], additional research is needed to examine whether the TTM stages (or other staging models [11]), including the transition from preparation to action, can accurately classify transitions from physical inactivity (i.e., sedentariness) to light activity or to moderate or vigorous activity that is below the currently recommended levels. However, such research will require parallel changes in the staging definition of physical activity.

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Appendix 1

Interview definition of participation in regular physical activity according to TTM stages [25, 26]:

"We will be talking about regular exercise for the next few questions."

"By regular exercise we mean any *planned* physical activity—for example, brisk walking, jogging, bicycling, swimming, dancing, tennis, rowing, or lifting weights—which is performed to increase physical fitness. Vigorous activity is hard physical effort that makes you breathe much harder than normal and should be performed *3 or more times* per week for *20 or more minutes* per session. Moderate activity is moderate physical effort that makes you breathe somewhat harder than normal and should be performed *30 or more minutes* a day, *5 or more days* per week. Exercise can be vigorous activity or moderate activity."

"So, according to the definition we just went through,

Do you currently engage in regular exercise?
Do you intend to engage in regular exercise in the next 6 months?
Do you intend to engage in regular exercise in the next 30 days?
Have you been exercising regularly for the past six months?"

Interview definition of participation in regular physical activity according to IPAQ [27]:

"I am going to ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport."

"Moderate physical activities make you breathe somewhat harder than normal and may include carrying light loads, bicycling at a regular pace, or doubles tennis. Do not include walking. Again, think about *only* those physical activities that you did for at least 10 minutes at a time. Vigorous activities make you breathe much harder than normal and may include heavy lifting, digging, aerobics, or fast bicycling. Think about *only* those physical activities that you did for at least 10 minutes at a time.

During the last 7 days, on how many days did you do moderate physical activities?"

How much time in total did you *usually* spend *on one* of those days doing moderate physical activities*?*

"Vigorous activities make you breathe much harder than normal and may include heavy lifting, digging, aerobics, or fast bicycling. Think about *only* those physical activities that you did for at least 10 minutes at a time.

During the last 7 days, on how many days did you do vigorous physical activities?

How much time in total did you *usually* spend *on one* of those days doing vigorous physical activities?"

Interview definition of participation in regular physical activity according to GLTEQ [28]

"How many days in a week do you do moderate activity for at least 30 minutes a day total?"

Moderate activity is activity that doesn't make you tired, and makes you sweat just a little.

Some examples would be fast walking, slow bicycling, easy swimming, weight lifting, baseball, softball, tennis, volleyball, hula, or dancing.

"How many days in a week do you do strenuous activity for at least 30 minutes a day total?"

"Strenuous activity is activity that makes your heart beat quickly, and makes you sweat. Some examples would be running, jogging, fast bicycling, aerobic dance, roller blading, paddling, fast swimming, soccer, basketball, football or martial arts."

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