TASK-SWITCHING, FLEXIBLE SELF-REGULATION, AND PHYSICAL ACTIVITY IN YOUNG ADULTS

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by

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INTRODUCTION

Regular physical activity across the lifespan helps prevent numerous chronic diseases such as type 2 diabetes, cardiovascular disease, osteoporosis, obesity, and some forms of cancer (Haskell et al., 2007; Knowler et al., 2002; Warburton, Nicol, & Bredin, 2006; Yusuf et al., 2004). Regular physical activity is defined as 150 minutes per week of moderate-intensity aerobic physical activity, 75 minutes per week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. (US Department of Health and Human Services, 2008). National statistics suggest that physical activity declines across the lifespan, beginning as early as emerging adulthood (Nelson, Story, Larson, Neumark-Sztainer, & Lytle, 2008). Indeed, approximately 40% of young adults (18-24) do not meet national activity guidelines (Center for Disease Control (CDC), 2013). Understanding the factors that predict physical activity success is critical, but even after decades of research, predicting actual behavior change in physical activity remains elusive. The current study sought to improve our understanding of successful physical activity maintenance by exploring a novel aspect of executive function and self-regulation: flexibility. I propose that mental flexibility and flexible self-regulatory behaviors may help explain why some individuals are better at enacting their physical activity goals than others.

The Intention-Behavior Gap in Physical Activity

One of the reasons behavior change in physical activity has been relatively intractable is that people’s intentions and subsequent behavior often do not align.
Traditional health behavior theories such as the Theory of Reasoned Action (TRA; Fishbein & Ajzen, 1975), Theory of Planned Behavior (TPB; Ajzen, 1991), and the Health Belief Model (Rosenstock, 1974) focus on the importance of motivational factors in behavior change, assuming that the same factors which produce changes in intention will produce changes in behavior. However, recent meta-analyses demonstrate that simply increasing intentions produces only small effects on subsequent physical activity (Rhodes & Dickau, 2012; Webb & Sheeran, 2006). Thus, a growing body of recent research has sought to understand and address the gap between intentions and behavior (e.g., Gollwitzer & Sheeran, 2006; Mann, de Ridder, & Fujita, 2013; Sniehotta, Schwarzer, Scholz, & Schüz, 2005).

**Executive Function and the Intention-Behavior Gap**

One possible explanation for why people fail to enact their intentions is that they lack the self-regulatory capacity needed to achieve their goals. Temporal Self-regulation Theory (TST; Hall & Fong, 2007) proposes that people’s capacity to self-regulate may play an important role in determining whether or not they will behave according to their intentions. Self-regulatory capacity is comprised of the factors that may affect a person’s ability to effortfully regulate their behavior, and is most often operationalized with measures of executive functions (Hall & Fong, 2007). Executive functions are a “set of general-purpose control mechanisms, often linked to the pre-frontal cortex of the brain, that regulate the dynamics of human cognition and action” (Miyake & Friedman, 2012, p. 8). According to TST, those with stronger executive functions should show a stronger relationship between their intentions and behaviors than those with weaker executive
functions (Hall & Fong, 2007). Using latent variable modeling, researchers have found that tasks of executive function tend to group together into three latent categories: updating, shifting, and inhibition (Friedman et al., 2008; Miyake & Friedman, 2012). In the context of TST, inhibition, or inhibitory control, has been studied more extensively than either updating or task-switching.

Inhibitory Control. Inhibitory control is the ability to inhibit dominant, automatic, or prepotent responses (Miyake et al., 2000), and is typically measured with either a Go/NoGo task (Allan, Johnston, & Campbell, 2011; Collins & Mullan, 2011; Hall, Fong, Epp, & Elias, 2008; Hall, 2012) or the Stroop task (Allan, Johnston, & Campbell, 2008; Hall, 2012; Mullan, Wong, Allo, & Pack, 2011). These measures assess a person’s ability to deliberately and quickly override the dominant response (Miyake & Friedman, 2012). Findings on the effects of inhibitory control on health behaviors are somewhat mixed. Hall (2012) found that inhibitory control (measured with the Go/NoGo and Stroop task) predicted lower consumption of fatty foods across a two week period, but Allan and colleagues (2011) found in one study that inhibitory control (measured with the Go/NoGo task) did not explain unique variance in the intention-behavior gap, and in another study (2011) that only inhibitory control measured with the Stroop task, not the Go/NoGo task, predicted variance in the intention-behavior gap. Wong and Mullan (2009) found that planning ability, but not inhibitory control (measured with the Go/NoGo task), predicted greater breakfast consumption. Empirical support for an association between inhibitory control and physical activity is limited but
promising. Specifically, research shows that inhibitory control, measured by a Go/NoGo task, moderates the intention-behavior relationship in physical activity (Hall et al., 2008).

One mechanism by which inhibitory control may predict better goal attainment is active or effortful inhibition of automatic, prepotent, or habitual behaviors (Hofmann, Schmeichel, & Baddeley, 2012; Logan, Schachar, & Tannock, 1997). For example, researchers have found that among people with high automatic affective reactions to candy, those with better inhibitory control ate less candy in a subsequent task than those with poorer inhibitory control (Hofmann, Friese, & Roefs, 2009). Essentially, those with high inhibitory control were able to override their prepotent response of eating candy, while those with low inhibitory control were not. However, the ability to inhibit automatic responses in a controlled lab setting may not accurately reflect self-regulatory success in real world settings. Indeed, in a recent review of self-regulation of health behaviors, effortful inhibition was identified as a potentially problematic self-regulatory strategy due to its drain on conscious resources (Mann et al., 2013). This suggests at the very least that other executive functions may be important factors in successful self-regulation.

**Updating and Working Memory Capacity.** Updating refers to the ability to keep information in an active and retrievable state and to keep that information shielded from distractions (Hofmann et al., 2012). The construct of updating is closely related to working memory capacity (Baddeley, 1992; WMC, Hofmann et al., 2012; Smith & Jonides, 1997). Typical measurement involves tasks which require individuals to hold information in memory while performing other tasks, and then recall that information at a
later time. For example, in the keep track task, an individual is presented with a series of words belonging to different categories and upon completion must recall the last item presented from different categories (Friedman et al., 2008; Miyake et al., 2000). To the author’s knowledge, no studies of TST have examined the unique effects of WMC on the intention-behavior relationship.

Despite the dearth of research within the TST, a number of mechanisms may explain why WMC would predict higher levels of goal attainment. First, WMC is associated with shielding goal-relevant processes from automatic processes (Barrett, Tugade, & Engle, 2004; Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008). For example, Hofmann and colleagues (2008) found an interaction between WMC and automatic attitudes toward candy; among those with very positive automatic attitudes toward candy, consumption of candy was lower among those with high WMC. Additionally, WMC predicted lower candy consumption among those with strong goals to forego sweets. WMC has also been linked to active representation of goals, attention (Unsworth, Schrock, & Engle, 2004), down-regulation of unwanted affect and urges (Schmeichel & Demaree, 2010), and inhibiting mindless/habitual behaviors (Houben & Wiers, 2009; Logan et al., 1997).

**Task-switching.** Task-switching is the ability to shift back and forth between multiple task sets (Miyake et al., 2000; Monsell, 2003). One frequently used paradigm for measuring task-switching is the task-cueing paradigm, in which an individual must perform one of two sub-tasks based on a cue provided with or before the stimulus (Miyake & Friedman, 2012; Monsell, 2003). Each trial is either a non-switch trial (same
sub-task as previous trial) or a switch trial (different from previous trial). Greater reaction time on switch trials compared to non-switch trials reflects the cost associated with switching. One study of the TST has examined the relationship between cognitive flexibility and health behavior (Allan et al., 2011). In this study, cognitive flexibility was a factor comprised of task-switching, measured using a trail-making task, as well as a verbal fluency task and a tower planning task. Cognitive flexibility was found to predict significantly smaller intention-behavior gaps for fruit and vegetable consumption and for snacking behavior (Allan et al., 2011). Thus, this avenue of research appears promising but requires further investigation.

The mechanisms by which task-switching may promote goal attainment are as of yet unknown, but task-switching may promote flexibility in goal-directed behavior (Hofmann et al., 2012). Hofmann and colleagues (2012) have proposed that task-switching may be associated with the self-regulatory behavior of means-shifting. Means-shifting occurs when a person flexibly switches the means they use to achieve or strive toward a focal self-regulatory goal (Hofmann et al., 2012). In terms of physical activity, means-shifting could manifest as changing aspects of one’s physical activity (e.g., activity type, location, intensity, time of day) while still striving towards one’s physical activity goals. Thus, task-switching may promote a unique type of self-regulatory behavior: flexible self-regulation.

Perspectives on self-regulation have largely focused on behaviors and processes that promote more rigid self-regulation, including narrowing one’s focus on the goal at hand, following strict guidelines, or forming habits that promote a specific response to a
cue. Thus, knowledge of the role of flexibility is sparse. Clearly, these more rigid behaviors and processes are important to self-regulatory success, as evidenced by a growing body of supportive findings (for review, see Mann et al., 2013). Processes like making concrete plans (Scholz, Schüz, Ziegelmann, Lippke, & Schwarzer, 2008; Sniehotta, Scholz, & Schwarzer, 2005) or implementation intentions (Gollwitzer & Sheeran, 2006), shielding goals from interference (Veling & Knippenberg, 2006), resisting temptation/effortful inhibition (Hofmann et al., 2009), and forming habits (Lally & Gardner, 2013) have all been found to improve the strength of the relationship between people’s intentions and actions. However, they generally do so by helping the individual to focus on particular means and ignore other influences. While these self-regulatory processes are undeniably important to successful goal-striving, one potential downside to rigid self-regulation may be that it prevents individuals from taking advantage of other (unplanned) opportunities by which to meet their goal. Indeed, initial support for this idea has been found in field of consumer research: Bayuk and colleagues (2010) found that having too specific of plans (i.e., holding a concrete mindset and forming implementation intentions) toward a goal prevented individuals from taking advantage of new opportunities that served the same goal (Bayuk et al., 2010).

Unlike rigid self-regulatory behaviors, means-shifting promotes flexibility within the context of goal-striving and self-regulation. Thus, alongside the more traditional, rigid self-regulatory behaviors, means-shifting may contribute uniquely to self-regulation. Means-shifting may be especially important for goals which may be achieved through any number of means. A goal to be more physically active, for instance, can be met in an
infinite number of ways—with a plethora of activities (running, yoga, kickboxing), in many locations (outdoors, gym, home), at any time of day, and at various intensities and durations. Alternately, flossing one’s teeth is probably best done with specific equipment (floss) in a specific location (bathroom) at a specific time (before bed), and thus would likely not lend itself to means-shifting. In addition to being more relevant to certain activities, means-shifting may be most important when other, more rigid processes fail, such as when plans are no longer viable. For example, if one plan fails (e.g., it is too snowy to run), a person could use means-shifting to select a new activity (e.g., doing yoga with a DVD). In this way, flexible self-regulation may help fill gaps in physical activity success that cannot be accounted for by rigid self-regulatory processes.

If task-switching does indeed predict meeting physical activity intentions, understanding the self-regulatory mechanisms which serve this relationship is important. Due to its connection to means-shifting, task-switching may promote flexibility in activity choice. People who are better at task-switching may be better at recognizing and engaging in alternative opportunities when their original plan has been abandoned. Importantly, I do not expect substitution of activities to fully explain the relationship between task-switching and physical activity, given that there are a number of other facets which could be flexibly substituted (e.g., time of day, duration, location, etc.). Activity substitution is only one type of means-switching which could be used to overcome barriers or setbacks.
Mediation of the Relationship between Executive Function and Goal Attainment

I have indicated the potential mechanisms through which each type of executive function may promote goal attainment. Broadly, research would suggest that those with stronger executive functions are more likely to engage in related self-regulatory behaviors and processes (for review, see Hofmann et al., 2012), and in doing so, increase their likelihood of goal attainment. For inhibitory control, one mediating self-regulatory behavior may be effortful resisting of temptations. For updating, a number of mediating behaviors may exist, such as goal shielding and down-regulation of urges. For task-switching, the mediating behaviors may include activity substitution or substitution of other aspects of physical activity. While research supports the individual legs of these mediation paths, to the author’s knowledge, no study has tested a model in which the effect of executive function on goal attainment is mediated by a relevant self-regulatory behavior.

Aims

The present study expands upon Temporal Self-regulation Theory (TST; Hall & Fong, 2007), which theorizes that people with better executive functions will be more likely to enact their intentions. My first aim is to extend this theory to a different type of executive function, task-switching, to determine whether task-switching affects the intention-behavior relationship in physical activity. I hypothesize that, controlling for baseline physical activity and intentions, those better at task-switching will be more physically active than those poor at task-switching. My second aim is to explore a potential mechanism through which task-switching may affect physical activity (see
Figure 1). I hypothesize that a form of means-shifting, substituting an alternative activity when the original activity is abandoned, will partially mediate the relationship between task-switching and physical activity. That is, people better at task-switching will be more likely to substitute a new activity when necessary, and greater likelihood of substituting will lead to greater physical activity. Finally, given the limited number of studies which have tested the association between the executive function of inhibitory control and physical activity, my third aim was to replicate the finding that those with better inhibitory control are more likely to meet their physical activity intentions.

Figure 1. The 2-1-1 multilevel mediation model testing the indirect effect of task-switching on physical activity via substitution of activities.
METHOD

Participants and Procedure

A sample of 128 college students (Table 1) participated in this study. I recruited people who had at least moderately strong intentions to exercise, and I excluded student athletes, given that I were interested in studying leisure-time activity rather than mandated activity.

Table 1

Demographic and Baseline Measures

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.9</td>
<td>3.4</td>
</tr>
<tr>
<td>BMI</td>
<td>24.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Baseline PA</td>
<td>263.0</td>
<td>190.6</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td>27.3%</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td>72.7%</td>
</tr>
<tr>
<td>Ethnicity</td>
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</tr>
<tr>
<td>African-American</td>
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<td>6.3%</td>
</tr>
<tr>
<td>Asian</td>
<td></td>
<td>3.9%</td>
</tr>
<tr>
<td>Caucasian</td>
<td></td>
<td>82.0%</td>
</tr>
<tr>
<td>Hispanic</td>
<td></td>
<td>5.5%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Note: N = (128). Baseline PA = Average weekly minutes of physical activity in past month.
During an initial lab session, participants completed baseline measures and four executive function tasks, and were provided verbal guidelines for the daily diaries along with a demonstration of the online form. Upon completing the lab session, participants were sent written instructions for completing the daily diaries via email. Each night for 14 nights, participants were sent a reminder email at 7:00PM with the link to the daily diary form. Participants recorded their physical activity within the last 24 hours. On the 14th day, participants received a link to a follow-up survey which reassessed a number of the social-cognitive measures assessed at the initial lab session.

Measures

**Go/NoGo Task.** Inhibitory control was measured with a single Go/NoGo computer task used in previous studies (Hall et al., 2008). The Go/NoGo task has been found to activate structures in the brain associated with behavioral self-regulation (Hester, Fassbender, & Garavan, 2004) and to correspond to higher intention-behavior relationships in physical activity (Hall et al., 2008). For the Go/NoGo task, participants were seated in front of a computer, and all instructions were provided on the screen. Participants were informed that they would be presented with a series of uppercase and lowercase letters on the screen. They were instructed to press the spacebar as quickly as possible when they saw a lowercase letter and to refrain from pressing the spacebar when they saw an uppercase letter. Participants completed 12 practice trials with 6 uppercase and 6 lower case letters. A preparation screen let participants know that the test trials were beginning and that both speed and accuracy would count. The test phase consisted of eight blocks of 60 trials each; in half of the blocks, lowercase letters were
predominant, and in half of the blocks, uppercase letters were predominant. Following precedent from previous studies (Hall et al., 2008), reaction times were computed for correct responses to lowercase letters, and combined across all test blocks to create an average Go/NoGo response time (RT) score. Lower Go/NoGo scores indicate better inhibitory control.

**Task-Switching.** Task-switching was measured with three computer tasks used in prior studies (Friedman et al., 2008; Miyake et al., 2000) that assess the cost in reaction time associated with switching from one task to another compared to performing the same task repeatedly (Monsell, 2003). Task-switching has been found to be associated with activation in the prefrontal cortex (Braver, Reynolds, & Donaldson, 2003; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000). For all three task-switching assessments, participants were provided with on-screen instructions, a practice block of 24 trials, and inter-block preparation screens which reminded participants to answer as quickly and as accurately as possible. Each of the three tasks contained two test blocks of 48 trials, each of which contained 24 no-switch and 24 switch trials. Each trial was preceded by a cue indicating which subtask to be performed, which appeared on the screen 150ms prior to the stimulus and remained on the screen with the stimulus until the participant responded. The dependent measure in each task was the average switch cost, which was the difference between average reaction times on trials where a switch was required and average reaction times on trials where a switch was not required (Friedman et al., 2008).
In the color-shape task (see Figure 2), participants saw a colored shape on the screen. One subtask was to indicate whether the color was blue or red, the other was to indicate whether the shape was a triangle or circle. The cue was a letter which appeared above the shape. Participants were instructed to respond to the color when the letter “C” was shown, and to respond to the shape when the letter “S” was shown.

![Figure 2. Illustration of the color-shape task-switching assessment.](image)

In the number-letter task, participants saw letter-number or number-letter combinations (e.g., 4G). One subtask was to indicate whether the letter was a consonant or vowel, the other was to indicate whether the number was even or odd. The cue was a square box which appeared either above or below a horizontal line which ran across the middle of the screen. Participants were instructed to respond to the letter when the box appeared above the line, and to respond to the number when the box appeared below the line.
In the category switch task, participants saw a word on the screen. One subtask was to indicate whether the word was smaller or larger than a soccer ball (e.g., smaller: goldfish, pebble; larger: bicycle, shark), the other was to indicate whether the word was living or non-living (e.g., living: alligator, sparrow; non-living: table, marble). The cue was a shape which appeared above the word. Participants were instructed to respond to the size when they saw an arrow cross (a square cross with arrows on all endpoints), and to respond to the nature (living/non-living) when they saw a heart.

Scores on the three tests of task-switching ($\alpha = .42$) were averaged to create a raw task-switching score. Raw task-switching scores reflect the difference in reaction times between switch and non-switch trials, with higher switch costs indicating poorer task-switching ability. Similarly, raw Go/NoGo scores reflect slower reaction times, which are associated with poorer inhibitory control. To ease interpretation of the results, the raw scores were standardized and reverse coded so that higher scores reflect better task-switching ability and better inhibitory control.

**Baseline estimated METs of physical activity.** Baseline physical activity was assessed with four questions which assessed the average number of days per week, and the average number of minutes per day of moderate and vigorous physical activity over the past month. Days and minutes were multiplied for each intensity level to obtain total weekly minutes of moderate activity and vigorous activity. To calculate an estimate of METs, moderate activity was multiplied by 4, and vigorous activity was multiplied by 8, and these two numbers were summed (Ainsworth et al., 2011).
**Intentions for physical activity.** Participants reported both the number of days and the minutes per day they intended to be physically active over the next two weeks. I multiplied these two numbers together to produce an intention measure which reflects the total minutes of physical activity intended for the two weeks following baseline.

**Potential activities.** Participants saw a list of 17 activities (e.g., running, using the elliptical, yoga, basketball); these 17 activities were those most commonly endorsed by a recent pilot sample of college students. Participants were asked to mark which activities they might use in the next two weeks to meet their activity goals. The number of potential activities was summed as an indicator of initial flexibility toward physical activity.

**Daily physical activity.** Daily physical activity was measured with an online interactive form (see Appendix). First, participants saw the list of 17 activities (e.g., running, using the elliptical, yoga, basketball) shown in the potential activities list in the baseline measure, plus an option to select and list “other” if the activity they engaged in was not listed. Participants were asked for each activity whether they did the activity, whether they planned to do the activity but did not, or whether they did not do the activity and had not planned to. For each of the activities a participant engaged in, duration (in minutes) and intensity (low, medium, high) of the activity were recorded. To obtain an estimate of daily METs, minutes of moderate activities were multiplied by 4, and minutes of vigorous activities were multiplied by 8, and these two numbers were summed (Ainsworth et al., 2011). For any day that a participant planned to do an activity but did
not, I coded whether the person substituted an alternate behavior or did not substitute
(i.e., reported no physical activity for that day).

**Demographics.** Participants reported their gender, age, ethnicity, height and weight via self-report. Body mass index (BMI) was calculated using the height and weight provided by participants.

**Data Analytical Plan**

All analyses were run using Stata 12. Due to the daily diary methodology, the data was structured as days (level 1) nested within people (level 2). Task-switching, baseline physical activity, and intention were measured at baseline (level 2). Substituting activities and physical activity METs were measured daily (level 1). To test the indirect effect of task-switching on physical activity via substituting activities, I used a 2-1-1 multilevel mediation model in which the independent variable and all covariates are level 2 and the mediator and outcome are level 1 (see Fig. 1). Because the mediator is a binary measure (i.e., substituted or not), this is a violation of the linearity assumption. However, to the author’s knowledge, no omnibus test exists that can account for both multiple levels in mediation and a categorical mediator. Thus, I also calculated an individual path estimate for the effect of task-switching on substitution likelihood using a generalized estimating equation (GEE) with a logit distribution, to account for the binary nature of the mediator. To test the multilevel mediation model, I used the ml_mediation program. I used bootstrapping with replacement and 1000 replications to obtain confidence intervals for all path estimates: total effect, direct effect, indirect effect, and ‘a’ and ‘b’ paths. If the
indirect path is significant (i.e., bootstrapped confidence interval does not contain 0), I will conclude that mediation is present.

To replicate the finding that inhibitory control predicts better physical activity success (Hall et al., 2008), I conducted a generalized estimating equation (GEE) model with a Gaussian (i.e., normal) distribution. The GEE framework allowed us to use all of the daily diary data while accounting for non-independence. The sample size for these analyses (N groups = 86, N observations = 1163) is smaller than that of the task-switching analyses; programming errors prevented us from obtaining Go/NoGo scores for 62 participants. I used bootstrapping with replacement and 1000 replications to obtain estimates and confidence intervals.
RESULTS

Preliminary Analyses

The average number of diaries completed was 12.12 (SD = 2.49). On average, participants engaged in some activity on 8.14 (SD = 4.02) days of the 14-day period. Participants reported that they had planned to do an activity but did not do it on an average of 3.86 (SD = 2.70) days. On days when a plan was abandoned, participants substituted an alternative activity on an average of 2.07 (SD = 2.40) days. See Table 2 for the matrix of correlations between variables.

Table 2

*Correlations Between Measures*

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Avg. PA (METs)</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Subst.</td>
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<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline PA</td>
<td>0.523</td>
<td>0.245</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Intentions</td>
<td>0.462</td>
<td>0.157</td>
<td>0.640</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possible activs.</td>
<td>0.054</td>
<td>0.223</td>
<td>0.068</td>
<td>0.111</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task-switching</td>
<td>-0.027</td>
<td>0.104</td>
<td>0.156</td>
<td>-0.188</td>
<td>0.150</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Inhibition</td>
<td>-0.015</td>
<td>0.235</td>
<td>-0.010</td>
<td>-0.048</td>
<td>0.030</td>
<td>0.158</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note: Variables measured at the daily level (physical activity and substitution) were averaged by individual prior to running the correlations.
To examine whether there were any differences in compliance due to demographic or baseline measures, I ran correlations between the number of diaries completed and each of the continuous variables, and conducted t-tests on the categorical demographic variables. Neither age, baseline physical activity, nor intentions predicted differences in compliance (all p’s > .05), and there was no difference in compliance between males and females (p > .05). However, there was a correlation between BMI and compliance such that people with higher BMIs tended to complete fewer diaries, \( r = -.22, \) \( p < .05 \). There was also a significant difference in number of diaries completed by White (\( M = 13.58, SD = 2.46 \)) and non-White participants (\( M = 12.35, SD = 3.52 \)), \( t(126) = 1.99, p = .048 \), although the average number of diaries was relatively high in both groups.\(^1\)

**Main Analyses**

I tested a multilevel mediation model, controlling for baseline physical activity, time, and intention. The indirect effect of task-switching on physical activity is comprised of the ‘a’ path, task-switching predicting substitution, and the ‘b’ path, substitution predicting physical activity (Figure 3). The ‘a’ path was significant and positive, \( b = .07, \) \( p < .001, CI: .04 – .10 \), indicating that people who were better at task-switching were more likely to substitute an alternate activity on any given day that their original plan was abandoned (see Table 3).

\(^1\) All analyses were re-run controlling for BMI and ethnicity. Significance tests yielded similar results and identical interpretations to the analyses conducted without these covariates.
Figure 3. Results of the multilevel mediation, controlling for baseline activity, intentions, and time.

Table 3

Results of the “A” Path of the Multilevel Mediation Model: Predicting Substitution

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR</th>
<th>Coefficient</th>
<th>Bootstrapped SE</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline PA</td>
<td>1.56</td>
<td>.00</td>
<td>.033</td>
<td>.059</td>
<td>-3.1e-6 – 1.5e-4</td>
</tr>
<tr>
<td>Intention</td>
<td>1.00</td>
<td>.00</td>
<td>4.1e-5</td>
<td>.586</td>
<td>-2.1e-4 – 3.8e-4</td>
</tr>
<tr>
<td>Time</td>
<td>.95</td>
<td>-.01</td>
<td>.004</td>
<td>.002</td>
<td>-.02 – -.004</td>
</tr>
<tr>
<td>Task-Switching</td>
<td>1.34</td>
<td>.07</td>
<td>.02</td>
<td>&lt;.001</td>
<td>.04 – .10</td>
</tr>
</tbody>
</table>

Note: The coefficients reported are unstandardized. Odds ratios (ORs) were obtained using a generalized estimating equation with a binary distribution. The standard error (SE), p-value, and 95% confidence interval (CI) for task-switching reflect bootstrapped estimates.

The ‘b’ path was significant and positive as well, b = 181.95, p < .001, CI: 162.59 – 201.32, indicating that people who were more likely to substitute an alternate activity on a day that their original plan was abandoned reported more physical activity on those days (see Table 4).
Table 4

Results of the “B” and “C Prime” Paths of the Multilevel Mediation Model: Predicting Estimated METs of Physical Activity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline PA</td>
<td>.03</td>
<td>.01</td>
<td>.003</td>
<td>.01 – .06</td>
</tr>
<tr>
<td>Intention</td>
<td>-.01</td>
<td>.04</td>
<td>.771</td>
<td>-.10 – .07</td>
</tr>
<tr>
<td>Time</td>
<td>-1.10</td>
<td>1.18</td>
<td>.349</td>
<td>-3.41 – 1.20</td>
</tr>
<tr>
<td>Task-Switching</td>
<td>-1.20</td>
<td>4.56</td>
<td>.792</td>
<td>-10.15 – 7.74</td>
</tr>
<tr>
<td>Substitution</td>
<td>181.95</td>
<td>9.88</td>
<td>&lt;.001</td>
<td>162.59 – 201.32</td>
</tr>
</tbody>
</table>

Note: The coefficients reported are unstandardized. The standard error (SE), p-value, and 95% confidence interval (CI) for task-switching and substitution reflect bootstrapped estimates.

The indirect effect of task-switching on physical activity via substitution of activities was significant, $b = 12.02$, $p < .001$, 95% CI: 6.31 – 17.73, indicating that substitution of activities mediated the effect of task-switching on physical activity.

Surprisingly, the effect of task-switching on physical activity was not significant, $b = 6.43$, $p = .223$, CI: -3.90 – 16.75 (see Table 5), and the direct effect remained non-significant when substitution was added to the model, $b = -1.20$, $p = .792$, CI: -10.15 – 7.74 (see Table 4). Thus, while there was no direct effect of task-switching on physical activity, there was an indirect effect in that task-switching predicted more substitution, which in turn predicted more physical activity.
Table 5

Results of the “C” Path of the Multilevel Mediation Model: Predicting Estimated METs of Physical Activity

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>SE</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline PA</td>
<td>.04</td>
<td>.01</td>
<td>&lt;.001</td>
<td>.02 – .06</td>
</tr>
<tr>
<td>Intention</td>
<td>.15</td>
<td>.03</td>
<td>&lt;.001</td>
<td>.08 – .21</td>
</tr>
<tr>
<td>Time</td>
<td>-1.58</td>
<td>.77</td>
<td>.040</td>
<td>-.07 – 3.09</td>
</tr>
<tr>
<td>Task-Switching</td>
<td>6.43</td>
<td>5.27</td>
<td>.223</td>
<td>-3.90 – 16.76</td>
</tr>
</tbody>
</table>

Note: The coefficients reported are unstandardized. The standard error (SE), p-value, and 95% confidence interval (CI) for task-switching and substitution reflect bootstrapped estimates.

As a follow-up analysis, I explored a possible reason that task-switching predicts greater likelihood of substitution. Task-switching could predict substitution for two reasons: task-switching may be associated with a general awareness of more opportunities by which to meet a goal and/or task-switching may predict greater likelihood of actually doing alternate behaviors. To examine this, I analyzed the relationship between task-switching and the number of activities individuals indicated at baseline that they might do to fulfill their activity goals. If task-switching promotes greater awareness of possible means, I would predict that those better at task-switching would endorse more possible activities at baseline. I found that the number of possible activities endorsed was marginally correlated with task-switching, $r = .15$, $p = .092$. Thus, people good at task-switching tend to be aware of more means by which they could meet their goals. Next, I tested a mediation model to assess whether the number of activities people endorse mediates the effects of task-switching on substitution, controlling for
baseline physical activity. The indirect effect of task-switching on substitution via endorsed activities was not significant, $b = .01$, $p = .126$, CI: $-.003$ – $.03$. The lack of an indirect effect indicates that the relationship between task-switching and substitution cannot be explained solely by the number of activities people perceive as possible means by which to meet their goals. Thus, task-switchers may be more likely to substitute activities because of in-the-moment decisions to switch, rather than a general awareness of more goal-relevant opportunities.

To test the relationship between inhibitory control and physical activity, I conducted a GEE, controlling for intention and baseline physical activity. Controlling for baseline physical activity and intention, the effect of inhibitory control on physical activity was significant, $b = 22.27$, $p < .001$, CI: 3.75 – 40.80 (see Table 6). Thus, controlling for intentions and baseline physical activity, people with better inhibitory control were more physically active than those with poor inhibitory control.

Table 6

*Results of the Bootstrapped Generalized Estimating Equation Predicting Estimated METs of Physical Activity*  

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>Bootstrapped SE</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline PA</td>
<td>43.44</td>
<td>19.05</td>
<td>.023</td>
<td>6.10 – 80.77</td>
</tr>
<tr>
<td>Intention</td>
<td>.14</td>
<td>.05</td>
<td>.005</td>
<td>.04 – .24</td>
</tr>
<tr>
<td>Inhibitory Control</td>
<td>22.27</td>
<td>9.45</td>
<td>.018</td>
<td>3.75 – 40.80</td>
</tr>
</tbody>
</table>
DISCUSSION

I hypothesized that activity substitution would mediate the relationship between task-switching and physical activity. Indeed, I found evidence for an indirect effect, even in the absence of a direct effect between task-switching and physical activity. That is, task-switching predicted greater physical activity only insofar as it predicted more flexible self-regulation which in turn predicted greater physical activity. This supports my theory that an underlying mechanism of the relationship between executive functions and physical activity is self-regulatory behaviors. It also supports my hypothesis that flexible self-regulatory behaviors play an important role in physical activity. In my replication analyses, I found a direct effect of inhibitory control on physical activity, controlling for intentions.

The results provide mixed support for Temporal Self-Regulation Theory (TST). On the one hand, I found a direct effect of inhibitory control on physical activity, controlling for intentions. This finding is in line with previous studies which have found an effect of inhibitory control on fatty food consumption and physical activity (Hall et al., 2008; Hall, 2012). On the other hand, I failed to find a direct effect of task-switching on physical activity. Similarly, other tests of the TST have failed to find specific relationships between certain executive functions and health behaviors. For example, Allan and colleagues (2011) found that in snacking behavior and fruit and vegetable consumption, cognitive flexibility, but not inhibitory control (measured with a Go/NoGo task), predicted a smaller gap between intentions and behavior. However, in a second
study, inhibitory control as measured by the Stroop task predicted a smaller gap between intentions and behavior in snacking (Allan et al., 2011). Wong and Mullan (2009) found that planning ability, but not inhibitory control, was associated with greater breakfast consumption. A number of plausible explanations for these inconsistent findings exist. First, it is likely that the relationships between executive functions and behaviors vary by executive function and behavior; task-switching may be more relevant to one behavior than another. Additionally, it is possible that some of the executive functions not shown to have direct effects could be indirectly influencing behavior through the promotion of specific self-regulatory behaviors. The data was able to address this possibility, and indeed, I found a significant indirect effect of task-switching on physical activity.

One explanation for finding an indirect, but not direct, relationship between task-switching and physical activity is the possibility that task-switching could both enhance and inhibit physical activity. In their review of executive functions and self-regulation, Hofmann and colleagues (2012) suggest that task-switching may promote both means-shifting and goal-switching. Means-switching, operationalized in this study as activity substitution, facilitates goal-striving. Goal-switching, on the other hand, involves disengaging from one goal in order to pursue alternative goals, either in acquiescing to temptations or shifting to a different focal goal (Baumeister & Heatherton, 1996; Fishbach, Zhang, & Koo, 2009). In the context of physical activity, switching to another goal could mean temporarily abandoning one’s activity goals to acquiesce to more immediately appealing goals like comfort or to more proximal, tangible goals like studying for an upcoming exam. Thus, while the indirect effect of task-switching through
means-shifting promotes physical activity, I speculate that the indirect effect of task-switching through goal-shifting may inhibit physical activity. However, as the current study cannot test this speculation, future studies will need to measure indicators of both means-shifting and goal-shifting to test this empirically.

To further understand the relationship between task-switching and substitution, I examined the association between task-switching and the number of activities people endorsed at baseline as possible means by which to meet their goals. The results indicate that people good at task-switching endorse marginally more activities than those poor at task-switching. Given that this relationship was only a trend, I believe that the greater substitution likelihood among task-switchers is not due solely to the number of activities endorsed, but also to the likelihood of choosing to make substitutions in moments which require alternate activities.

This is the first study to examine the relationship between task-switching and physical activity, and the first to suggest the mediating role of activity substitution as a mechanism of this relationship. To the author’s knowledge, this study is only the second study to examine the association between task-switching and any health behavior (Allan et al., 2011). My research is strengthened by the use of three measures of task-switching. While the relationships between these tasks were relatively weak, other studies of executive functions have similarly found weak associations between related tasks (Humes, Welsh, Retzlaff, & Cookson, 1997; Miyake et al., 2000). Another strength of my research is the use of a daily assessment of physical activity; daily reports are less prone to retrospective reporting errors than a weekly diary (Baranowski, 1988). Importantly, the
daily assessment also allowed us to assess daily occurrences of substituting alternative activities when original plans were abandoned; this daily-level event would have been washed out in a weekly summary.

**Limitations**

There are several limitations to my study. First, the data is correlational, so I cannot assume unidirectional relationships. For example, while I hypothesized that task-switching ability predicts the occurrence of activity substitution, the repeated practice of activity substitution could also improve task-switching ability over time. Second, I used self-report measures of physical activity, which can be prone to subjectivity and memory errors. However, by using a daily assessment of physical activity rather than a week-long recall, I reduced the likelihood of retrospective reporting errors. Third, the generalizability of the results is limited due to the young adult student sample I used. Additional research is needed to see if these results generalize to other adult populations.

A number of future directions should be explored. First, the novel findings presented here indicate a fruitful area of research in the relationships between task-switching, flexible self-regulation, and other health goals. Second, work is needed to clarify the conditions under which executive functions predict variability in the intention-behavior gap. Specifically, it will be important to assess multiple executive functions within a study to test which executive functions are relevant to specific behaviors. Third, theories should strive to model the mechanisms through which executive functions affect behavior. Different executive functions will likely promote different types of self-regulatory behaviors, and these differences in self-regulation strategies will likely explain
why specific executive functions relate to some behaviors but not others. Fourth, the relationship between task-switching and physical activity is still largely unknown, so further research is needed to clarify the relationships tested here. The measure of means-shifting was activity substitution, but future studies could explore other forms of means-shifting such as changing location, time of day, duration, intensity, or context of physical activity. Finally, I speculated that the direct effect of task-switching may be suppressed by goal-shifting, but research is needed to test the possible occurrence and effects of means-shifting and goal-shifting simultaneously.

Conclusions

Temporal Self-Regulation Theory is the first theory to incorporate executive functions into more traditional models of health behavior change. While initial studies indicate that executive functions contribute uniquely to these models, the relationships between executive functions and health behaviors are still not well understood. This study replicated previous findings (Hall et al., 2008) that inhibitory control significantly predicts physical activity, and made new progress in understanding the relationships between executive functions and physical activity by testing a pairing which has not yet been explored: task-switching and physical activity. Further, I modeled an indirect effect via activity substitution, a flexible self-regulatory behavior relevant to task-switching. The indirect effect of task-switching on physical activity via activity substitution was significant, suggesting that the mechanisms of the executive function-behavior relationship may be a fruitful area for research. Task-switching and flexibility represent novel components of self-regulation and offer a unique approach to understanding and
intervening on health behaviors. Future research should explore the role of task-switching in other health behaviors where flexibility may be beneficial, such as diet and nutrition.
REFERENCES


APPENDIX

Online Daily Diary Measure of Physical Activity

Screen 1: Indication of activities.

We are interested in the physical activity you did today (in the last 24 hours)

Please indicate which of the following exercise(s) you did today, which you planned to do but didn't, and which you didn't do or plan to do.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Yes, I did this</th>
<th>No, I planned to but didn't</th>
<th>No, I hadn't planned to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking for exercise (including hiking)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliptical machine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary bike</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stair climb machine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soccer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basketball</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swimming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yoga</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video game-based exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise video</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-guided home exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other exercise not listed here</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

>>
Screen 2: Duration and intensity of all activities the participant engaged in.

<table>
<thead>
<tr>
<th>Activity</th>
<th>How long did you do this?</th>
<th>At what intensity did you do this?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elliptical machine</td>
<td>35 minutes</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>

Screen 3: Barrier for all activities the participant planned to do but did not do.

For each of the activities you planned to do but didn’t, please tell us what prevented you from doing the activity.

- Running
  - Issues with motivation (feeling bored, lazy, etc.)
  - Issues with time (having school, work, home obligations, etc.)
  - Issues with environment (lack of facilities or equipment, bad weather, etc.)
  - Issues with discomfort (not liking the way it feels, embarrassment, etc.)
  - Issues with support (not having people to do it with)