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Social Engagement and Task Complexity: Physical Activity Characteristics and Executive Function Among Older Adults

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Abstract

Physical activity participation has been found to favorably influence cognitive function across the lifespan. Specific characteristics, or qualities, of physical activity involvement (e.g., type, intensity, level of cognitive demand) may yield particular benefits. The purpose of this study was two-fold. The first objective was to develop taxonomies for two physical activity characteristics of interest: the level of task complexity (motoric and cognitive) and the level of social engagement. The second objective was to assess the relationships between these two characteristics and the level of cognitive function among active, older adults. Physical activities reported by the participants (N = 75) were evaluated separately for the level of task complexity and social engagement. Three components of cognitive function were measured as indicators of executive function: inhibition; cognitive flexibility; and working memory. Results from multiple regression analyses revealed that engagement in physical activities that had higher levels of social engagement, or involved more complexity, were not associated with improved executive function outcomes. However, the taxonomies developed to directly assess the variability in social engagement and task complexity for a variety of physical activities makes for a meaningful contribution to the literature and may be utilized in the design of physical activity interventions across the lifespan.

Keywords
Exercise; older adults; executive function; social engagement; task complexity

1. Introduction

Much of the motivation underlying research in gerontology involves examination of how various behavioral interventions improve physical, mental, and/or emotional health, as well as the impact on functional independence for aging adults [1]. The preservation and maintenance of cognitive function contributes to such independence and may be stimulated through involvement in socially integrated networks, engagement in cognitively-based leisure activities, or participation in regular physical activity (PA) [2]. Research results indicate improved brain structure and function [3, 4] in healthy older adults, and enhanced performance on a variety of cognitive tasks, particularly those that require executive processes [3, 5-7] following PA interventions. Executive functions (EFs) are cognitive processes that help regulate goal-directed behavior through effortful thinking and reasoning [8], and assist with everyday tasks such as planning, problem solving, driving, or learning a novel skill [9]. Adult PA experiences can be designed to stimulate the social and cognitive engagement of participants, and thereby enhance the potential for maintenance of cognitive function, or more specifically EF, into older adulthood [10].

While previous research has been designed to explore the influence of quantitative PA characteristics (e.g., intensity, duration) on cognition [11], it has been suggested that other PA characteristics may also influence cognition [12]. These characteristics may include task complexity (TC) and social engagement (SE). The level of TC is reflected by the motoric, or coordinative behavioral demands of the task, as well as the cognitive, or mental, demands of the activity. For example, a PA that requires multi-limb coordination (e.g., trail hiking) would be more complex than a single-limb movement (e.g., throwing a dart). Similarly, a group game setting (e.g., basketball) requires concentrated mental engagement and rapid decision-making while adapting to the behavior of others, and thus would be considered more cognitively-demanding and complex than an activity performed individually (e.g., jogging on a track) without additional cognitive demands [13]. PA interventions that have been designed to include greater levels of TC have resulted in improved brain structure and enhanced cognitive function in youth and adolescent populations [14, 15]. Comparable findings have been reported in studies exploring the differences in brain structure following engagement in complex versus simple exercise training with rodents [16, 17].

Similar findings have been evaluated among older adult populations. Dai et al. [18] conducted a cross-sectional study and found that participants who reported engagement in more complex PA settings (e.g., tennis, table tennis) showed significantly better EF performance when compared with older adults who reported participation in less complex activities (e.g., swimming laps). These researchers attributed the superior performance to the cognitive demands associated with participation in complex PAs. Other researchers [19] designed a multicomponent PA intervention for adults 65-75 years that included coordination, strengthening, balance, and agility training. The variety of activities were designed to engage the participants in upper and lower body coordinative movements and involve the executive processes through cognitively demanding tasks (e.g., task switching) as the individuals completed the activities. A separate group engaged in progressive resistance training involving free weights and machines. Both groups participated for one hour, twice a week for a total of three months. Pre- and post-executive task performance assessing executive processes revealed significant improvements to inhibition in both groups. Further mediation analyses showed the multicomponent training directly improved inhibition, while the strength gains in the resistance training group mediated the improved inhibition. The researchers attributed the gains in EF to the greater cognitive and coordinative demand of the activities in the multicomponent setting. The researchers proposed that similar activities that reflect "gross-motor cognitive training" may have a potential moderating role on the exercise-cognition relationship [19].

Social interaction represent another potentially important PA characteristic that may moderate the relationship between activity engagement and cognitive function. Researchers have found improved memory recall and EF among youth participants when social interaction opportunities were enhanced during PA [14, 15]. Research among older adults has shown that those who exercise with others, as opposed to alone, have lower risk of depression [20], fewer falls [21], higher perceived health [22] and better mental health [23]. A randomized control trial [24] assigned participants (aged 60-79 years) into one of four groups: a Tai Chi group, a walking group, a social interaction group, or a control group, for a total of 40 weeks. The social interaction group met with two researchers at a community center; while initially the researchers provided instructions and topics for the group discussions, participants eventually interacted without being provided directions from the researchers. Pre- and post-EF tasks and brain volume were assessed, and results showed increases in both outcome variables for the Tai Chi and social interaction group, whereas no differences were observed for the walking or control group. The researchers proposed that improvements could be due to the concentration and mindfulness required in the Tai Chi activity, and the intellectual stimulation provided by the weekly social interactions. A more recent study exploring the relationship between PA context, physical function, and mental health found that exercising with others predicted greater PA participation levels and better mental health than exercising alone [25]. Finally, results from a meta-analysis showed greater exercise adherence among older adults who participated in group walking sessions when compared with younger adults [26], indicating the group exercise setting may influence participation to a greater extent among older adult participants. Social interaction opportunities may be particularly salient for this age group. Empirical evidence suggests better cognition among those older adults who report strong, positive, and more frequent social networking experiences, even after controlling for other lifestyle factors such as socioeconomic status or physical health [27].

Previous research findings provide support for the potential for TC and SE to impact cognitive performance among youth, adolescent, and older adult PA participants. However, for researchers to assess the direct, or indirect, influence of these PA characteristics on cognition and to design interventions that include these considerations, it is imperative to first operationally define TC and SE within a PA context. Thus, the first objective of this study was to develop taxonomies for the assessment of TC and SE for various physical activities. This approach would benefit subsequent efforts to establish the levels of TC, and/or the degree to which SE occur during a PA intervention.

A second objective was to explore the relationship between EF, and the frequency with which older adults reported engagement in more complex physical activities, and/or more socially engaging PAs. To accomplish this second objective, we employed a cross-sectional approach, and utilized the newly developed taxonomies from the first objective to define TC and SE in reported activities. Based on the previous research discussed, it was hypothesized that individuals who report engagement in complex and/or socially engaging PAs would perform significantly better on EF tasks when compared to individuals who participated in less complex, and/or less social engaging PAs.

2. Method

The following sections describe the participants, the PA recall methods employed, the description of the taxonomy components, and the scoring procedures for assessing the various activities for TC and SE. This section also describes the instructions provided to the Subject Matter Experts (SMEs) to establish TC and SE scores for the physical activities and describes the calculation procedures for the final TC and SE activity score. The tasks utilized to evaluate EF performance among participants is described below.

2.1 Participants

Following approval from the Institutional Review Board, participants who self-identified as being physically active were recruited from various local fitness centers, gyms, CrossFit boxes, yoga and Pilates studios, senior centers, and through word-of-mouth efforts with recruitment flyers, newsletters, group fitness class announcements, and via email. The inclusion criteria required participants to be at least 60 years of age or older, physically active and to pass the Mini Mental State Examination (MMSE) with a score of 24 or higher [28]. Participants (N = 75) ranged in age from 60 to 73 years and were predominately female (60%). All participants provided their informed consent prior to participation in the study. Cardiorespiratory fitness was evaluated using the YMCA step test, which assesses resting heart rate following three minutes of stepping on and off a 12-inch platform at a pace of 96-beats per minute. This test was used to estimate an individual’s current aerobic capacity or VO_2max [29] and is safe for healthy older adults to perform without a medical release [30]. Participants were asked to self-report their perceived health, as well as their perceived health compared to peers, on a scale of 1-4 where *1 = Fair* and *4 = Very Good*; the average of these scores represented the overall perceived health. Participants were also asked to describe their current living situation in an effort to identify the number of household members. A complete list of participant characteristics can be seen in Table 1.

Table 1 Participant characteristics.

Gender (N = 75)	Female (n = 45; 60.0%) Male (n = 30; 40.0%)
Age	Mean Age = 64.43 years, SD = 3.60 Range: 60-73 years
Race/Ethnicity	Native American (n = 1; 1.3%) Caucasian (n = 74; 98.7%)
Completed Years of Education	Mean Ed = 17.08, SD = 2.65 Range: Less than High School to Graduate Levels
Perceived Health (M = 4, SD = .80)	Fair 1 (n = 2; 2.7%) Good 2 (n = 12; 16.0%) Very Good 3 (n = 32; 42.7%) Excellent 4 (n = 29; 38.7%)
Additional # of Household Members	1 (n = 10; 13.3%) 2 (n = 57; 76.0%) 3 (n = 6; 8.0%) 4 (n = 2; 2.7%)
MMSE Score	Mean = 28.85, SD = 1.22 Range: 25-30
Fitness Levels YMCA Step Test	Female Mean 99.16 bpm; SD = 19.40 Male Mean 89.28 bpm; SD = 20.75

Note. M = mean, SD = standard deviation, bpm = beats per minute.

2.2 Physical Activity Recall

Semi-structured interviews were conducted to assess each participant’s average weekly PA engagement. Participants were asked to elaborate on the location in which they engaged in each form of PA (i.e., at home, at the gym) and to provide relevant details of the activities reported (i.e., resistance training with equipment, group fitness class with body weight only). The interview was designed to correspond with the leisure subscale of the Physical Activity Scale for Elderly Adults (PASE) [31]. Only intentional PAs (e.g., lifting weights, attending a dance class) were accounted for in the recall; household or occupational activities were excluded (e.g., mowing the lawn, taking the stairs).

We then compiled a list of all reported activities, and SMEs (N = 5) were recruited to score each activity for the level of SE and TC, separately. The SMEs were graduate students in sport and exercise science from various disciplines (e.g., biomechanics, social psychology of physical activity). The SMEs were provided with an explanation for how to assess the individual activities for both SE and TC and examples were provided for clarification.

All activities recalled by participants for their typical seven-day period received a separate score for TC and SE based on the combined results from the SMEs activity scoring. The mean for each activity across the 7-day PA recall was calculated such that the participant was assigned a final TC score, and a final SE score. Frequency of activity engagement was accounted for and each participant was also given an individual score based on the number of times they engaged in physical activities throughout the 7-day recall. The average TC or SE score was multiplied by the frequency score, resulting in a FREQxTC and FREQxSE score for each participant. Higher score indicated more frequent participation in activities that were more complex, or more socially engaging.

2.3 Task Complexity

The development of the taxonomy to describe the complexity of PA was derived from Gentile's Taxonomy of Motor Skill Classification [32], and an additional score representing the motor response to the reaction or anticipation of others. The taxonomy was developed so that each PA was assessed with an 'either/or' dichotomy for each characteristic where a scoring the activity with a '2' would indicate a more complex activity, and a score of '1' would indicate a less complex activity. The characteristic of the activity includes five components: body stability versus body transport; object manipulation; intertrial variability; the environmental context; and reaction or anticipation to other people.

The first component of body stability occurs when the activity requires the person to remain in one place (e.g., using an elliptical machine). Body transport occurs when the activity requires the participant to physically move their body between two or more location points, such as jogging around a track or on a trail. Activities that involve body transport are considered more complex than activities that involve body stability.

Object manipulation occurs when the activity itself requires the individual to manipulate an object while engaged. For example, playing soccer, using resistance bands, or skiing are all activities where object manipulation occurs, and are more complex. Performing a lunge with body weight only or completing a set of ten sit-ups are examples of activities where there is no object manipulation; such activities are considered less complex.

Intertrial variability represents the variability that may, or may not, exist between each performance trial. Intertrial variability is present when each attempt at performing an activity is different from a previous or future attempt. When an activity is performed the same way for each trial, then intertrial variability is absent. Swimming laps in a pool using only the backstroke would be an example of PA where intertrial variability is absent. Meanwhile, golf is an example an activity where intertrial variability is present, or each trail is performed a different way. Activities that involve intertrial variability are considered more complex, as the performer is confronted with novel experiences while engaging in repeated attempts during the activity.

The last concept of Gentile's taxonomy of motor skills is in reference to the environmental context. The environmental context is 'in motion' if the individual must conform his or her movements to that of the environment while performing the activity (e.g., skiing, playing tennis). An environmental context that is considered 'stationary' is one where the individual does not have to adjust his or her movements to the environment (e.g., performing a bench press, using a rowing machine). An 'in motion' environmental context adds complexity to the activity being performed.

An additional dimension to the TC taxonomy was created to take into account the complexity that is added if the individual is required to respond to, or anticipate, the movement of others while engaging in the activity. If the activity is self-initiated, and the participant does not have to respond to the movements of other individuals, it would be considered less complex (e.g., performing a squat, mowing the lawn, jogging on a treadmill). However, if an individual is required to react to others (e.g., playing basketball) or to anticipate the movement of others (e.g., following a group fitness instructor) the activity would be classified as more complex. Table 2 shows the constructs, scoring and example activities for TC.

Table 2 Task Complexity (TC) construct and score.

Category	Component	Examples
A	Body Stability (1) Body Transport (2)	Darts Walking
B	No Object Manipulation (1) Object Manipulation (2)	Jumping Jacks Skiing
C	Intertrial Variability Absent (1) Intertrial Variability Present (2)	Bench Press Golf
D	Environmental Context Stationary (1) Environmental Context in Motion (2)	Swimming Laps Tennis
E	No Anticipation/Reaction to Others (1) Anticipation/Reaction to Others (2)	Stationary Bike Soccer

For each activity recalled by the participants, the SMEs individually provided a score for the activity based on each of the five components identified. The scores were then averaged, and the activity was given a score for TC with a range of 1.0-2.0 where an activity closer to 2.0 was considered more complex. See Table 3 for example for example of individual SME scoring for example activities. Table 4 shows the final scoring of the activity for TC based on the average of all SME ratings.

Table 3 Example of individual SME scoring for activity Task Complexity (TC).

Physical Activity Example	Component					Final TC Score
	A	B	C	D	E	
Resistance training Body Weight (no objects) alone at home	1	2	2	2	1	1.6
Rowing Machine at Gym	1	2	1	1	1	1.2
Senior Circuit Group Fitness Class	2	2	2	2	2	2.0
Walking the Dog (alone)	2	2	1	1	1	1.4

Table 4 Example of scoring activities based on all SME Task Complexity (TC) rating.

Physical Activity	Final Task Complexity Score	SME #1	SME #2	SME #3	SME #4	SME #5
Resistance Training Body Weight (no objects) Alone at Home	**1.24**	1.2	1	1.4	1	1.6
Rowing Machine at Gym	**1.36**	1.4	1.4	1.4	1.2	1.4
Senior Circuit Group Fitness Class	**1.96**	2	2	1.8	2	2
Walking the Dog (Alone)	**1.24**	1.4	1.2	1.2	1.0	1.4

2.4 Social Engagement

The taxonomy for SE during PA was developed with a 5-point scale, where 1 = no social engagement, 2 = limited social engagement, 3 = some social engagement, 4 = frequent social engagement, and 5 = constant social engagement. Activities labeled a ‘4’ or a ‘5’ were derived from Landers and Lüschen’s [33] description of interactive and coactive sports. According to this definition, coactive sports require much less, if any, team interaction and coordination to achieve their goals (e.g., golf, bowling, track and field). In contrast, interactive sports require team members to work together to coordinate their actions (e.g., soccer, basketball). SME were provided Table 5 with scoring, definitions and examples to follow when scoring the physical activities for social engagement. For each activity recalled by the participants, the SME’s individually provided a social engagement score for the activity. The scores were then averaged, and the activity was given a score for TC with a range of 1.0-2.0 where an activity closer to 2.0 was considered more complex (see Table 2 for example scoring). See Table 6 for example activities and final SE scores based on the average SME rating.

Table 5 Definitions and examples for Social Engagement (SE).

SE Score	Definition	Example Activity
No SE (1)	Activity is performed alone; no social interaction occurs	Walking on a treadmill at Home Resistance Training at Home
Limited SE (2)	Due to the context, social engagement may occur, but it is not necessarily required during the activity.	Hiking on a public trail Elliptical at a Gym
Some SE (3)	Context includes some social engagement while doing the activity.	Group Fitness Class Golfing in a group
Frequent SE (4)	Context offers frequent social engagement but success with the activity is not necessarily dependent on the interaction.	Group Fitness Class where partner work is required. Softball/Baseball
Constant SE (5)	Interacting socially with one (or more) people while engaging in the activity and is required to be successful.	Doubles Tennis Basketball

Table 6 Example of scoring of activities for Social Engagement (SE).

Physical Activity	Final SE Score	SME #1	SME #2	SME #3	SME #4	SME #5
Resistance Training Body Weight (no objects) Alone at Home	**1.16**	1	1	1.4	1	1.6
Rowing Machine at Gym	**2.0**	2	2	2	2	2
Senior Circuit Group Fitness Class	**3.0**	3	4	4	4	3
Walking the Dog (Alone)	**1.0**	1	2	1	1	1

2.5 Executive Function Measures

Three cognitive tasks were utilized to evaluate the core components of EF: cognitive flexibility/shifting, inhibition, and working memory, as well as a simple reaction time task to assess response latency. A computerized version of the Visual Choice Reaction Time task [34] was administered first to all participants to provide a pure measure of central processing speeds based on finger responses (pressing the space bar) to a visual stimulus. The subsequent three cognitive tests were administered in a randomized order to minimize learning effects from serial testing. Time to complete all four cognitive tasks was approximately 25 minutes.

2.5.1 Shifting / Cognitive Flexibility

The shifting component of EF refers to an individual's ability to alternate attention between two tasks with different overall goals [35]. The paper and pencil version of the Trail Making Test was utilized, as it has been found to be an efficient and sensitive instruction that reliability discriminates between normal individuals and those with cognitive impairment [36]. Poor performance on the Trail Making Tests may indicate a difficulty in shifting from one mental task to the other and predict issues with maintaining functional autonomy and independent living, particularly in daily activities [37]. Participants were instructed to first complete Trail Making Test A, where they are required to draw lines to connect numbers sequentially as fast as possible without lifting the writing utensil off the paper until all 25 numbers have been connected. Trail Making Test B was then administered immediately following the completion of the first test and required the participants to connect letters to numbers in sequentially (1 → A, A → 2, 2 → B, etc.) as quickly as possible. The time to complete each task was assessed, and larger differences (time to complete part B – time to complete part A) between the two tasks was indicative of greater impairment to shifting [38].

2.5.2 Inhibition

The flanker task [39] was used to assess inhibition, which refers to the ability to resist the interference of distracting stimuli and change a prepotent response [40]. This cognitive task has been utilized in previous research studies intended to examine an individual's ability to manage interference (irrelevant stimuli) and inhibit a prepotent response [41]. It has also been found to effectively evaluate executive control in older adult populations [42]. The flanker task is a computerized test that requires participants to identify the orientation of a central arrow cue "flanked" by other arrows congruent or incongruent with the target arrow. Congruent trials occur when the orientation of the flanking arrows is the same as that of the target arrow (→→→→→). Response latencies are typically faster, and responses tend to be more accurate during congruent trials. Incongruent trials occur when the orientation of the flanking arrows are in an opposite direction to the central target arrow (→→←→→). Incongruent trials require greater interference control utilizing inhibition than in congruent trials and typically result in longer response latencies and greater error [43]. The difference between the average response latency (milliseconds) and accuracy scores for incongruent trials was subtracted from the average response latency and accuracy for the congruent trials to determine the latency cost and accuracy cost with smaller differences indicating better inhibitory ability.

2.5.3 Working Memory

Researchers who have assessed EF with older adult populations have typically utilized the verbal digit span task and found it to be a valuable tool to measure working memory [44]. During the verbal digit span forward task, the participant is asked to repeat each sequence of numbers exactly as presented whereas the verbal digit span backward task requires the participant to repeat the sequence of numbers in *reverse* order (i.e., 6 – 9 – 4 should be repeated as 4 – 9 – 6). For the digit span sequential task, the test administrator provides a series of numbers and the participant is required to repeat the numbers in sequential order (lowest to highest). For example, 2 – 3 – 1 would be recalled out loud in the following order 1 – 2 – 3 if the participant is to be considered successful and allowed to move to the next trial of numbers. Each of the three tasks began with a sequence of two digits and increased by one digit each time to as many as eight digits for the backward digit span tasks and as many as nine digits for the forward and sequencing tasks. The testing was promptly stopped when the participant was unable to successfully recollect any two sequences within the same digit length for as many as 14 sequences. The overall score for the forward, reverse, and sequential digital span tasks was recorded and used as an index of working memory where greater scores indicated better working memory.

3. Results

The following sections include the results from the results from participant scoring for TC and SE according to their average weekly reported PA engagement, and EF task performance outcomes. Preliminary analyses and descriptive statistics in the form of means, standard deviations, and correlations were calculated for the demographics, predictor, and outcome variables. Findings from the multivariate multiple regressions conducted to assess the relationship between participants' TC and SE scores and EF performance are also reported.

3.1 Scoring and Distribution of TC and SE

Interrater reliability assessments assessed variations among the SMEs' scoring for each activity [45], and results indicated acceptable levels of interrater reliability among the raters for TC (.87) and SE (.97). Participants' PAs were recorded and TC and SE scores were assigned. To account for frequency of engagement in each activity, the scores for TC and SE were summed across the 7-day recall, which resulted in an average TC and SE score, as well as a FREQxTC and FREQxSE score (see Table 7 for example participant final scoring for SE, FREQxSE, TC, and FREQxTC). The sample mean value for SE was 2.76 (SD = 1.14) with a range of 1-5 and the sample mean value for FREQxSE was 24 (SD = 13.63). The sample mean value for TC was 1.57 (SD = .21) with a range of 1.3-1.9) and the sample mean value for FREQxTC was 14.17 (SD = 6.92).

Table 7 Example participant final TC, SE, and frequency scoring.

PPT ID: 114-RM	Avg SE	FREQxSE	Avg TC	FREQxTC
Day 1 (SE; TC) Walk Dog alone (1;1.24) Rowing Machine at Gym (2; 1.36)	1.5	3	1.3	2.6
Day 2 (SE; TC) No Activity Reported	0	0	0	0
Day 3 (SE; TC) Walk Dog w Spouse (4; 1.24) Yoga at Home No Video (2; 1.20)	3	6	1.22	2.44
Day 4 (SE; TC) Yoga at Home No Video (2; 1.20)	2	2	1.2	1.2
Day 5 (SE; TC) Senior Circuit Group Fitness Class (4; 1.96)	4	4	1.96	1.96
Day 6 (SE; TC) Walk Dog w Spouse (4; 1.24)	4	4	1.24	1.24
Day 7 (SE; TC) Walk Dog w Spouse (4; 1.24)	4	4	1.24	1.24
Total SE and TC Scores	**2.31**	**23**	**1.36**	**10.86**

3.2 Executive Function Outcomes

The mean response latency on the simple reaction time task for this sample of older adults was 309.80 milliseconds (*SD* = 59.08) with a range of 224.28 to 521.85 milliseconds. To assess cognitive flexibility, the total time to complete Trail Making Test (TMT): B was subtracted from TMT. The average time between the two tasks for the participants was 35.68 seconds (*SD* = 15.04).

Inhibition was assessed with a computerized version of the flanker task (Eriksen & Eriksen, 1974) where each participant received a score for response latency and success rate between the congruent and incongruent trials. The average difference in response latency for this sample of older adults was 33.53 seconds (*SD* = 19.68) and the average difference in correct responses was .68 (*SD* = 1.69) out of a total of 96 trials following 48 practice trials. The success rate in the data showed that the majority of participants performed congruent and incongruent trials without error. Thus, the success rate during the flanker test was removed from subsequent analysis based on the clear violation of the assumption of normal distribution.

To examine working memory, the verbal digit span task was administered and included the forward, backward, and sequential digit span tasks. Each participant could earn a possible 16 points for the three tasks, resulting in a total score of 48 points. The average score for the total digit span task for this sample of older adults was 29.24 (*SD* = 4.50) with a range of 16 to 41 points. Table 8 provides the means and standard deviations for all EF task outcomes and response latency.

Table 8 Results for executive function task performance.

Task	Mean, SD, Range
Response Latency	M = 39.80 ms, SD = 59.08 Range = 224.28 - 521.85 ms
Trail Making Test B – A	M = 35.68 sec, SD = 15.04 Range = .15 - 64.44 sec
Flanker Task	M = 33.53 ms, SD = 15.04 Range = 8.44 – 99.69 ms
Verbal Digit Span Score	M = 29.24, SD = 4.50 Range = 16-41

Note. M = mean, SD = standard deviation, ms = milliseconds, sec = seconds

3.3 Preliminary Analysis

To determine if multicollinearity was present for the two predictor variables (SE and TC), correlational analyses were conducted. Multicollinearity exists when two or more variables are highly correlated ($r > .70$) and suggests the PA characteristics assess similar constructs. In this case, no collinearity was detected. Table 9 shows the results from the correlational analyses between predictor and outcome variables, as well as the skewness and kurtosis values.

To assess the relationships among demographics and the EF outcomes, various analyses were utilized for the various demographic data. Independent sample t-tests were calculated for the binary categorical data (gender) and the cognitive outcome variables. These findings indicated no differences for EF value and average response latency times for males and females. A one-way ANOVA was conducted to compare the effect of additional household members on response latency, and the EF outcomes. The results indicated no significant difference between participants' current number of household members and EF performance and average response latency. Finally, simple linear regressions were conducted to evaluate the relationships among the remaining continuous demographic variables: age, completed years of education, physical fitness levels, and the outcome variables. The results of the first simple linear regressions indicated age did not explain a significant amount of the variance in response latency or executive function performance across tasks. Due to the lack of significant relationships, these demographic variables were removed from subsequent multivariate multiple regression analyses.

Table 9 Correlational analyses, kurtosis and skewness for predictor and outcome variables.

Variable	1	2	3	4	5	6
1. SE						
2. TC	.67**					
3. Response Latency	-.08	-.15				
4. Trail Making Test	-.12	.09	-.08			
5. Flanker Response Latency	.18	.25	.02	.10		
6. Digital Span Total	-.10	-.23	-.05	-.30*	-.35*	
Skewness	.32	.62	1.4	.75	.48	-.14
Kurtosis	-.13	-.67	2.4	.16	-.08	.50

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.4 Main Analyses

Multivariate multiple regression analysis was conducted to determine is a significant relationship existed between the set of predictor variables and the set of outcome variables. The analyses revealed a non-significant relationship among SE and performance on EF tasks and average response latency: Wilks' Λ = .09, F (12, 149) = 1.3, p = .53. The relationships among the predictor variable TC and the EF and response latency constructs were also non-significant: Wilks' Λ = .12, F (32, 189) = .88, p = .86. These results indicate that the level of TC and SE associated with PAs did not independently explain any significant portion of the variance in EF performance or average response latency. Table 10 displays the summary of the relationship between the predictor variables and the outcome variables.

Table 10 Summary of multivariate regression analyses for the PA characteristics predicting response EF and response latency.

Variable	Wilks' Lambda	Response Latency	Trail Making Test	Flanker Response Latency	Digit Span Total
SE Score	Wilks' Λ = .09, F(12, 149) = 1.3, p = .53	$R^2 = .00$	$R^2 = .04$	$R^2 =.01$	$R^2 =.00$
TC Score	Wilks' Λ = .12, F(32, 189) = .88, p = .86	$R^2 =.01$	$R^2 =.00$	$R^2 =.00$	$R^2 =.01$

4. Discussion

Previous research results suggest that engagement in cognitively demanding or socially interactive activities may be beneficial for cognitive function in older adults [2]. PAs can be designed to be both cognitively demanding, and/or socially engaging, in an effort to maintain, or even improve, cognition for aging adults. Results from previous studies examining TC and SE in a PA context among children and rodents indicate that these PA characteristics may positively influence brain structure and function [14-16]. This cognitive stimulation augments the many physical benefits (e.g., improved mobility, strength) older adults can experience through PA participation.

The first purpose of this study was to develop a measurement tool to assess the level of TC as well as SE within various activities and contexts. This effort was intended to assist future researchers to better design PA interventions in relation to these PA characteristics. The taxonomies that were developed allow the researcher to obtain a value to describe the TC and SE levels for any given PA. The direct, or indirect, influence of these characteristics on cognitive function can then be evaluated.

The second study purpose was to examine the influence of the predictor variables (TC and SE) on EF performance in active, older adults. It was hypothesized that older adults who report participation in PAs that were motorically/cognitively complex in nature, and/or socially engaging, would perform better on cognitive tasks that require executive processes when compared to older adults who report more frequent engagement in simple, or individualized physical activities. The results indicate that variance in EF performance among older adults was not explained by their engagement in socially engaging or complex activities. This finding contrasts with recent randomized control studies that reported more PA participation and better mental health [25] among older adults who engaged in socially interactive activities. The cross-sectional approach implemented in the current study was similar to the approach of Dai and colleagues [18], however, the results are inconsistent. Results from Dai et al. [18] showed superior EF performance among participants who reported more frequent engagement in complex exercise settings, while the current results show that more frequent engagement in complex or socially engaging PA settings do not influence the variance in EF performance. To more effectively address this research question, a controlled research design (e.g., randomized control trial) would be beneficial to evaluate the relationship between TC and SE activity characteristics and cognitive function.

5. Limitations and Considerations for Future Research

Several limitations should be considered in the interpretation of the results from the main analyses of this study. The first objective was to identify the levels of TC and SE associated with the types of physical activities recalled by the participants. While the Gentile's taxonomy provides a great starting point to operationalizing TC for a PA, other components may also create more, or less, complexity such as movement speed, or previous experience with the activity. Such additional complexity components should be considered when assessing this activity characteristic. Similarly, other SE components could be considered in future studies aiming to quantify this activity component, such as preferred level of SE or the degree to which a verbal interaction occurs during the activity. Future studies should also consider the use of technologies (e.g., fMRIs) to further explore the relationship between activity characteristics and cognition. Finally, an interview was conducted to assess a typical week of PA for each participant. Although this method has been used in various studies to assess PA frequencies, durations, and intensities [46, 47], an inaccurate portrayal of typical weekly PA engagement is often reported. This limitation might be due to social desirability effects where a participant may over-report positive behaviors such as healthy eating or regular participation in PA [47, 48]. To counteract these results, a validated questionnaire should be administered [48] or, an objective assessment can be employed such as observations or through the use of a technology (e.g., Fitbit or pedometer) to obtain a more valid measure of PA.

6. Conclusion

Operational definitions and a taxonomy to quantify the PA characteristics of TC and SE was proposed in the current study. Although results from the current study indicated SE and TC were not significantly related to EF outcomes, the methodological approach to operationalizing these two characteristics for various types of PAs can make a meaningful contribution to the literature. PA contexts that offer both — complexity and social interaction, may result in greater gains to cognitive function than simple, or individualized, PA environments. PA has been found to have a positive impact on performance on tasks requiring EF [e.g., 7]. PA interventions for older adults that involve high levels of TC and SE may help to prevent, slow, or even reverse age-related cognitive decline through the preservation of executive functioning. Intentionally designed PA interventions have the potential to improve cognitive function through purposeful integration of complex PAs and opportunities for SE during the activity for older adults.

Author Contributions

Drs. Koon, Brustad and Babkes Stellino worked together to establish the objectives of this research study and the methods employed. Data collection efforts were those of Dr. Koon, data analysis and the results were supervised and conducted by Drs. Brustad and Koon. The overall preparation and revision of this manuscript was a combined effort by all three authors.

Competing Interests

The authors have declared that no competing interests exist.

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