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Examining the Relationship Between Health-Related Fitness and Motor Competence in College-Aged Students

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Examining the Relationship Between Health-Related Fitness and Motor Competence in College-Aged Students

by

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Introduction

Sustaining a healthy population is a global goal. For adults, participating in 150 to 300 minutes of moderate-to-vigorous physical activity each week confers a multitude of health benefits (U.S. Department of Health and Human Services, 2018; Piercy and Troiano, 2018). However, U.S. adults are falling short of this goal. A report from the Centers for Disease Control in 2018 indicated that only 24% of U.S. adults meet the guidelines for aerobic physical activity and muscle-strengthening activity (Center for Disease Control, 2018). A core outcome related to physical activity is one's level of health-related fitness (HRF). While physical fitness is defined as "a set of attributes that people have or achieve that relates to the ability to perform physical activity", HRF involves those components of physical fitness that have specifically been linked to health outcomes (e.g., cardiorespiratory endurance, muscular strength, muscular endurance, flexibility, and body composition) (Morrow et al, 2015, pg. 13). As HRF components have found to be a stronger predictor of morbidity and mortality compared to physical activity, it is vital to understand HRF levels in low-active populations (Lavie et al., 2019).

A key correlate of physical activity and HRF is one's level of motor competence (MC; Sallis et al., 2000; Barnett et al., 2016). MC is defined as goal oriented human movement and is known by a number of different terms including, but not limited to: motor proficiency, motor performance, fundamental movement/motor skill, motor ability, and motor coordination (Robinson et al., 2016). A specific subcomponent of MC are fundamental movement skills (Logan et al., 2017). Fundamental movement skills are also referred to as basic 'building blocks' of more advanced movements and represent discrete movements with a common, developmental pattern that occur when an individual performs the skill (Clark & Metcalfe, 2002; Logan et al., 2017). There are three distinct categories of fundamental movement skills including: locomotor, object control, and stability (Logan et al., 2017). Locomotor skill involves moving from one place to another through space (e.g., walking, running, or skipping). Object control skills are gross motor movements used to project or receive an object (typically a ball) in space often done using the hands or feet (e.g., throwing, kicking). Stability skills are those in which axial movements and other movements support in balance while the base of the body does not move (e.g., twisting, swaying) (Gabbard, 2018). Most of the evidence around competence in fundamental motor skills has been in pediatric and adolescent populations (Hulteen et al., 2020). This is due to the importance of developing a wide base of skill competencies from an early age to give an individual more choice, opportunity, and possible success when being active (Clark & Metcalfe, 2002; Hulteen, Morgan, et al., 2018). However, motor skills remain important across the lifespan and there is a critical need for a greater understanding of MC in older populations (Barnett, Stodden, Hulteen, and Sacko, 2020).

When assessing MC two broad types of measures are used, product measures and process measures (Hulteen et al., 2019; Logan et al., 2016). Product measures involve recording and grading the quantitative outcomes of skills (e.g., kicking speed, distance a ball is thrown). Product measures are only concerned with the quantitative outcome without an understanding of *how* the movement was completed. In contrast, process measures involve grading skills based upon technique through the observation of whether specific criteria were performed or not (Barnett, Stodden, Hulteen, and Sacko, 2020). These measures are concerned with *how* a movement is performed without (typically) the outcome of the movement being considered. Such information is useful for the identification of skill deficiencies and providing more specific feedback to participants. Common examples of process measures include: the Test of Gross Motor Development (Ulrich, 1985; 2000; 2019), the Lifelong Physical Activity Skills Battery (Hulteen, Barnett, et al., 2018a), or the Victorian Fundamental Motor Skill Assessment (Department of Education Victoria, 1998). A con of process measures is that the rating of each movement can be very time consuming (i.e., videoed and scored at a later date), requires more subjective decision making, and involves more training and coding. Previous studies have found that both product and process measures can be used to assess MC and when used together provide a more holistic understanding of MC. For example, Logan et al. (2017) found weak to strong correlations (r = .26–.88) between process and product- fundamental motor skill performances. Ultimately, our choice in MC measurement may affect the statistical associations that we may find with other health-related variables (e.g., physical activity, fitness, perceived competence).

In 2008, Stodden and colleagues published a conceptual model which proposed a synergistic relationship between MC and physical activity (Stodden et al., 2008). This relationship was suggested to be mediated by HRF and perceived competence. Taken together, these core constructs were hypothesized to predict weight status and one's positive or negative trajectory for obesity. Since its publication, many studies have examined the multitude of pathways proposed by Stodden and colleagues (Barnett et al., 2021; Robinson et al., 2016). HRF and MC has been one of the more popular pathways examined in cross-sectional and longitudinal studies. While recent work has shown the MC-HRF pathways has strong empirical support in younger populations, we still know very little about the relationship between MC-HRF in older populations (18+ years old).

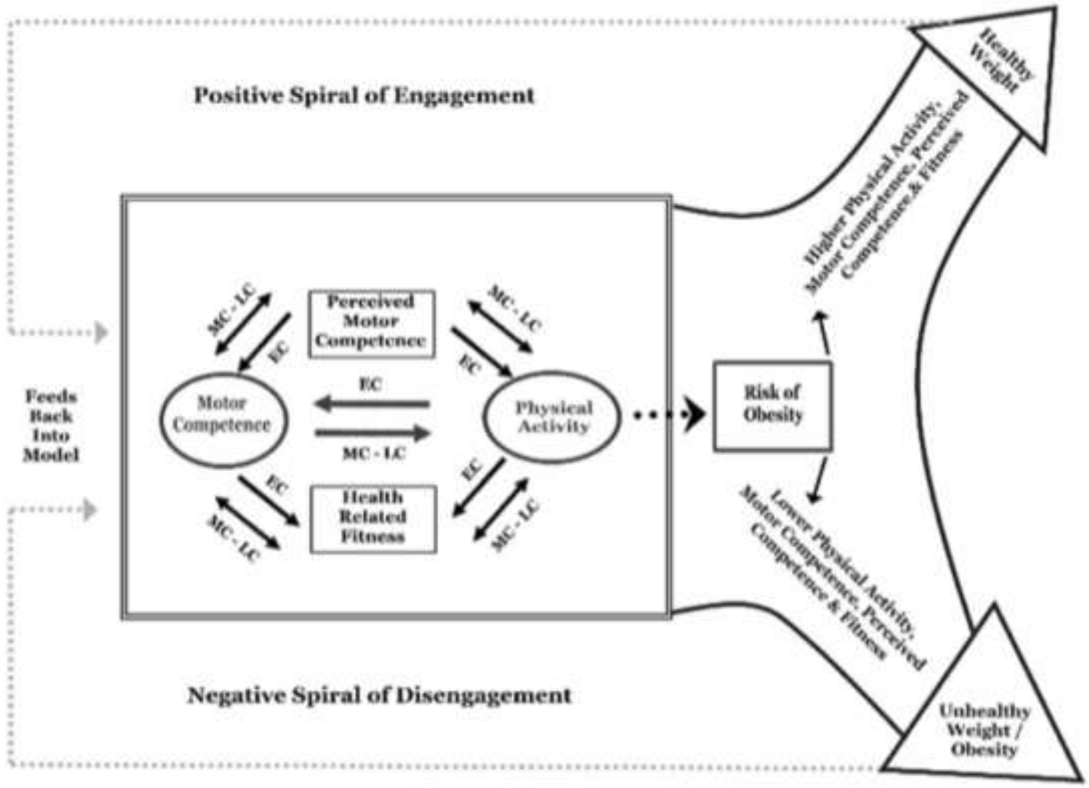

Figure 1. Copy of Conceptual Model from Stodden et al. 2008 with permission from Taylor and Francis at www.tandfonline.com

In one of the few studies that exist measuring MC and HRF in older populations, Moss and colleges examined the relationships among MC, HRF, and perceived motor competence, in college-aged males (Moss et al., 2020). The study involved 57 male participants who were enrolled in an undergraduate kinesiology class. MC was quantified as a product measure of max throwing speed, max kicking speed, and standing long jump distance. HRF was measured using three tests: push-ups, sit-ups, and the Multistage 20-meter Shuttle Run Test. Stodden and colleagues in 2013 published a study which examined MC and HRF in college-aged individuals (Stodden et al., 2013). Seventy-nine males and one-hundred and nine women participated in the study. Similar to Moss et al., 2020, MC was quantified as a product measure of max throwing speed, max kicking speed, and standing long jump distance. HRF was measured using six tests: 12-minute walk/run, body fat percentage, curl-ups, grip strength, sit and reach, and maximum leg press. These studies have been an important step forward for the field in terms of expanding the age groups that MC is assessed. However, more evidence is needed and this research may further benefit from looking at both product and process MC scores and its relationship to fitness outcomes.

The purpose of this study is to determine the relationships between MC, as assessed using both process and product outcomes, with components of HRF in a sample of college-aged students.

Aims and Hypotheses

Aim 1: Determine the relationship between product and process MC outcomes and components of HRF in college aged students.

Hypothesis 1: There will be moderate to strong correlations between product and process MC outcomes and all aspects of HRF. These correlations will all be positive except for cardiorespiratory endurance and body composition which will be inversely (negatively) associated with MC outcomes.

Aim 2: Determine the associations between process- and product-oriented MC outcomes for matched skills in college aged students.

Hypothesis 2: There will be weak to moderate associations between process- and product-oriented scores for all motor skills.

Methods

This project was approved by the LSU IRB; all participants were provided with a consent form and information on the study prior to completion of any study assessments. Participants were able to ask the study team any questions they had. Once consent was received, data collection was scheduled at a time convenient to each participant. For the health and safety of participants, pre-screening was conducted and consisted of completing the Physical Activity Readiness Questionnaire for Everyone (PARQ+) and the Electronic Physical Activity Readiness Medical Examination (ePARmed-X+; Warburton et al., 2011). If during the ePAR-medX+ the participant indicated yes to any of the questions, then physician's approval was required to participate in the study. The participant was made aware of this after examination of their survey and prior to be contacted about scheduling for the study.

Sample

Data for the current project were collected during the 2021-2022 school year. All participants were recruited from a large university in the Southeastern United States. Inclusion criteria for the current study was a) individuals who are currently enrolled as a student at the target university, b) individuals are between the ages of 18 and 25 years, and c) participants must have the physical capacity to complete a variety of motor skills and physical fitness testing.

Procedure

All assessments were all completed with one to two participants at a time. Time to assess a single participant was between one and one and a half hours. All measures were administered by a trained research assistant in the same order for all participants. The participants were given free time to rest after each test and trial. Participants started with the collection of their height, weight, and body fat percentage. Next, the participant would be lead through a warmup or allowed to warm up on their own if requested. The one-mile run was completed. The participant then completed the sit and reach followed by the hand grip strength test. The participant could then complete the two-minute push-up or sit-up test in whichever order they preferred. Next, the overhand throw and kicks were completed. Finally, the standing long jump was completed ending with the hopping test. The trained research assistant received a minimum of two hours training and was supervised by another researcher with 8 years of research experience. All protocols were administered following standardized procedures as outlined in a written study protocol document. All assessments took place at the university recreation center at either the indoor track or a hardwood, indoor squash court.

Demographics

Ethnic background, hometown, and country of origin were self-reported on an online Qualtrics questionnaire. Questions were aligned with similar demographic questions from the U.S. census. Demographic details for the sample can be seen in Table 1.

Health-Related Fitness

All components of HRF were measured in the study. This includes: body composition, cardiorespiratory fitness, flexibility, upper and lower body muscular strength, and upper body and abdominal muscular endurance. Specific protocol details are listed below.

Body Composition

Two outcomes related to body composition were assessed, body mass index and body fat percentage. Shoes, socks, bulky clothing (e.g., sweatshirt), and items in pockets (e.g., phone, keys) were removed prior to the assessment of height and weight. Height was assessed using a portable stadiometer (Model number Seca 213) to the nearest 0.1 centimeter. A minimum of two measurements for height were taken to ensure that measured height was within 0.3 centimeters of each other. If this did not occur, a third measurement was taken. Weight and body fat percentage was assessed using a bioelectrical impedance scale (Model number Tanita BF-679W). Weight was measured to the nearest 0.1 kilogram and body fat percentage was reported as displayed on the scale to the nearest tenth of a percentage. Results from height and weight were used to calculate body mass index.

Cardiorespiratory Fitness

Cardiorespiratory fitness was assessed using the one-mile run/walk. For this assessment, participants were told to run/walk a mile as fast as possible with the time taken to complete the mile recorded as their final result. Prior to the one-mile run/walk, each participant was led through a guided warm-up or participants could choose to complete their own warm-up. This was done to decrease the risk of any injury, as well as ensure the participant was warmed-up for additional assessments (i.e., flexibility). The one-mile run/walk was completed at an indoor track (three laps in total). General encouragement was given by the data collection team (i.e., “Good job, keep it up”) and lap times were read aloud, if requested by the participant. Previous research has found a strong correlation ($r = 0.78$) between results in the one-mile run and VO2 max in college aged students (Sharon and Liu 1999).

Flexibility

The back-saver sit and reach was used to measure trunk and hamstring flexibility. Flexibility is joint specific so no one test can accurately gauge a person's "general" flexibility. This was the first assessment completed after the one-mile run. Shoes were taken off for this assessment. After a brief explanation and demonstration, participants were given three attempts to obtain their highest result while keeping their legs straight and on the ground. If participants raised their knees off the floor at any point throughout the assessment, they were given one retry per attempt. If two consecutive attempts had the knees come off the ground a score of zero was recorded for that attempt. Results were recorded in centimeters. The average of the three results were taken and used as the final result for analytic purposes.

Upper-body Muscular Power

A Jamar hydraulic hand dynamometer (serial # 1611864) was used to measure handgrip strength of each participant's left and right hand. First, each participant was given a verbal explanation of procedures and a visual example of how the assessment was to be completed. The dynamometer was then adjusted to fit the participant's hand size. Next, the participant gripped the device with their arm down by their side with elbow extended. Each participant was instructed not to twist their elbow or wrist during the trial (i.e., such movements would count as an invalid attempt). A count down was given to each participant and when "zero" was reached, the assessment began with participants squeezing for three seconds. During the assessment the data collectors provided a countdown to alert participants to keep squeezing the dynamometer. Two trials for each hand were completed with attempts alternating from left to right hand. Self-paced rest was provided for participants between each attempt. Results were recorded to the nearest whole number in kilograms.

Lower-body Muscular Power

The standing long jump was used to measure lower-body muscular power with results recorded to the nearest centimeter. Participants were directed to stand with both toes behind the starting line. The participant was instructed to jump as far as possible while landing on their feet and holding their position until their result could be recorded. Measurements were taken from the heel of the back most foot. If the participant fell or moved both feet forward, the trial was redone. A maximum of three jumps was given for each trial (jump only redone if failed attempt occurred for the trial). If the jump was voided three times in a row that trial was assigned a score of zero. If a participant landed, but then took a step backward, this was a valid trial with a result recorded. Five trials (non-voided jumps) were recorded per participant.

Upper-body Muscular Endurance

A two-minute push-up test was used to measure upper-body muscular endurance. Push-ups were performed in accordance with the U.S. Army Physical Fitness Test. (Department of the Army, 1992). Participants had two minutes to complete as many proper form push-ups as possible. Proper form includes keeping the body in one straight line, bending elbows to 90 degrees, nose close to touching the ground, and keeping your balance on your toes (i.e., no knee push-ups for women). The test was self-paced, participants could stop and rest at their own discretion. If elected to, participants were given 1-minute, 30 second, and 15 second time warnings. Prior to beginning the assessment, a demonstration of a proper push-up was given. If during the trial participants were completing the push-up incorrectly, feedback was provided so the participant could make adjustments. The final result recorded was the number of correct push-ups completed in the two-minute time period.

Abdominal Muscular Endurance

The two-minute sit-up test was used to measure abdominal muscular endurance. Sit-ups were performed in accordance with the U.S. Army Physical Fitness Test. (Department of the Army, 1992). In a similar manner to the push-up test, participants had two minutes to complete as many proper form sit-ups as possible. Proper form includes keeping the arms crossed in front of the chest, hitting the elbows to the knees, and touching the back to the ground. A demonstration was provided to each participant prior to beginning the test. The test was self-paced, participants could stop and resume at their own discretion during the testing period. If elected to, participants were given 1-minute, 30 second, and 15 second time warnings. Participants feet and ankles were held by a research assistant for the duration of the test. The final result recorded was the number of proper sit-ups completed in two-minutes.

Motor Competence (MC)

Four skills were assessed using various process and product measures. These skills included two object control skills (throw, kick) and locomotor skills (hop, jump). For each of these motor skills there were either four trials (hopping; hopping on each foot twice) or five trials (throw, kick, jump). Further details outlining the process and product outcomes for each skill is detailed below.

Overhand Throw

Competence in overhand throwing was assessed via developmental sequences (process; Roberton and Konczak, 2001) and maximum throwing speed (product; (Stodden et al., 2013)). Each participant threw a tennis ball from approximately 20 feet away from a wall. There was a camera (i.e., Apple iPad) from the lateral view to examine the developmental sequences at a later time using Dartfish. The research team stood 10 feet behind the participant to measure ball speed with a radar gun (Stalker Pro II + model number KA-2M). See Diagram 1 for a visual representation of each motor skill set up. Prior to the actual throwing assessment taking place, each participant was asked to complete a progressive warm-up to decrease the possibility of injury when throwing with maximal capacity. This warm-up was self-paced, and participants could take as long as they needed. The participant then, upon the direction of the research team, completed five valid throws (i.e., ball speed recorded and camera capturing movement). The only instructions given to each participant was that they should "throw the ball as hard and as fast as possible." The mean of the five throws were used as the final product outcome and the median score for developmental sequences were used for each component and then summed to create a skill score to be used in the final analyses.

Kick

Competence in kicking was assessed via developmental sequences (process; Sacko et al., 2021) and maximum kicking speed (product; (Stodden et al., 2013)). Each participant kicked a kickball from approximately 20 feet away from a wall. The kickball was placed in a square marker made from duct tape. There was a camera (i.e., Apple iPad) from the lateral view to examine the developmental sequences later using Dartfish. The research team also stood behind 10 feet behind the participant to measure kickball speed with a radar gun (Stalker Pro II + model number KA-2M). See Diagram 1 for a visual representation of the set up. Prior to the actual kicking assessment taking place, each participant was asked to complete a progressive warm-up to decrease the possibility of injury when kicking with maximal capacity. This warm-up was self-paced, and participants could take as long as they needed. The participant then, upon the direction of the research team, completed five valid kicks (i.e., ball speed recorded and camera capturing movement). The only instructions given to each participant was that they should "kick the ball as hard and as fast as possible." The mean of the five kicks were used as the final product outcome and the median score for developmental sequences were used for each component and then summed to create a skill score to be used in the final analyses.

Standing Long Jump

The standing long jump has been used in prior studies as both a measure of fitness (Hulteen, Barnett, et al., 2018b) and a measure of MC {Logan et al., 2017; Stodden et al., 2013). Thus, in this study the standing long jump was also used as a motor skill assessment. Protocols for the standing long jump were exactly the same as described above. The product outcome was distance jumped (in centimeters) and the process of the movement was examined using developmental sequences by a member of the research team after testing (Clark and Phillips 1985,1989). A camera (e.g., Apple iPad) was placed at the lateral view to record all jumps. See Diagram 2 for specific set-up details. The mean of the five jumps were used as the final product outcome and the median score for developmental sequences were used for each component and then summed to create a skill score to be used in the final analyses.

Hop

Hopping was assessed by examining the average hop distance (product outcome; (Logan et al., 2016)) and the process of how the hop was completed via developmental sequences for both the left and right leg (Roberton and Halverson, 1988). Cones were placed twenty feet apart with different color cones five feet further on each side of the original cones. See Diagram 3 in supplementary files for specific set-up. The participants were asked to hop on one leg “as hard and as fast as possible” from the set of cones that were farthest away from one another. This was done to ensure that hopping could be safely performed in the enclosed court space used for analyses. Two trials on each leg were performed for a total of four trials. The camera was placed at the lateral view and focused specifically on the inside set of cones, as these were the only hops to be examined. The mean of the hops completed within the 20-foot area for the left and right foot were used as the final product outcome. The median score for developmental sequences was used for each component and then summed to create a skill score to be used in the final analyses.

Analyses

Version 28 of SPSS (SPSS Inc., Chicago, IL, USA) was used to conduct all analyses. Prior to analyses, data were checked for missing and invalid values (values outside of possible ranges), however, no missing data or invalid values were found. Means and standard deviations were calculated for the total sample, as well as for males and females. Both Pearson’s Product-Moment and Spearman’s Rho correlation coefficients were calculated. Pearson Product-Moment correlation coefficients were calculated to examine the relationship between individual measures of HRF and MC outcomes. Spearman’s Rho correlation coefficients were calculated to determine the relationship between product and process measures of MC. Standard categories for interpretation of correlation coefficients are as follows: low (r = 0.01-0.29), moderate (r = 0.30-0.49), and high r ≥ 0.50) (Cohen, 1988).

Results

Demographics

Participants in the study (n = 15.00, 7.00 men, 8.00 women; *M* age 21.00 +/- 1.51 years) were recruited from a large southeastern university. The majority of participants were American (n = 8.00). Five participants reported multiple ethnicities. Full demographic details can be viewed in Table 1.

Table 1. Demographic Information of Participants

Variables	**Male**	**Female**	**Total**
Number	7.00	8.00	15.00
Age (Mean)	20.71	21.25	21.00
Age (SD)	1.38	1.67	1.51
Ethnicity			
American	4.00	4.00	8.00
Italian	0.00	1.00	1.00
Persian	1.00	0.00	1.00
Mixed	2.00	3.00	5.00

SD = standard deviation

Health-Related Fitness

The average participant had a "normal" body mass (*M* BMI= 24.02, standard deviation = 3.19). The average male participant was in the "overweight" category (*M* BMI for males = 26.2, standard deviation = 2.88) while the average female participant was in the normal range (*M* BMI for females = 22.1, standard deviation = 1.95). Males tended to outperform females on measures of HRF, except for the sit and reach (*M* male value = 27.86, standard deviation = 8.06; *M* female value = 37.04, standard deviation = 7.35) and sit-ups (*M* male value = 39.71, standard deviation = 9.10; *M* female value = 48.75, standard deviation = 12.61). A detailed overview of HRF outcomes for the total sample and split by self-reported gender can be viewed in Table 2.

Table 2. Mean and standard deviation values for health-related fitness outcomes

Variable	Male Average	Male SD	Female Average	Female SD	Total Average	Total SD
Weight (kg)	81.86	8.65	59.68	7.16	70.03	13.74
Height (cm)	176.74	6.44	164.27	4.45	170.09	8.31
BMI	26.20	2.88	22.10	1.95	24.02	3.19
Body Fat %	20.05	6.60	24.81	5.69	22.59	6.39
Mile Time (Min:Sec)	7:53	2:01	8:55	1:07	8:26	1:38
Sit & Reach (cm)	27.86	8.06	37.04	7.35	32.75	8.79
Grip Strength Right (kg)	18.37	5.38	10.74	2.49	14.30	5.57
Grip Strength Left (kg)	17.27	6.98	10.17	3.03	13.48	6.26
#Push-Ups	29.14	11.08	8.25	6.43	18.00	13.77
#Sit-Ups	39.71	9.10	48.75	12.61	44.53	11.69
Standing Long Jump Distance (cm)	191.14	50.67	153.86	22.91	171.26	43.20

kg = kilogram; cm = centimeters; min: sec = minutes: seconds;

Motor Competence

Males outperformed females in all MC product and process outcomes. As one example, males outperformed females on throwing speed (*M* male = 47.54 mph; *M* female = 38.73 mph) and developmental sequence score (*M* male = 12.00; *M* female = 11.13). Average scores and their standard deviations for males and females as well as the total average and standard deviation can be found in Table 3.

Table 3. Mean and standard deviation values for MC product and process outcomes

Variables	Male Average	Male SD	Female Average	Female SD	Total Average	Total SD
Over-Hand Throw (mph)	47.54	7.83	38.73	11.59	42.84	10.71
Over-Hand Throw[a]	12.00	1.63	11.13	2.42	11.53	2.07
Kick (mph)	44.71	5.93	33.10	5.46	38.52	8.18
Kicking[b]	12.86	1.77	11.14	1.07	11.87	1.68
Standing Long Jump Distance (meters)	1.91	0.51	1.54	2.29	1.71	4.32
Standing Long Jump[c]	18.29	2.29	17.88	2.29	18.07	2.31
Hopping Left (meters)	1.81	0.18	1.52	0.09	1.66	0.12
Hopping Left[d]	7.00	1.07	6.07	1.02	6.57	1.15
Hopping Right (meters)	1.71	0.21	1.47	0.15	1.58	0.18
Hopping Right[d]	7.00	1.19	5.94	0.68	6.43	1.07

mph = miles per hour; a = max score possible is 15; b = max score possible is 18; c = max score possible is 23; d = max score possible is 9

All Pearson Product-Moment correlation values can be viewed in Table 4. Overall, values ranged from weak to strong and 22 correlations were found to be significant between components of HRF and MC outcomes. Product outcomes of MC displayed more significant correlations and to a stronger degree compared to process measures of MC and HRF. Product outcomes of MC for the standing long jump (n = 4) and kick (n = 5) had the most statistically significant correlations with HRF outcomes. Push-ups were significantly correlated to kicking product score (r = .82). The one-mile run/walk was negatively correlated with all other aspects of HRF and MC product and process outcomes. Similarly, body fat percentage was inversely correlated to all other components of HRF and the product and process measures of MC, except for developmental sequences for hopping on the right leg (r = .12).

Table 4. Pearson Product Correlations Between Components of Health-Related Fitness and Motor Competence

MC→ HRF↓	Standing Long Jump (Product)	Throw (Product)	Kick (Product)	Hop Right Leg (Product)	Hop Left Leg (Product)	Throw (Process)	Kick (Process)	Standing Long Jump (Process)	Hop Right Leg (Process)	Hop Left Leg (Process)
BMI	.17	.11	.41	.02	-.01	-.02	.12	-.07	.50	.40
Body Fat %	-.46	-.33	-.33	-.46	-.47	-.28	-.28	-.18	.12	-.047
Mile	-.65**	-.40	-.54*	-.63*	-.55*	-.28	-.23	-.52*	-.39	-.26
Sit and Reach	.09	-.43	-.34	-.00	.14	-.22	-.30	-.03	-.12	-.15
Grip (Right)	.67**	.41	.72**	.41	.50	.24	.42	.20	.55*	.55*
Grip (Left)	.54*	.34	.58*	.30	.39	.14	.25	.11	.44	.49
Push-Ups	.65**	.66**	.82**	.43	.47	.41	.51*	.16	.25	.48
Sit-Ups	-.49	-.18	-.28	.07	.04	-.26	-.48	.17	-.24	-.13
Standing Long Jump	1.00	.57*	.84**	.80**	.87**	.47	.79**	.44	.59*	.53*

BMI – Body Mass Index, *correlation is significant at the .05 level, **correlation is significant at the .01 level

Product vs Process Measures

All results for the Spearmen's rank correlation coefficients can be found in Table 5. Notably, object control skills had significant relationships when matching skills (e.g., kick product vs kick process), while locomotor skills did not. The relationships between object control skills were also stronger (throw r = 0.88; kick r = 0.79) as compared to locomotor skills (standing long jump r = .47; hopping right r = .48 hopping left r = .35). The process score for kicking was significant with every product outcome of MC.

Table 5. Spearman's Rank Correlation Coefficient Between Product and Process Motor Competence

Product→ Process↓	**Throw**	**Kick**	**Standing Long Jump**	**Hopping Right**	**Hopping Left**
Throw	.88**	.56*	.43	.43	.49
Kick	.77**	.79**	.66**	.58*	.52*
Standing Long Jump	.37	.45	.47	.68**	.55*
Hopping Right	.25	.59*	.60*	.48	.32
Hopping Left	.57*	.65**	.57*	.41	.35

*correlation is significant at the .05 level, **correlation is significant at the .01 level

Discussion

The purpose of this study was two-fold. First, to examine the association between components of HRF and MC outcomes in college-aged students. Second, to determine the association between process and product measures of MC in college-aged students. Studies examining HRF and MC relationships in college-aged people are lacking. This study fills a gap in the current literature and while small in sample size, the use of novel MC measurement techniques (product- and process-oriented tools) provide unique insight into the potential importance of MC assessment practices.

The relationship between HRF and MC was mixed with correlations ranging from weak to strong. Product outcomes such as the standing long jump and kick appear to have a stronger relationship to fitness outcomes relative to other skills. The standing long jump may be more strongly correlated to measures, as it can be classified as both a fitness measure (lower body muscular power) or a motor skill depending on how it is assessed. The extent to which product and process outcomes of kicking related to push-ups and grip strength is surprising. It could be that people who had a good standing long jump were more muscularly fit overall. Surprisingly, the relationship between push-ups and multiple components of MC were strongly and significantly related. Given three out of the four MC measures involved use of the lower body, we might expect lower body-oriented fitness measures to correlate more strongly than the push-ups which measures upper body muscular endurance. Balanced against the smaller sample in this study this result should be interpreted with caution, as it may not hold up if the sample size was expanded. This result is also interesting because in a study by Moss et al. 2020 which examined college-aged males, push-ups were weakly correlated to throwing ($r = .23$), moderately correlated with kicking ($r = .35$), and strongly correlated to the standing long jump ($r = .60$). These are substantially different values than what we observed. This could possibly be explained by our inclusion of females in the current study's sample, or it could be a true difference. Further studies with a larger sample will be necessary to more conclusively determine the association between push-ups and MC outcomes.

The relationship between product and process measures of MC appears to be stronger and more closely linked with object control skills (throw $r = 0.88$; kick $r = 0.79$) compared to locomotor skills (standing long jump $r = .47$; hopping right $r = .48$ hopping left r = .35). A previous study looking at the correlation between product and process MC measures in children, Logan and colleagues found that the correlations for throwing (object control skill) increased in strength with age. However, locomotor skills of jumping and hopping demonstrated a declining strength of relationship with age. This trend fits the current data presented in this study. Indeed, the strength of relationship between throwing product and process outcomes was even stronger in the current study (r = 0.88) compared to Logan et al's study in children (r = .29-.71). However, the study in children reported a stronger correlation between product and process outcomes for hopping (r = .56-.76) compared to the current study (r =.32-.48). The relationship between product and process outcomes for jumping were also stronger in the oldest child age group (r = .65) compared to the current study (r =.47). It seems that object control skills product-process correlational relationships tend to strengthen over time while locomotor skills product-process relationships tend to decrease over time. This could be explained due to object control skills developing later in life as compared to locomotor skills.

As with any study, there are some notable limitations to this study. First, this study relied on a convenience sample and only included 15 participants, all of whom attended a single southeastern public university. Recruiting and assessing a small, homogenous sample limits the generalizability of our results. The sample also appeared to be relativity fit which could have an unknown impact on variable relationships. Another limitation of this study was that only four motor skills were assessed. Assessing a limited number of skills provides only a narrow understanding of MC in this population.

The strengths of this study include the use of both product and process MC assessments. This provides a more holistic understanding of MC and may tell us unique information about the relationship between HRF and MC that we would not have if only process or product measures were used. Further, the use of five trials for skills and the use of developmental sequences is advantageous it allows for discrimination and sensitivity to note differences among participants. Another strength includes the comprehensive number of fitness assessments used that targeted each aspect of HRF.

In the future, completing this study again with a greater and more diverse sample size would be interesting to see if the results and relationships found would remain constant. A study like this one to specifically look at sex differences could provide valuable new data as gender/sex differences were not calculated. Continuing to increase the testing of MC in older populations (25+ years) would also be interesting to begin to understand the potential lifespan importance of MC and its relationship with HRF. Completing a longitudinal study examining these same participants in 5-10 years to examine developmental changes could provide data on how HRF and MC change with age as well as how product-process outcomes for locomotor and object control skills would change.

Conclusion

The relationships between HRF and MC as well as the relationships between product and process outcomes of MC can vary greatly. However, this study did find that there was generally a strong correlation between HRF and MC in college-aged people. Product outcomes of MC tended to have a stronger relationship with HRF than process outcomes of MC. The MC product-process relationships varied based on the type of skill, but object control skills showed a stronger relationship than locomotor skills. Examining the correlation between HRF and MC is important as both can be potential indicators of health. The insight on the relationship of product to processes evaluations of MC is important as selecting which evaluation to use in a motor study can have a great impact on the results drawn from the study.

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Supplementary Files

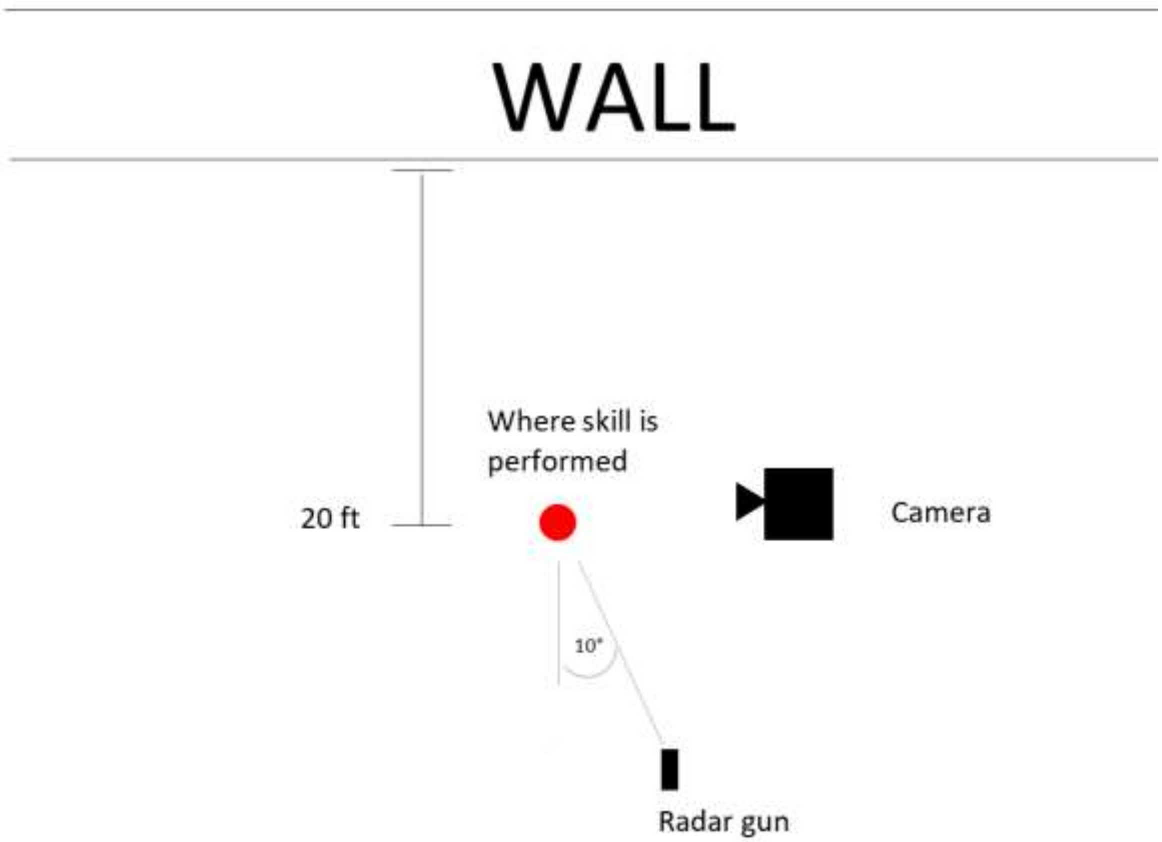

Diagram 1. Throw and Kick Set-Up

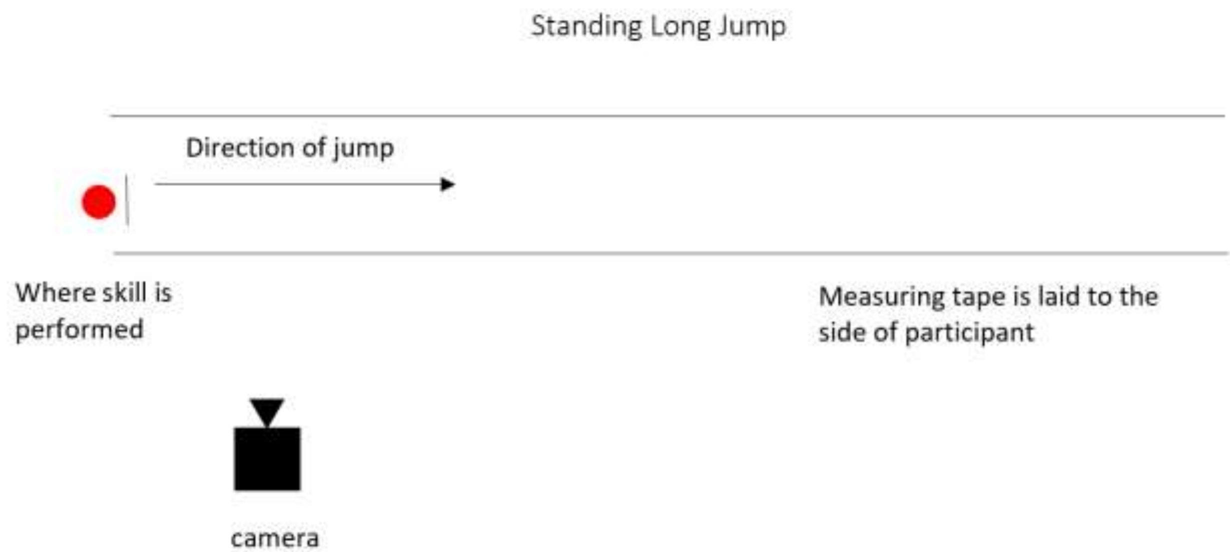

Diagram 2. Standing Long Jump Set-Up

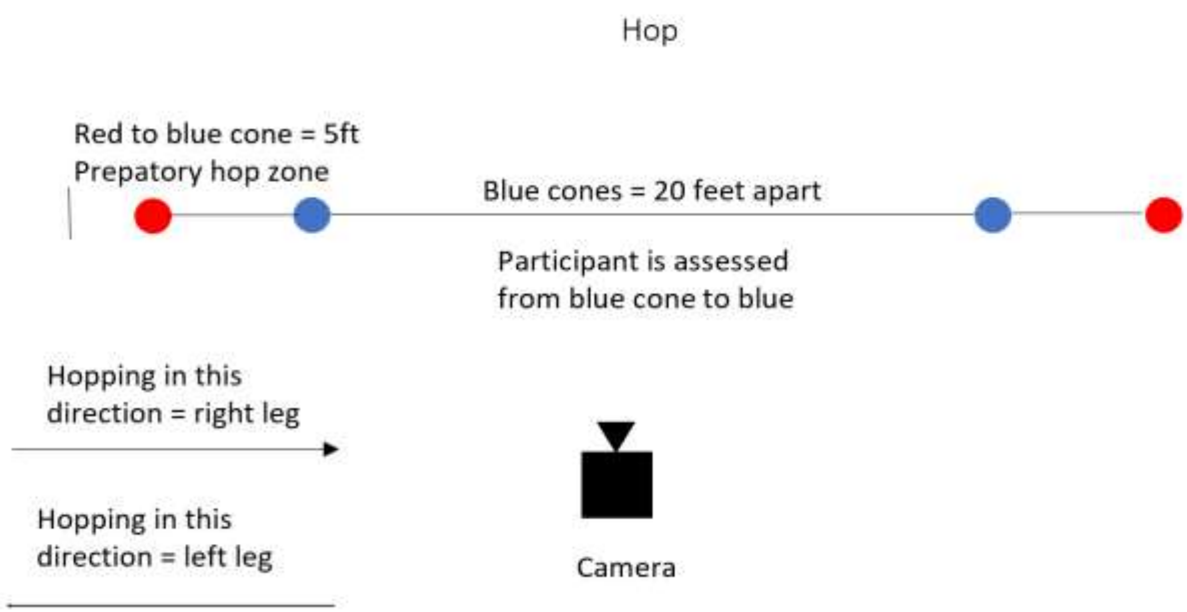

Diagram 3. Hop Set-Up

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