Journal of Physical Activity and Health, 2019, 16, 37-42
https://doi.org/10.1123/jpah.2017-0557

Human Kinetics
ORIGINAL RESEARCH

Duration–Response of Light-Intensity Physical Activity and Glucose Dynamics in Older Adults

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Background: Older adults spend 30% of their day in light-intensity physical activity (LPA). This study was designed to determine if increasing the proportion of time spent in LPA would affect glucose control. **Methods**: Older adults (N = 9) completed four 3-hour treatment conditions consisting of a seated control and 3 randomized conditions: (1) 20% time spent in continuous LPA, 80% seated; (2) 40% time spent in continuous LPA, 60% seated; and (3) 60% time spent in continuous LPA, 40% seated. Energy expenditure was measured continuously, and glucose was measured prior to mixed-meal ingestion and hourly thereafter. Glucose area under the curve was compared between conditions using Friedman test. **Results**: There was a significant difference in glucose area under the curve by time spent in LPA ($P < .001$); specifically, between the seated and 60% LPA (mean difference = 35.0 [24.6] mg/dL, $P = .01$), seated and 40% LPA (mean difference = 25.2 [11.8] mg/dL, $P = .03$), seated and 20% LPA (mean difference = 17.8 [22.5] mg/dL, $P = .03$), 20% LPA and 60% LPA (mean difference = 17.2 [22.5] mg/dL, $P = .01$), and 40% LPA and 60% LPA (mean difference = 9.8 [7.3] mg/dL, $P = .01$). **Conclusion**: These results provide experimental evidence to the importance LPA has on metabolic health. If older adults who already spend, on average, about 3 hours per day in LPA, further increase their LPA, they could see benefit to glucose control.

Keywords: aging, exercise, physical activity prescription, medicine, prevention

The United States and other industrialized countries are in the midst of an inactivity epidemic.[1] High levels of sedentary behavior paired with low levels of health-enhancing moderate- to vigorous-intensity physical activity are negatively impacting the health of our nation.[2] Specifically, physical inactivity is a risk factor for heart disease, diabetes, certain cancers, and premature death.[2] Until recently, researchers and clinicians have largely ignored light-intensity physical activity (LPA; defined as 1.6-2.99 metabolic equivalents [METs][3]) and any benefit of LPA to metabolic health. One theory for the lack of empirical evidence on the role of LPA is a historical focus on the health benefits of moderate to vigorous physical activity.[4] However, when examining temporal patterns of daily activity, studies have shown that the majority of daily active time is spent performing activities that are of a light-intensity level. Therefore, researchers have begun to elucidate the importance of LPA to our total daily energy expenditure and provide evidence for the beneficial health effects of low-intensity movements.[5–7] This is especially true in older adults. For example, findings from a study by Buman et al[8] found that older adults who engage in LPA reported improved physical health and well-being.

Much of our experimental understanding of the health benefits of LPA is derived from sedentary behavior research. Although little experimental research examining the deleterious health effects of sedentary behavior has been performed, research in adults has shown that breaks from sedentary behavior are beneficial for glucose regulation.[9,10] These proposed breaks are generally accomplished by introducing some type of LPA such as standing or slow walking; range in duration from 2 to 5 minutes in length; and occur frequently, usually 1 break every 20 minutes.[9,10] Although these sedentary behavior–focused studies have provided valuable evidence for the role LPA may play in postprandial glucose regulation, this prescription was developed with the intention of breaking up sedentary behavior. The metabolic benefits of varying levels of LPA and the amount of LPA necessary to obtain these benefits still remain unknown. Understanding the health effects of LPA, which provides a more feasible alternative to accumulating activity when compared with higher intensities, could aid in decreasing the inactivity epidemic across our nation and therefore aid in increasing the overall health status and ultimately the quality of life for older adults. What is still unknown is the optimal dose of LPA for glucose response in an older adult population. Therefore, this study was designed to examine how increasing the proportion of the day spent in LPA would affect glucose control. The purpose of this study was to determine the duration–response of proportion of time spent in LPA on postprandial glucose response in older adults in a controlled environment. We hypothesized glucose area under the curve (AUC) will progressively decrease as time spent in LPA increases.

Methods

Participants

Participants were recruited from a Midwest community, including local senior centers, older adult programs, senior residential communities, campus resources, word of mouth, announcements, and flyers. Inclusion criteria consisted of men or women aged 60 years and older; overweight or obese, defined as a body mass index equal to or greater than 25 kg/m^2; and inactive, defined by asking participants if they accumulate less than 150 minutes per week of moderate or vigorous physical activity. Participants were excluded from the study if they were not able to ambulate without assistance, had any other limitations to walking on a treadmill, weighed over 136.4 kg (based on equipment specifications), had been diagnosed with diabetes or were taking any glucose-lowering medications, or had any major signs and symptoms of cardiovascular

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disease (dyspnea, dizziness, tightness or pain in chest, or unusual fatigue at rest or with light exertion).

Overview

The study design was a single subject, alternating treatment design with a randomized treatment order. Participants completed 4 visits to the Physical Activity and Health Research Laboratory. Participants reported to the laboratory having refrained from eating and consuming caffeine or any other stimulants for 4 hours and exercising for the past 24 hours. During their first visit to the Physical Activity and Health Research Laboratory, participants provided verbal and written consent by reviewing and signing an informed consent approved by the University of Wisconsin-Milwaukee Institutional Review Board. In addition, participants completed a health history questionnaire and had their height and weight measured following standard procedures.[11] During the first visit, all participants completed the seated control condition where participants remained seated for 3 continuous hours. At the end of the 3-hour period, participants underwent a treadmill walk test to determine the treadmill speed to be used during the activity conditions to verify a light intensity was reached and not surpassed. During the treadmill walk test, participants walked on a treadmill for a total of 15 minutes. Speed was gradually increased every 5 minutes, starting at 1 mile per hour (mph), and increasing to 1.5 and 2 mph. During the treadmill walk test, energy expenditure was measured using a portable metabolic system. Average walk speed during the activity conditions was 1.4 (0.3) mph. Finally, participants completed a body composition measurement at the end of their first visit to determine percent lean body mass.

Participants then visited the laboratory on 3 subsequent occasions, completing one of 3 activity trial conditions at each visit. In between each visit, participants were asked to maintain their normal routines to adequately capture the effectiveness of the experimental conditions. At all visits, physical activity and diet surveys were completed to monitor consistencies or changes in activity levels and dietary intake throughout the testing weeks.

Experimental Conditions: LPA Conditions

The 3 activity-related conditions were 3 hours in length but varied by percent of time spent in LPA over the 3-hour measurement period. The 3 conditions included a 20% (36 min), 40% (72 min), and 60% (108 min) LPA routine consisting of treadmill walking and household, occupational, and leisure-time activities at the beginning of the visit followed by sitting for the remainder of the visit (Table 1). Activity conditions were designed to elicit a dose–response effect of postprandial glucose, if one existed. In addition, the percentage of time for each condition was set based on the average LPA accumulated each day in the American population (~30%).[12]

The physical activity conditions were randomly ordered. Because of the effect of physical activity on insulin sensitivity, at least a 72-hour washout period occurred between visits (~72 h)[13] to eliminate any previous physical activity effect.

Measures

Energy Expenditure. Energy expenditure was measured continuously throughout each 3-hour condition (seated and physical activity conditions) using the Cosmed K4b^2 (Cosmed Corp, Rome, Italy). The Cosmed K4b^2 is a portable metabolic system and battery pack that can be worn by a participant on a harness secured to their trunk. The portable unit is a small ($170 \times 55 \times 100$ mm) and lightweight (400 g) device that secures onto the individual's chest, while the small battery ($120 \times 20 \times 80$ mm) is placed on the upper back. Oxygen and carbon dioxide are sampled from the face mask covering the participant's nose and mouth, and a turbine attached to the face mask measured ventilation. Breath-by-breath data were averaged into 1-minute values. The Cosmed K4b^2 has shown to be a valid measure of oxygen uptake during exercise and rest,[14,15] showing small differences in oxygen consumption (VO_2), ranging from 0.088 to 0.092 L/min, when compared with the Douglas bag method.

Mixed-Meal Tolerance Test. Participants were asked to consume a standard mixed-meal drink (8 fl oz, Ensure PLUS, Abbott Laboratories, Lake Bluff, IL) prior to beginning each 3-hour measurement (seated and physical activity) to measure the postprandial effect of LPA.[16] The drink had 350 total kilocalories consisting of 51 g of carbohydrates (57%), 11 g of fat (28%), and 13 g of protein (15%). Participants were instructed to complete ingestion within 5 minutes. The activity condition time began once the mixed-meal drink was completely consumed.

Glucose Measurement. A capillary blood sample was obtained from the lateral side of the participant's finger hourly throughout the 3-hour condition measurement period (total of 4 samples; Figure 1). As the figure indicates, the baseline sample was taken prior to the start of the condition and prior to ingestion of the mixed meal. Samples 2 to 4 were each taken 1, 2, and 3 hours after complete consumption of the mixed-meal beverage. Three capillary

Table 1 Activity Routine for Each Activity Condition and Time Spent in Minutes for Each Activity

Activity	Condition 1: 20% time in light-intensity physical activity	Condition 2: 40% time in light-intensity physical activity	Condition 3: 60% time in light-intensity physical activity
Treadmill walking, min	4.5	9	13.5
Household: folding laundry/dusting/sweeping, min/min/min	1.5/1.5/1.5	3/3/3	4.5/4.5/4.5
Treadmill walking, min	4.5	9	13.5
Occupational: standing work, min	4.5	9	13.5
Treadmill walking, min	4.5	9	13.5
Leisure time: playing cards/cycling/light calisthenics, min/min/min	1.5/1.5/1.5	3/3/3	4.5/4.5/4.5
Treadmill walking, min	4.5	9	13.5
Seated, min	148.5	117	85.5

tubes were filled for a total sample of 150 µL for each sample taken. Blood samples were immediately transferred to tubes containing an anticoagulant. Whole blood glucose was measured by the YSI 2300 STAT Plus glucose analyzer (YSI Incorporated, Yellow Springs, OH). This analyzer uses 25 µL of whole blood for each measurement. This method of glucose assessment has been shown to provide valid and reliable measurement of glucose concentration.[17,18] AUC was then calculated from the baseline and hourly glucose samples using the trapezoid method.[19] Glucose values are reported as whole blood values.

International Physical Activity Questionnaire. At each visit, participants filled out the International Physical Activity Questionnaire (IPAQ), which asks questions about the moderate to vigorous activity the participant has engaged in over the previous 7 days.[20] This information was analyzed using standard procedures. The results of the questionnaire provided information on whether the participants maintained or changed their usual activity levels over the experimental period. The IPAQ has shown good concurrent validity for total physical activity ($\rho = .55$) when compared with an activity monitor and log book.[21]

Automated Self-Administered 24-Hour Dietary Recall. At each visit, participants completed a computer-based 24-hour recall questionnaire, which prompted the participants to report all the food and drink consumed over the past 24 hours. The automated self-administered 24-hour dietary recall has been shown to be valid at assessing dietary intake, showing 80% agreement between recalled intake and true food intake.[22] This information was used to test for change in diet prior to each visit.

Body Composition. Total body 3-compartment body composition was measured using dual-energy X-ray absorptiometry to determine total fat-free mass (GE Lunar Prodigy; GE Healthcare, Madison, WI). Dual energy X-ray absorptiometry has been shown to be a valid and reliable measurement of body composition.[23]

Statistical Analyses

All statistical analyses were done using SPSS (version 24; IBM, Chicago, IL). Descriptive statistics were used to describe the study population. Because of the nonnormal distribution of the data, Friedman test and Dunn's multiple comparison test were used to test the main purpose of the study, which was to compare glucose AUC response from the 4 proposed conditions. In addition, Friedman test and Dunn's multiple comparison test were used to determine if there were differences in total weekly physical activity (measured by the IPAQ) and nutritional intake (measured by the automated self-administered recall system [ASA24]) prior to each data collection period.

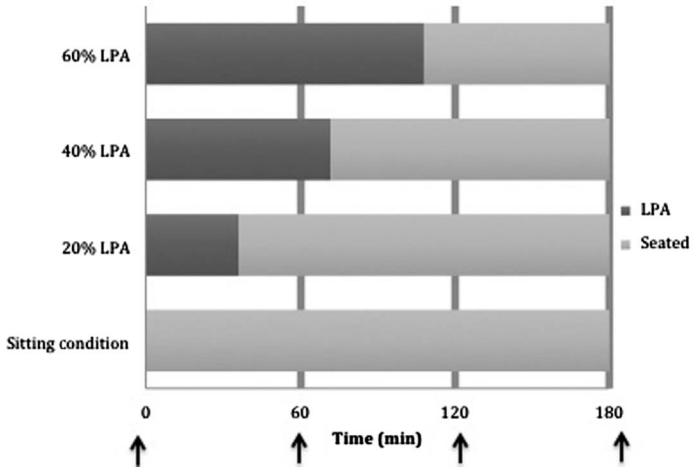

Figure 1 — Blood sample timing (sample time represented by each arrow). LPA indicates light-intensity physical activity.

Results

Nine participants (3 men and 6 women) completed all study conditions and provided complete data. Participants were older adults (mean [SD] 71.1 [3.6] y) with a 28.0 (3.3) kg/m^2 body mass index and a lean body mass percent of 72.9% (14.6%) (Table 2). All participants were white and all were highly educated. Participants' physical activity at baseline showed 1645.2 (99.6) MET-minutes per week measured by the IPAQ and an average caloric intake of 1698.6 (638.4) kcal/day. There were no significant differences in physical activity ($P = .63$) or dietary intake ($P = .86$) between each laboratory visit.

Figure 2 shows the change in postprandial glucose over the 3-hour test time across each activity condition. As Figure 2 depicts, the greatest peak glucose excursion occurred during the seated condition. At 1-hour postload, results revealed a significant difference in glucose values by activity condition. All LPA conditions were significantly different from one another ($P < .05$), except between the seated and the 20% LPA condition ($P = .37$). At 2- and 3-hour postload, there was no significant difference in glucose values between activity conditions.

Similarly, Figure 3 illustrates the measured energy expenditure (in kilocalories per hour) for each hour during each activity condition. Total energy expenditure for each condition was calculated. As designed, results indicate a significantly greater amount of energy was expended with each increase in percent of time spent in LPA ($P < .001$).

The overall Friedman test revealed a significant difference in glucose AUC between proportions of time spent in LPA ($P < .001$). When single conditions were compared with one another, there was a significant difference between the seated condition and 60% LPA condition (mean difference = 35.0 [24.6] mg/dL, $P = .01$), seated and 40% LPA condition (mean difference = 25.2 [11.8] mg/dL, $P = .03$), seated and 20% LPA condition (mean difference = 17.8 [22.5] mg/dL, $P = .03$), 20% LPA condition and 60% LPA

Table 2 Participant Descriptives at Baseline (Mean [SD] or %)

Gender (%male)	33.3%
Age, y	71.7 (3.6)
Race (%white)	100%
Education, %	
College	55.6%
Graduate school	44.4%
Mass, kg	72.9 (14.6)
Height, cm	163.3 (10.5)
Body mass index, kg/m^2	28.0 (3.3)
Lean mass, %	67.4 (9.5)
Fasting glucose, mg/dL	90.0 (6.6)

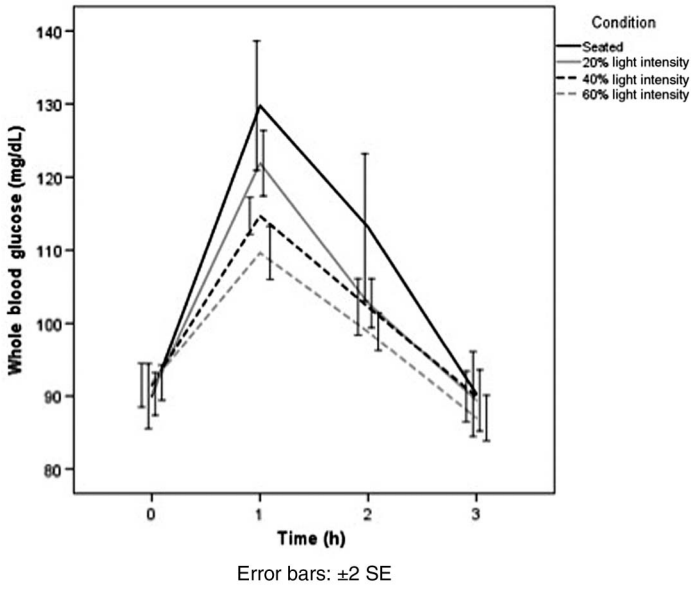

Figure 2 — Postprandial glucose (mg/dL; mean and SE) changes across time by activity condition in response to mixed-meal ingestion.

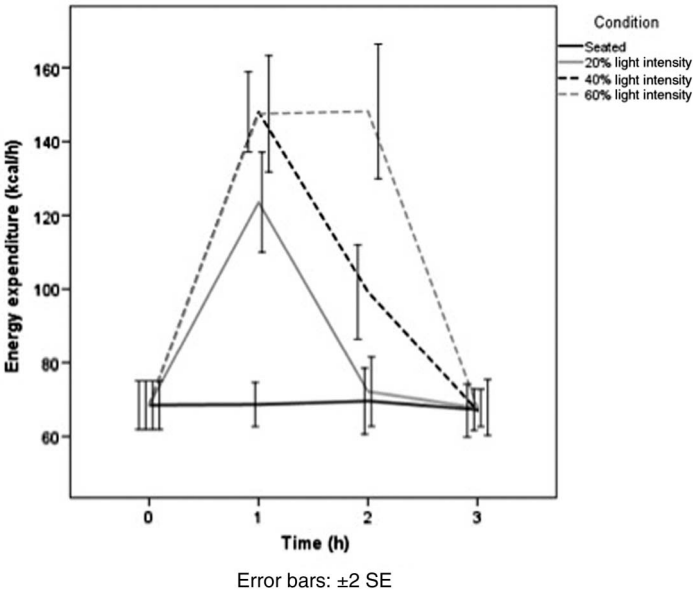

Figure 3 — Energy expenditure (in kilocalories per hour) each hour by activity condition.

condition (mean difference = 17.2 [22.5] mg/dL, $P = .01$), and 40% LPA condition and 60% LPA condition (mean difference = 9.8 [7.3] mg/dL, $P = .01$). There was no significant difference in glucose AUC between the response to the 20% and 40% LPA conditions ($P > .05$; Table 3).

Table 3 Glucose Area Under the Curve by Activity Condition in Response to a Mixed-Meal Ingestion (Mean [SD])

	Area under the curve, mg/dL		Post hoc comparisons (*P* value)			
	Mean	SD	Seated	20%	40%	60%
Seated	332.9	28.6		.03	.03	.01
20%	315.1	13.0	.03		.17	.01
40%	307.7	11.7	.03	.17		.01
60%	297.9	11.8	.01	.01	.01	

Discussion

Our results indicate LPAs significantly reduced peak postprandial glucose excursion in older adults. In addition, there was a significant effect of activity condition on glucose AUC. These results suggest the addition of LPA may help improve glycemic control in older adults. Our results are in parallel with previous research examining light-intensity breaks from sedentary behavior.[9] Bailey and Locke[9] compared the effect of a seated condition and seated condition with 2-minute light-intensity walking breaks (about 2.0 mph) every 20 minutes on postprandial glucose changes over a 5-hour period. Their LPA stimulus resulted in a significant 17% decrease in peak glucose excursion at 1-hour postload when compared with the seated condition.[9] Our stimulus displayed a 20.5%, 41.6%, and 55.3% decrease in peak glucose excursion in the 20%, 40%, and 60% LPA conditions, respectively. Bailey and Locke[9] participants were young adults (24.0 [3.0] y) with a slightly lower body mass index (26.5 [4.3] kg/m^2), which may account for the slight differences in percent response at 20% of the hour spent in LPA; however, both studies saw a similar significant reduction in postprandial peak glucose response. In addition, our results also showed a much larger decrease in 1-hour postload glucose excursion for greater time spent in LPA compared with results from previous work. This is likely due to the much greater duration of the activity, eliciting a greater energy expenditure over the initial hour.

We also inquired whether there was a dose–response relationship between time spent in LPA and glucose AUC to identify the optimal amount of LPA required to elicit a beneficial response in glucose AUC. Results revealed a significant difference in glucose AUC by percent of time spent in LPA. More specifically, spending 60% of time in LPA had the greatest effect on decreasing postprandial glucose AUC (10.5% lower than the sedentary condition), significantly different than all other experimental conditions. To our knowledge, no other studies have examined gradations of time spent in LPA and its effect on glucose; however, previous work has compared glucose AUC between a fully seated activity condition and a seated condition with small bouts of LPA throughout the time period.[9] Bailey and Locke[9] found a 16.7% decrease in glucose AUC between a seated condition and 2 minutes of light-intensity walking every 20 minutes over a 5-hour measurement period. Similarly, Dunstan et al[10] saw a 24.1% decrease in glucose AUC with 2 minutes light-intensity walking breaks every 20 minutes when compared with a seated condition over a 5-hour testing period. Evident from the above findings, LPA shows benefit to decreasing glucose AUC when compared with sitting. What is dissimilar between the current study and previous work is the duration of the activity bout—ours a single, continuous bout, the others short, frequent bouts. Both study designs concluded that LPA, whether obtained in multiple bouts or continuously, is a viable option for reducing postprandial glucose AUC. However, the results from the study by Dunstan et al[10] suggest that there may be greater benefit in multiple, short bouts of activity as opposed to a single, longer period of activity, or that the mode of activity is important (ie, walking). Future research should continue to

examine this notion of bouted LPA versus continuous LPA to better understand the effect of LPA on postprandial glucose AUC, which would help to frame any potential future LPA prescription or recommendation.

Another key difference and novelty of our study compared with previous research is the mode of activity requisition during the experimental condition. Since LPA can be accumulated in all activity domains, our study investigated the use of multiple physical activity modalities, which provides a unique aspect when compared to studies investigating moderate-and vigorous-intensity physical activity. During each LPA condition, participants engaged in LPA in each activity domain, including doing laundry, working at a standing desk, and light calisthenics. In contrast, previous work has only included walking as the LPA stimulus; therefore, prior to the current study, it was unknown whether multiple modes of activity would elicit the same metabolic response that had previously been seen with walking.[9,10] Since we did see a duration–response effect using multiple modes, this indicates we could promote greater varieties of physical activity other than walking, cycling, or other more exercise-related activities. In addition, for older adults who may find it difficult to engage in these exercise-type activities, beginning to incorporate physical activities such as housework or low-level leisure activities such as playing cards into their lives could provide a slow "step up" approach into eventually including higher level activities while still stimulating a metabolic benefit.

The notion that increasing physical activity would benefit postprandial glucose control is not a new idea. A review by Kelley and Goodpaster[24] reports the therapeutic and preventative effects of physical activity for individuals with diabetes or those who wish to prevent the development of diabetes, emphasizing the importance of contraction-mediated glucose uptake when insulin-mediated uptake is impaired. Perhaps one of the most widespread examples of this comes from the Diabetes Prevention Program, which reported a 30% decreased risk of type 2 diabetes diagnosis after 3 years with lifestyle modifications, which included increasing exercise to 150 minutes per week of moderate-intensity activity.[25] Few studies have examined whether a lower intensity would provide a sufficient stimulus to elicit the contraction-mediated effect similar to that in higher intensities (moderate- or vigorous-intensity activities). Dunstan et al[10] compared the effect on glucose AUC of breaking up time spent sitting with either light-intensity or moderate-intensity walking breaks, 2 minutes in duration, every 20 minutes for 5 hours. Results showed that there was a significant decrease in glucose AUC for both intensity conditions when compared with the seated condition; however, there was no difference between the 2 activity conditions (light intensity: 24.1% lower AUC, and moderate intensity: 29.6% lower AUC).[10] Although we do not have a direct comparison to moderate activity, our results provide evidence that there is a dose–response relationship for postprandial glucose between LPA with increasing duration of time, suggesting a lower intensity stimulus may be sufficient.

Strengths of this study include the measurement of energy expenditure during each activity condition and the inclusion of multiple modes of LPA in the activity conditions since LPA is generally accumulated in a number of ways, not predominantly ambulatory like moderate- or vigorous-intensity activities. A limitation to this study was using a 3-hour time period to simulate 1 day; however, continuous energy expenditure measurement with indirect calorimetry limited our measurement time. Future work could expand upon these findings by examining additive or sustained effects of LPA throughout a day. Another limitation to this study was the use of a controlled laboratory setting. Our positive findings from the controlled condition indicate future studies in free-living conditions are warranted. Finally, our findings limit generalizability due to the homogenous sample of white, highly educated, older adults; future work should expand this work to a larger, more diverse sample to determine if these results are reproduced in other groups.

Conclusion

The current study shows that there is a dose–response relationship between time spent in LPA and postload glucose response in older adults. These results translate to clinical practice in the general older adult population, suggesting by increasing time slightly beyond what is already spent in LPA each day, older adults can see further benefit to postprandial glucose response. This provides experimental evidence to the importance LPA may play in the overall metabolic health of our older adult population. Future research should continue to refine this relationship between LPA and glucose (such as examining timing and bouted effects) in addition to applying this model to other inactive populations that would benefit.

Acknowledgments

This study was funded by the Center for Aging and Translational Research at the University of Wisconsin-Milwaukee. W.A.W. is supported by National Institutes of Health/National Cancer Institute training grant CA193193.

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