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The use of predictive modeling in determining the relationship of physical activity and mental health in older adults

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Abstract--- *The spread of dementia and depression resulting from mental health related disorders in conjunction with the non-communicable diseases (NCD) has been partly attributed to lifestyle related change. Lifestyle related changes are prominent features in many developing countries that have undergone socio-cultural transition from diet to level of activity. Critical to this understanding is the role of physical activity as a key determinant in the developmental origins of mental health and non-communicable diseases. The increase of physical inactivity in older individuals is a significant risk factor in the development of chronic diseases. Lack of adequate physical activity leads to physiologic changes that affects sleep, metabolic demands, cognitive skills, and behavioral outcomes. Measuring the level of activity serves an important function not only in determining normative values but to improve our understanding on the relationship of physical activity and mental health. Recent studies have shown the importance of physical activity in mental health, but very studies have investigated how the hidden physiological underpinning of physical activity affects the outcome of mental health using advance mathematical algorithm. This study aims to investigate the role of physical activity in the elderly population and its implication in cognitive and mental health outcomes based on neuropsychiatric assessment through the use of rating scales, while using computational algorithm as a tool to expand current knowledge on this dynamic relationship.*

Keywords--- behavioral, cognitive, physical activity, mental health, non-communicable diseases, predictive modeling analysis*.*

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I. INTRODUCTION

There are specific and far ranging implications when it comes to physical inactivity. Physical inactivity as a function of lifestyle change have led to increase sedentary behavior, and a decline in active recreational pursuits. The current global transition from nutrition to lifestyle changes have brought profound implications in the overall socio-cultural change. For instance, leisure type activities are primarily indicated by lack of active lifestyle, sedentary and limited physical exercise. This socio-cultural behavioral transformation in low/middle income countries has been implicated as a key determinant in the rise of depression, dementia, cardiovascular diseases, obesity, and metabolic diseases. These conditions have led to widespread increase prevalence of non-communicable diseases (NCD) and mental health disorders (MHD), two of the leading causes of morbidity and mortality in the world which reflect poor health outcomes. In many developing countries, strong evidence indicate that older adults are especially prone to higher rates of mortality from coronary heart disease, high blood pressure, stroke, diabetes, colon cancer and breast cancer with increased status of physical inactivity (*WHO, 2010*). Biomarker profiles of older adults also point to unfavorable results while carrying higher incidence of cardiovascular diseases and diabetes type 2. Comparative evidence also suggests poor cognitive function and markedly increase incidence of depressive symptoms associated with sedentary lifestyles

In developing countries, the challenges brought about by the spread of non-communicable diseases and mental health threatens to overwhelm health care infrastructure. For instance, in southeast (SE) Asia studies on disease burden revealed that 3.2% of coronary heart disease, 3.9% of type 2 diabetes, and 5.7% of colon cancer (Lee IM, Shiroma) were attributed to physical inactivity. Moreover, 5.1% of premature mortality in SE Asia or 9% worldwide (approximately 5.3 million) could have been avoided with the reversal of inactivity behavior. Scale-up approach to reverse physical inactivity through health programs have shown increase life-expectancy by 0.68 (0.41 to 0.95) years (Lee IM, Shiroma).

The link on lifestyle related changes and chronic diseases are also supported by findings from basic science research. Recent studies (*Samonte, 2017; Popkin, 2012; Kenny, 2011*) on metabolic related diseases (i.e. diabetes, obesity) implicate the role of chronic behavioral and lifestyle related changes in the form of nutrition and physical inactivity as key factors that directs the mechanism of gene related modifications (epigenetic) that can lead to poor health outcome. The mechanism involve in epigenetic modification provides an explanation into the molecular link of the body's intrinsic response when chronic exposure to nutrition and reduced physical demands leads to alteration in the genetic profile of an individual. This alteration can potentially create a new genetic profile that makes an individual more prone to develop chronic diseases. The susceptibility change brought about by these perturbations can lead to later disease outcomes. In the elderly, these implications are more readily observed with an efficient gene transcription process which directs the body to develop chronic diseases such as dementia and depression. Animal model studies (*Samonte, 2017; Wang 2008*) provide similar findings that described how the process of metabolic changes can alter the subsequent production of genes with negative implications, towards intractable conditions and related disease outcome. Epigenetic changes in animals also revealed these alterations and modifications that can lead to premature development of dementia, cardiovascular diseases, diabetes, and cancer.

Indeed, in large population studies, the association of non-communicable diseases and mental health offers a clearer relationship and association from these chronic conditions. For instance, population level analysis of the Philippines

(*Samonte, 2020*) which looks at the trajectories of mental health and NCD from 2002-2016 have revealed a strong association between dementia, depression, and behavioral changes in relation to various non-communicable diseases. This population level study noted important hidden relationships in the developmental outcomes of health from a developing country perspective. Using predictive modeling analysis, the large data analysis implicated the role of diabetes and obesity as central to mental health and later development of cardiovascular diseases. Although the association between diabetes and mental health have been well elucidated before, the study serves an important purpose in clearly linking the role of diabetes as an important clinical condition that can lead to premature and early advancement of mental health conditions. In addition, the study also revealed a strong relationship in the development of dementia and depression- two of the leading causes of mental health disorders worldwide (*GBD, 2016; Leonore, 2018*)- following metabolic related perturbations. Finally, the Philippine population analyses used of statistical predictive modeling to forecast relationships based on integrated approach is an important step in health policy studies when looking at large data. These findings reflect key trajectories important in redirecting and

redistribution of health resources with specific strategies aimed at incorporating mental health and NCD diseases in a unified primary health policy framework.

Country-level systems gaps continue to impede health delivery to bring down the prevalence of chronic diseases. Equity in health care remains a significant challenge (*ADB, 2018*) brought about by expensive biochemical test, diagnostic modalities, and medications that are not always readily available. The need for health promotion and interventional programs that will mitigate these conditions are generally deficient or lacking in developing countries, and even when available, are generally unsustainable due to inherent challenges related to costs and available resources. In vulnerable groups, particularly the adolescent and the elderly, creating a unified approach to health care promotion and delivery can significantly reduce the morbidity and mortality associated with these condition.

Literature Review

Health policy and promotion on physical activity:

Health strategies that aim to address these conditions have focused across the lifespan. From the young to older adults, these individuals are highly affected by nutrition and lifestyle related perturbations, factors that have been attributed as important determinants in the epidemic of obesity and metabolic disorders (*Khambalia; Nixon, 2012*). Health intervention focusing on physical activity (walking, running, recreational activity) is an important agent that promotes healthy fitness and emotional well-being. There have been significant advances implicating the benefits of physical activity in improving the health outcomes of individuals and communities. Public health programs that are designed to improve the quality of life while decreasing the burden of disease progression have revealed a strong association between physical activity and favorable health outcomes. In adults, for instance, global guidelines on physical activity recommends engaging for at least 150 minutes of moderate intensity physical activity (*WHO, 2010*) or at least 75 minutes of high intensity activity based on a weekly schedule. Ordinately to gain marked benefit an adult individual will require a moderate amount of at least 2 ½ hours of activity each week. This level of physical activity leads to increase percentage of total energy expenditure which in turn increases caloric use. As a result, by increasing the level of activity from moderate to high intensity, then a proportional

amount of energy expenditure occurs along with improve metabolic balance. Indeed, fundamental to understanding the role of physical activity is the level of energy expenditure that occurs.

Attempts to improve health care promotion services have been directed towards community based interventional programs to mitigate the spread of chronic diseases. These programs are aimed to provide efficient health care delivery thru nutrition counselling, medical assessment, and organized physical activity. Proper dietary guidelines and nutrition supplementation activities are geared towards reducing dependence on processed food with caloric density. Part of the current strategy in health care promotion in the elderly is centered on Senior Citizens / Program for the Elderly (*WHO, 2019*) at the community or barangay level where the benefits of physical activity intervention can reverse previous trajectories of poor health into a more robust healthy outcomes even while addressing cost efficiency measures.

The Longitudinal Study of Aging and Health in the Philippines (LSAHP) in 2018 was a comprehensive national study on Filipinos aged 60 and above. Part of the study looked at the level of activity for older persons by classifying daily activities as sedentary (watching tv, reading, listening radio), physically active (exercise), and social (religious). Findings of the study revealed that although older persons remained engaged in activity, however, majority of respondents were mostly engaged in sedentary activity (66%) compared to physically active (52%) individuals (*Cruz, 2019*). These results can indicate significant risk assessment for the continued increase mortality and morbidity related to chronic diseases. The Philippine study emphasizes the need to strategize national health policy in older adults.

Nonetheless, national data on mental health disorders are insufficient and current data are primarily based on random survey. Recent survey on > 1400 participants in Manila (Philippines) showed the prevalence of dementia at 10.6% (95% CI 9.0 to 12.4) (*Dominguez J, 2018*). Furthermore a W.H.O. survey conducted in the Philippines (2005) involving > 10,000 participants, found that schizophrenia (0.4%) and depression (14.5%) were present (*Lally, 2019; WHO/DOH, 2006*). These findings support similar studies and implicate the role of chronic physical inactivity as an important determinant in the development of reduce cognitive function and worsening of depression (*Biddle S., 2016*).

What are the benefits of PA on NCD and mental health?

The positive effects of physical activity (PA) in improving health outcome in developing countries is an important opportunity in mitigating the spread of non-communicable diseases (NCD). Meta-analysis data into exercise therapy (*Chau J., 2017; Lee, 2012*) revealed the beneficial effects of managing NCD thru augmented programs focusing on physical activity by lowering elevated blood pressure (*Hegde SM., 2015*), weight reduction, and improved cardio-pulmonary functional capacities (*Myers J, 2019; Sallis R.E., 2016*). These benefits are also markedly noted in the elderly population based on measured physiologic functional domains. Changes that have been clearly elucidated involved significant enhancement of muscle bulk & strength, immune function, and balance & coordination (*dela Vega, 2006*); while cardiovascular function and blood glucose levels (*Ekelund U., 2007; Colberg SR, 2010*) revealed improved morphology and measurement results. These findings continue to expand and support global recommendations for PA by engaging for at least 150 minutes of moderate activity weekly.

Recent studies *(Sylvia, 2014; Sallis, 2010*) on the use of wearable devices (pedometer, fitness tracker) to measure physical activity (PA) revealed important benefits in managing chronic medical conditions (*Silfee, 2018)* particularly on individuals with lifestyle related diseases. These devices have proven to be reliable in (*Strath, 2013*) as an objective, direct measurement used to assess the outcomes of lifestyle PA interventions. The widespread availability and use of wearable devices provide an additional tool and instrument in managing disease outcomes especially in health promotion efforts. Electronic pedometers provide a low-costs, objective measurement of regular activity (*Bassett, 2002*) which have been widely used in longitudinal, epidemiologic studies (*Cameron, 2007*) while providing significantly more accurate data than self-reporting or recall based (journal, diary) data collection method. Although many of these wearable devices also include sleep activity measurements, clinical validation on its role in determining or monitoring pathological clinical conditions have remained (*Shelgikar, 2016*) anecdotal. In healthy individuals the use of wrist devices revealed reliable data particularly in measuring sleep-wake cycle activity. These devices have the potential to measure and characterized the quality of sleep-based on the level or intensity of movements.

Unlike NCD that primarily relies on biochemical analysis for diagnosis, mental health can often be diagnosed thru screening or rating scales. For dementia, the use of Montreal Cognitive Assessment test (MoCA) (*A. Inocenti, 2017*) provides a rapid cognitive screening tool that allows for easy administration and reproducibility. The test allows cognitive domains to be assess including visuospatial abilities, executive functions, attention, concentration, working memory, language, and orientation to time and place. In contrast, Hamilton Depression Rating Scale (HAM-D) is widely used instrument that was designed to measure frequency and intensity of depressive symptoms in individuals with major depressive disorder. The easy access and use of these diagnostic tests can provide a cheap and reliable assessment for mental health & related disorders particularly in poor resource settings where biochemical analysis may not be accessible or readily available. There has been no recent study looking at the role of physical activity in mental health conditions with the use of these diagnostic and rating scale tests.

III. **Methodology**

Data Source & Collection:

A longitudinal cohort study involving healthy elderly participants with no known history of non-communicable diseases were enrolled. A total of 15 participants were randomly selected from a community health center for senior citizens in Subic, Zambales. Prior to the enrollment status proper consent was obtained. During the enrollment phase, participants were informed that they can withdraw anytime during the study. Personal information provided were kept confidential, while a random identifier was assigned to each enrolled participant.

An initial assessment comprising of detailed questionnaire to determine health status and medical condition, including but not limited to diabetes, hypertension, seizure, cancer, and metabolic disorders, were obtained. Anthropometric measurements (weight, height, BMI), and vital signs (heart rate, blood pressure, respiratory rate) were also determined as part of the screening procedure. Biochemical tests were not obtained. In addition, a baseline assessment of mental health was obtained using the Hamilton rating scale for anxiety (HAM-A) and depression (HAM-D), and the Montreal Cognitive Assessment (Tagalog version, MoCA-P) (*Dominguez, J., 2018*). The results were provided and discussed with the enrolled participants.

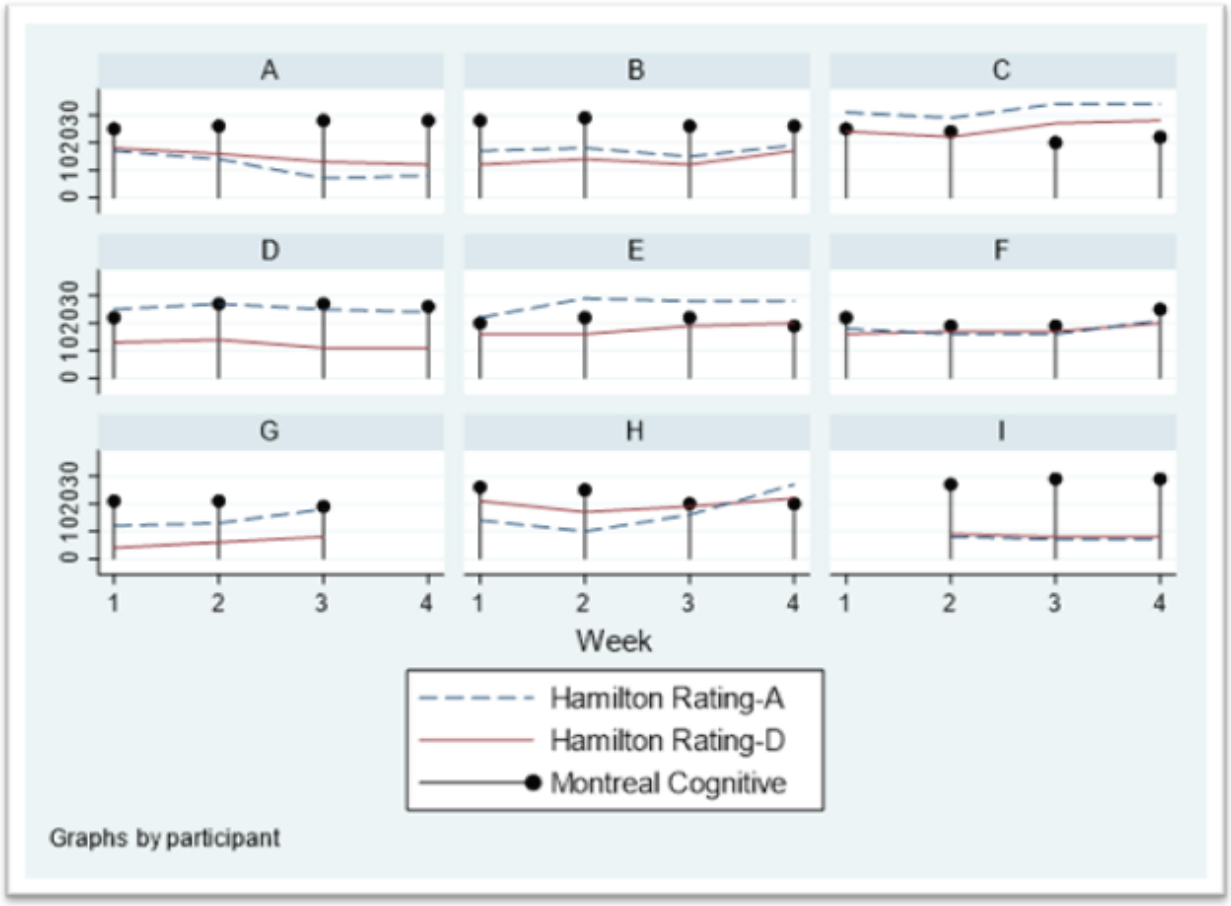
During the initial enrollment phase, an AMIOO (®brand) wearable, health tracking device with Bluetooth connectivity was fitted individually to each participant. The health tracking device measures physical activity through the pedometer, while at the same time measuring blood pressure, heart rate, and oxygen saturation. The sleep cycle activity was also recorded daily.

The participants were asked to perform regular activity. Data gathered were recorded through a mobile app (tablet or smartphone) application. Every week the participants were interviewed while the pedometer-, cardiovascular-, and sleep/wake activity- data were all recorded. The Montreal Cognitive Assessment and the Hamilton rating scale assessment for anxiety and depression were also performed weekly.

The participants were followed over a 4-week course with weekly assessment for anxiety, depression, and cognition. Of the 15 participants who were initially enrolled, six (6) dropped-out due to personal matter and only nine (9) participants had enough recorded data used for this study. Two (2) participants (Graph 1: G & I) managed to complete only 3 weeks of recorded activity due to technical problems on the wearable device, while the remaining seven (7) participants completed the entire 4-weeks of recorded activity with no associated problems.

IV. DATA ANALYSIS

The relationship between physical activity and mental status was evaluated with a longitudinal study of nine participants. Physical activity was measured with average daily steps and weekly total steps. Mental status was evaluated with the Hamilton rating, for Anxiety (A) and Depression (D), and with the Montreal cognitive scale. The measures were recorded for 4 weeks (Graph 1, below).



Longitudinal regressions with random effects were estimated with the data of mental status (dependent variables) against the data of physical activity (independent variables). Additional control covariates/factors were included in the regressions to account for the individual characteristics of the participants: age, gender, blood pressure, and average sleep per night.

Statistically significant results were found only for the effect of physical activity on depression. The null of no effects of average physical activity on depression can be rejected with a significance level of 5% but not 1% (estimated regression coefficient: -.001598, s.e.: .0007634, p-value: 0.036). The regression estimates indicate that, on average, 3107 daily steps reduce 5 points of the Hamilton depression rating.

The results also revealed the lack of clear relationship between physical activity, cognition, and anxiety. It revealed no statistical evidence found for the relationship between physical activity with anxiety, and physical activity with cognition. In the regression of anxiety against physical activity, the null of no effects of average daily steps cannot be reject at conventional significance levels (p-value: 0.907). In the case of the regression of cognitive abilities against physical activity, the estimates of the coefficient are negative, but the null of no effects of average daily steps cannot be reject also at conventional significance levels (p-value: 0.907).

The proportional reduction in average depression risk over the time interval in the study achieved by the exposure of individuals to physical activity keeping other risk factors unchanged─ was calculated with the Population Attributable Fraction (PAF), using the formulas describe in Rockhill et al. (1998) and Zapata-Diomedi et al. (2016):

PAF = p(RR-1)/p(RR-1) +1	*Equation 1*
PAF = p {(RR-1)/RR}	*Equation 2*

Where **p** is the prevalence of the risk factor (the proportion of cases exposed to the risk of depression) and **RR** is the risk ratio (the ratio of two cumulative incidence proportions). Equation 1 is the conventional formula to calculate PAF, while equation 2 was suggested by Rockhill et al. (1998) to calculate PAF when confounding of exposures exist.

The value of **p** was calculated as the cardinality of the individuals in the study with Hamilton depression ratings above 16 points during the 4 weeks of the longitudinal study. This is, 17 of 36 observations (**p = 0.4722**).

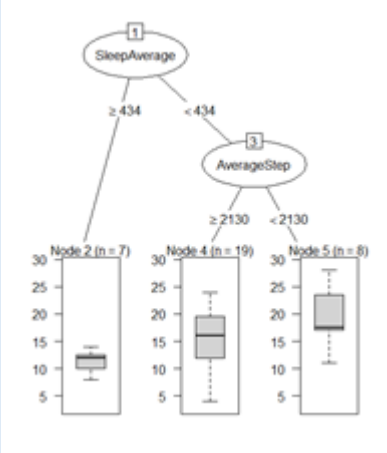
The risk ratio was estimated with a generalized linear model with a logistic link function, using the physical activity above average as the indicator function. A relative risk of (**RR = 0.6263158**) was obtained for the relationship of physical activity with depression, indicating that those that walked more than 3107 steps daily reduce their risk of depression in 63%.

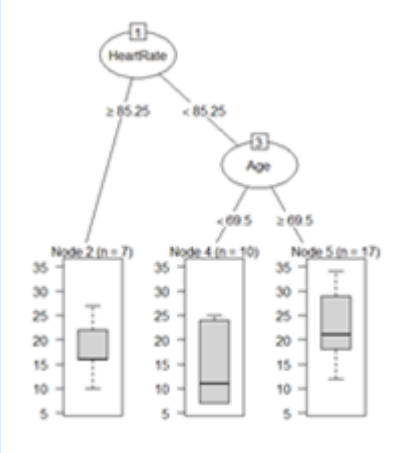
Based on the values of **p** and **RR,** the **PAF** is equal to –.214261 (-21.4%) without considering confounding effects (equation 1), and -.281733 (-28.2%, equation 2). These values indicate that 21.4% (28.2%) of the population risk of depression would be prevented if daily physical activity above 3107 steps is performed.

Finally, predictive modelling was applied with the data of the study. The results again support the effect of daily physical activity on depression, but no effects were found for anxiety and cognitive abilities.

The predictive model indicates that sleep average above or equal to 434 minutes/per night can significantly reduce depression (Hamilton rating below 15 points). If the average sleep per night is below 434 minutes, then daily physical activity of more than 2130 steps can compensate for the lack of good sleep and keep depression in mild to moderate levels.

Hamilton Rating-D	**Hamilton Rating-A**	**Montreal Cognitive Test**


1
SleepAverage
≥ 434
< 434
3
AverageStep
≥ 2130
< 2130
Node 2 (n = 7)
Node 4 (n = 19)
Node 5 (n = 8)


1
HeartRate
≥ 85.25
< 85.25
3
Age
< 69.5
≥ 69.5
Node 2 (n = 7)
Node 4 (n = 10)
Node 5 (n = 17)

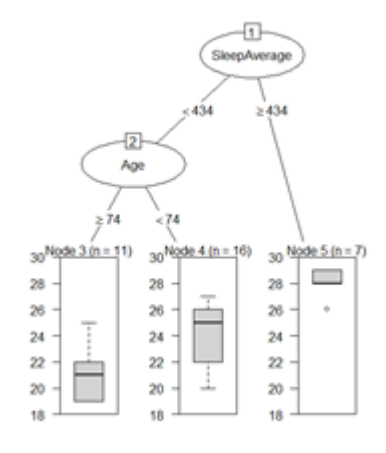

1
SleepAverage
< 434
≥ 434
2
Age
≥ 74
< 74
Node 3 (n = 11)
Node 4 (n = 16)
Node 5 (n = 7)

Table 1 above presents percentages distribution of experts responses to factor effecting female driving pattern, demand, and behavior in Saudi Arabia. The next part of this study present the preliminary determination of these factors based on the panel of expert's agreements.

VI. STUDY RESULTS, SUMMARY AND CONTRIBUTION

Discussion:

Rapid demographic and lifestyle related changes have converged to create enormous challenges in health care delivery systems. The increase in elderly population coupled by the rise of non-communicable diseases and mental health related neuropsychiatric disorders create enormous impact and complicated challenges in managing the health care needs, particularly in less developed countries. The need to adapt sustainable health promotion strategies aimed at mitigating the spread of diseases must look at community-based programs that focuses on practical and inexpensive strategies such as promoting physical activity in elderly health care centers.

While the benefits of physical activity are not only limited to reducing morbidity related conditions from non-communicable diseases, it also extends to include mental health disorders. The results support previous observations on the link between physical activity and mental health. Our results support the relationship of physical activity in the form of number of steps taken (pedometer) with the mental health status through clinically validated rating scale assessment. Indeed, the linear-regression analysis indicates that improvement in depression is correlated with increase physical activity based on the number of steps taken. On average, 3107 daily steps (approximately 21,000 steps *weekly*), can reduce depression symptoms by at least 5-points on the Hamilton depression rating scale (Hamilton-D). Physically active participants also revealed a relative risk score (RR = 0.63) which indicates a significant reduction in depression following physical activity of at least 3107 daily steps.

Unlike physical activity (PA) and depression, the relationship effect of physical activity on anxiety found no determinable significance based on the number of daily steps. Similar result was also noted between physical activity and cognition. The lack of significant difference (p-value: 0.907) between the observed relationship may not necessarily indicate a lack of association but could reflect the need for a higher level of activity needed to provide a more robust clinical improvement. Studies that have quantified the number of steps needed to provide health protective mechanisms from PA indicate more than the 3107 steps noted in our study. Comparative studies looking at the association of anxiety with PA (*Yuenyongchaiwat, 2014*) revealed significant improvement following 10,000 steps daily over a 12-week period. Decrease tension, anger, fatigue, and confusion were also observed in adults with mood disturbances. Furthermore, the widely accepted norm for healthy lifestyle and PA indicate that at least 10,000 steps daily (*Tudor-Locke, 2011*) provides a reasonable benefit.

One of the objectives of our study was to quantify the contribution of risk factors to the burden of mental health disorders in older adults. The population attributable fraction (PAF) provides an additional level of analysis that investigates the incidence of disease based on the assumption that if the exposure to a risk factor was reduced, then an alternative exposure result will follow. Our results indicate that the PAF value of between 21.4% to 28.2% of the population at risk for depression can be prevented if adequate physical activity in the form of 3107 steps are taken daily. The attributable fraction provides strong indication to improve health outcomes following increase activity. Even though the study lacks a significant number

of participants, however, these results confirm previous implications on the preventive value of physical activity in reducing the burden of depression.

Another important finding in our study lies on the value of forecasting by using predictive analysis. By looking at the integration of sleep and physical activity as key variables in determining its effect on mental health outcome, we attempted to explore this association and expand on the current understanding. The results of predictive modeling revealed the link of sleep duration in reducing depression. Our analysis showed that an average sleep totaling above or equal to 434 minutes/per night can significantly reduce depression symptoms, leading to Hamilton depression rating score of 15 points or below. Furthermore, the combination of reduced sleep to below 434 minutes per night coupled by at least 2130 steps daily, confer protective attributes in managing depression and lowering Hamilton rating scores.

Study Limitations:

The study had enumerable limitations encountered throughout its course. One of the glaring limitations is the small number of participants enrolled in addition to the short amount of time duration needed for data gathering. These important factors contributed to the small data sample collected, which affected the quality of data sets and the statistical power of the results. Linear regression and predictive modelling studies are good analytical instruments which rely on large data sets to provide a high degree of reliability and confidence interval.

Another key limitation is based on health policy restrictions in the setting of quarantine laws imposed during the study. Community wide quarantine was in place during the data collection process due to the coronavirus pandemic. The strict quarantine policies and social protocols imposed in the community led to wide-spread adaptations and related restrictions which ultimately affected the participants' level of physical activity engagement. These restrictions took the form of socio-behavioral modifications with important implications in reducing the level of regular daily activities (shopping, outdoor exercise, visits) and travel movements. Participants were generally limited to home and backyard level of activity based on the prevailing health ordinance and policy adaptive measurements during the pandemic. Overall, the enrollment of participants and needed scheduled follow-up on participants were affected due to travel restrictions.

Conclusion:

The results of the study provide an important addition to recent research studies on the positive influence of physical activity. The results support previous validations on the positive health outcome in depression, a key mental health disease, based on the Hamilton rating scale and following sustained increase in physical activity even though cognitive and anxiety levels had no statistically significant findings. The lack of symmetrical statistical outcome between the independent (physical activity) and dependent (depression/anxiety/cognition) variables were likely the result of small sample data with low statistical power to capture the true relationship, rather than from the lack of immutable relationship. Future studies should involve a larger group of participants to better distinguished the link while providing a higher power of association between the independent and dependent variables. In short, the study supports recent findings of improvement in depression symptoms from physical activity though a larger sampling population will likely generate a more robust association.

There is also an important paradigm that must be considered in this study. Since the study was conducted at the height of the pandemic lockdown, the results should also be interpreted as a proximal assessment of the effects of physical activity

(or inactivity) in the setting of community quarantine procedure. The possibility of subclinical depression, anxiety, and cognitive regression as a result of the quarantine should be strongly considered.

Finally, the strength of our study should be interpreted based on the underlying effects of physical inactivity following environmental (communicable diseases) and socio-cultural (community law) influences in the elderly. The strict quarantine laws imposed had profound impact in limiting the movement and level of activity in our participants (elderly). Extreme health policy strategies aimed at mitigating the spread of coronavirus led to community lockdown causing significant limitations and restrictions resulting in physical inactivity. Future health promotion strategies in response to pandemics should provide alternative programs designed not only to control the spread of communicable diseases, but in formulating health policy strategies to prevent the expected development of mental health disorders particularly in the vulnerable groups (children, elderly). Health care strategies aimed at improving the older adult health issues in pandemic must look into promoting physical activity awareness as part of health promotion thus decreasing the burden and susceptibility from developing mental health illness. In conclusion, health policy strategies aimed at older adults, and regardless of circumstances, should strongly consider the need to promote increase physical activity designed to improve the state of mental health.

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