: Frequency, Intensity and Duration of Muscle Strengthening Activity and Associations with Mental Health

Abstract

Objectives: Despite growing emphasis on the benefits of physical activity for promoting mental health, inclusion of muscle-strengthening (MS) (e.g., body-weight exercises, resistance machines) activities is limited. Notably, few studies collectively assess MS behavioural frequency, duration, and intensity. To address the gap, the current study examined associations between frequency (days), intensity (rating of perceived exertion in relation to repetitions in reserve [RPE/RIR]), and duration (minutes per typical session) of MS activities on anxiety, depression, and mental well-being.

Method: A cross-sectional study of 601 participants (Mean age = 30.92 years [SD =12.70]; 57.7% female) across Ireland was conducted. Participants completed a self-report questionnaire containing MS instruments previously used, or adapted from valid and reliable measures (i.e., International Physical Activity Questionnaire IPAQ, RPE/RIR), alongside, the Generalised Anxiety Disorder-7 (GAD-7), Patient Health Questionnaire-8 (PHQ-8) and the Mental Health Continuum- Short Form (MHC-SF). A multivariate regression model was tested in MPLUS, using dummy coding for MS frequency in relation to no activity (i.e., 0-days) non-adherence (i.e., 1-day), adherence (i.e., 2-days) and enhanced adherence (i.e., $\geq$3 days) to the MS public health guidelines, with the mental health variables representing the dependent variables. Intensity and duration were specified in the model as continuous variables; gender and age were included as statistical controls.

Results: Three or more days engaged in MS activities was associated with fewer anxiety (β = -.12, p <.05) and depression (β = -.14, p <.01) symptoms. Increased intensity had a negative association with anxiety (β = -.10, p <.05) and depression (β = -.15, p <.001). Unexpectedly, adherence to the MS guidelines (2-days) did not predict any of the mental health outcomes, whereas 1-day of MS activity was associated with fewer depression symptoms (β = -.11). No effects were observed for mental well-being, and MS duration exerted a null effect across all mental health outcomes.

Conclusion: Higher frequency and intensity of MS activities may protect against anxiety and depression symptoms. Doing some MS activities (at least 1-day) is likely more beneficial than none for depression. Evidence-based, MS interventions may help curb mental illness rates, and future longitudinal, intervention-based research could consider inclusion of MS

frequency, intensity and duration variables to enhance efforts to identify at-risk groups and trends within physical activity and mental illness surveillance.

Keywords: resistance; exercise; mental illness; mental well-being; epidemiology.

Frequency, Intensity and Duration of Muscle Strengthening Activity and Associations with Mental Health

Keyes (2002) outlined a two-continua model of mental health comprising a positive mental well-being dimension alongside a distinct, but correlated, mental ill-being (e.g., anxiety, depression) dimension. Mental health disorders such as anxiety and depression are among the most common causes of disease burden worldwide. For example, mental ill-being increases risk of chronic illness including cardiovascular and Alzheimer's Diseases, Type-2 Diabetes, and, ultimately, increased mortality (Banatvala et al., 2019). Contrastingly, mental well-being is associated with increased longevity and healthy physical and social functioning (Lawrence et al., 2015). Therefore, understanding modifiable lifestyle factors for mental health promotion and mental illness prevention represents a contemporary goal for public health policy, research, and practice (Huppert, 2009).

Physical activity, defined as any bodily movement by the skeletal muscles that leads to energy expenditure (Caspersen et al., 1985), is a modifiable lifestyle behaviour associated with mental and physical well-being at various durations (e.g., short through to long bouts), intensities (e.g., light through to high-intensity) and modalities (e.g., resistance, aerobic, and recreational/sporting behaviours) (Biddle et al., 2014; Way et al., 2016; Mcleod et al., 2019). To this end, the World Health Organisation (WHO; 2020) public health guidance recommends that all adults participate in a minimum of: (i) 150 minutes/week of moderate-intensity (or 75 minutes of vigorous-intensity) aerobic physical activity (e.g., walking, running); and (ii) two days per-week of muscle-strengthening (MS) activities (e.g., resistance training).

Although the scientific evidence on aerobic physical activities and benefits to mental health is relatively mature (Teychenne et al., 2020), MS research has only gained traction in public health research within the past decade (Milton et al., 2018). Some have characterised the WHO's (2020) MS component as the 'forgotten' guidelines, to the extent that MS behaviours are largely unaccounted for in prevalence statistics and identification of at-risk populations (i.e., Strain et al., 2016). Among the existing data, researchers have reported that while ~66% of adults do not meet the MS component of the guidelines (Strain et al., 2016), those that do achieve the recommended two days per-week report lower prevalence of mental illness (Bennie et al., 2018; De Cocker et al., 2020; Oftedal et al., 2019). Some studies have further classified days of MS activities into 'frequency' categories (e.g., 0, 1, 2, 3-4, ≥5 days),

and showed negative correlations among higher frequency categories with physical health disease incidences including insulin resistance (Cheng et al., 2007), diabetes, stroke, and cancer (Bennie et al., 2018). However, it remains unclear whether such 'frequency' categories convert to improved mental health status. Furthermore, Teychenne et al. (2020) concluded that the optimal duration (e.g., mean minutes) and intensity (e.g., perceived exertion) of MS activities for mental health is unaccounted for in existing research. Such perspectives contrast with findings that different durations and intensities of aerobic activity can exert distinct changes on mental well-being (e.g., Reed & Ones, 2006), and reinforces a need to examine similar relationships for MS activity.

A recent systematic review by Shakespear-Druery et al. (2021) adds further weight to the issue of MS inclusion in public health research. These authors outlined a clear discrepancy within the systems/surveys used to assess MS behaviours in public health surveillance. Specifically, only 23.7% and 1.3% of the 156 studies included items of MS duration and intensity, respectively. Relatedly, the European Psychiatric Association (Stubbs et al., 2018) among others (e.g., American College of Sports Medicine [ACSM]) have called for more data and clarity on the association between MS activities and mental health outcomes. To gauge intensity and accrue health benefits, many organisations such as the National Strength and Conditioning Association (Baechle & Earle, 2008) and the ACSM (Haskell et al., 2007) recommend between 6-12 repetitions of MS activities at a moderate-to-vigorous intensity per-session. Furthermore, the American Heart Association and the ACSM have outlined exercise prescription criteria for MS activity wherein a moderate-to-vigorous intensity equating to a score of >5 (1 'no effort' to 10 'maximal effort') on the Rating of Perceived Exertion (RPE) scale is recommended to accrue health benefits (Nelson et al., 2007).

To our knowledge, the only study incorporating both MS intensity and frequency (days) in relation to mental health associations (Harada et al., 2015), reported a positive trend for increased frequency and intensity of MS activities and health-related quality of life, a global measure of health incorporating mental health items. However, Harada et al. (2015) did not use a validated measure of intensity such as an RPE scale, meaning the categories of light, moderate, and high-intensity were arbitrarily chosen by respondents. Furthermore, while RPE has subjective value in determining MS intensity (Humphries et al., 2018), Helms et al. (2016; 2018) recommended a more context appropriate RPE scale in relation to Repetitions in Reserve (RIR) (Zourdous et al., 2016). Specifically, a point on the 1-10 RPE

scale is anchored to how many remaining repetitions the subject feels they could do. To date, no studies have included the RPE/RIR scale in relation to the association between MS activity and mental health outcomes.

Additionally, unlike aerobic physical activity guidelines (i.e., ≥150 minutes of moderate-intensity activity per-week) the duration of MS activity is not specified in public health guidance. However, researchers (e.g., Lopez et al., 2021) are working in related health fields (e.g., cancer) to determine if optimal duration(s) of MS exist for disease prevention, and its inclusion in public health studies is deemed important for clarifying health promotion guidance (Bennie et al., 2020). The few studies incorporating items related to MS duration are restricted to determining prevalence statistics (e.g., Bennie et al., 2016; Brown et al., 2013), and studies have yet to test if associations with mental health outcomes exist. Moreover, the assessment of MS duration varies widely across studies, ranging from average minutes per-week to hourly categories (e.g., 1, 1-2, 6-7) (Shakespear-Druery et al., 2021). As such, items within the International Physical Activity Questionnaire (IPAQ) used to classify duration of aerobic and sedentary behaviours may serve as a starting point for the much-needed standardisation of MS activity duration (Bennie et al., 2020; Shakespear-Druery et al., 2021).

As a first step to address these knowledge gaps, the present cross-sectional study was conducted to examine whether MS frequency (i.e., day categories of 0, 1, 2 or ≥3 in the previous week), perceived intensity (i.e., RPE/RIR), and duration (i.e., mean minutes per-session) were associated with mental health outcomes of anxiety, depression, and mental well-being. Based on previous epidemiological studies (e.g., Bennie et al., 2018; Bennie et al., 2019; Milton et al., 2018; Oftedal et al., 2019), Hypothesis 1 (H_1) was that those meeting (i.e., 2-days per-week), or exceeding (i.e., ≥3 days per-week) the guideline for MS frequency, and those engaged in some (i.e., 1-day per-week) MS activity in the previous week would score more favourably on mental health than those not doing any MS activity in the previous week. We expected a linear relationship in these comparisons to the extent that more MS activity would exert larger effects. Moreover, we hypothesised that increased duration (H_2), and intensity (H_3) of MS activity would negatively predict anxiety and depression, and positively predict mental well-being. Additionally, we controlled for gender and age as potential confounding factors related to mental health (Bauman et al., 2012; Bennie et al., 2019).

2.0 Methods

2.1 Inclusion criteria, recruitment, procedure and participants

Ethical approval for the study was granted by the authors' academic institution (code: MG15). Only participants who were aged 18 years and older, and who provided informed consent, were invited to participate. Recruitment strategies involved the invitation line: 'This survey is about physical activity and mental health. We would appreciate 10-minutes of your time, and/or forwarding of the link'. Survey links were distributed on social media (e.g., Twitter, Facebook) by the research team who tagged public health accounts. The forwarding of links was encouraged through subsequent posts (i.e., snowball sampling). The online cross-sectional survey was conducted through SurveyMonkey software (Palo Alto, CA). The survey comprised demographic questions (i.e., gender, age), alongside MS measurements and psychometric scales (see below).

A total of 601 individuals took part (mean age: 30.92 years [SD = 12.70, range=53]; 57.7% female) across the island of Ireland between January-April 2021. This timeframe corresponded to periods of Government social distancing restrictions due to the Covid-19 pandemic, meaning that intermittent opening and closing of exercise facilities was likely across the island. Accordingly, at the time of the survey 65.4% of the sample reported they were only leaving home for Northern Ireland and Republic of Ireland Governments' deemed 'essential' activities such as food shopping, visiting a health care professional or for daily exercise.

2.2 Measures

Frequency of Muscle-Strengthening Physical Activities

Days of participation in the MS activities during the previous week was assessed using the Behavioural Risk Factor Surveillance Survey (BRFSS) instrument (Yore et al., 2007). Through a 7-day recall period, respondents identified the number of days that were spent doing 'exercises or physical activities that strengthened the major muscles (e.g., legs, hips, back, abdomen, chest, shoulders and arms)'. To ensure responses distinguished between MS and aerobic activities, participants were instructed to 'NOT count aerobic activities like walking, running, or bicycling', but 'DO COUNT activities that involve using your own body weight like yoga, sit-ups, or push-up, and/or those activities using weight machines, free weights, or elastic bands'. The measure has previously shown test-retest reliability and concurrent validity (Yore et al., 2007).

Intensity of Muscle-Strengthening Physical Activities

A single item reflecting Rating of Perceived Exertion in relation to the Repetitions in Reserve (RPE/RIR) (Zourdous et al., 2016) was used as an indicator of MS activity intensity. If participants indicated that they had completed at least one-day of MS activity, as per the BRFSS scale, they were subsequently prompted to report on '*the overall perceived exertion experienced during such MS activities'*. The RPE/RIR was a 7-point scale, with scores encompassing: 1 (RPE: 1-2,'little to no effort'), 2 (RPE: 3-4, 'light effort'), 3 (RPE: 5-6, 4-6 reps remaining), 4 (RPE: 7, 3 reps remaining), 5 (RPE: 8, 2 reps remaining), 6 (RPE:9, 1 rep remaining) and 7 (RPE: 10, 'maximum effort'). As detailed, an RPE score of 10 was activity-anchored to no remaining repetitions in reserve and maximum effort, whereas an RPE rating of 8 equated to two repetitions in reserve. The RPE/RIR scale has shown extensive reliability and validity to accurately classify resistance exercise intensities, even when sets and repetitions are taken near and to volitional failure (Helms et al., 2016; 2018).

Duration of Muscle Strengthening activities

As no standardised or validated instrument existed for defining the duration of MS activities (Shakespear-Druery et al., 2021), we adapted items from the International Physical Activity Questionnaire Short-Form (IPAQ-SF; Craig et al., 2003), a widely validated and robust self-report measure of physical activity (Bauman et al., 2009). If participants indicated participation of MS on at least one day in the BRFSS, they were subsequently prompted to report on the time (hours and minutes) they '*usually spent doing MS activities on one of those days'*.

Anxiety

The seven-item Generalized Anxiety Disorder (GAD-7: Spitzer et al., 2006) scale was used as a measure of anxiety. Using a two-week recall period, respondents indicated the degree to which they had been bothered by anxious feelings (e.g., restlessness, afraid as if something might happen) with a 4-point Likert scale, ranging from 'Not at all' (0) to 'Nearly every day' (3). Sound psychometric properties and diagnostic efficacy have been shown for the GAD-7 among large clinical and non-clinical samples (Löwe et al., 2008), including online study methodologies (Donker et al., 2011). Possible total scores range from 0-21, with higher scores representing increased anxiety symptoms.

Depression

Depression symptoms were assessed using the eight-item version of The Patient Health Questionnaire (PHQ-8: Kroenke et al., 2009). The PHQ-8 is a diagnostic and severity measure for major depressive disorders in large clinical and non-clinical samples (Razykov et al., 2012), and has sound psychometric properties (Wu et al., 2019). Respondents indicated the number of days in the past two weeks in which they experienced a particular depressive symptom (e.g., anhedonia, hopelessness) on a 4-point Likert scale, ranging from 'Not at all' (0) to 'Nearly every day' (3). Possible total scores range from 0-24, with higher scores representing greater severity of depression.*Mental Well-Being*

Respondents completed the Mental Health Continuum - Short Form (MHC-SF: Keyes et al., 2008), which assesses the positive mental health dimension of Keyes (2005) two-continua model. The MHC-SF is a 14-item scale deriving hedonic (i.e., items 1-3), social (i.e., items 4-8) and psychological (i.e., items 9-14) mental well-being dimensions. Corresponding with the other mental health outcomes, the recall period for the MHC-SF was adapted to the 'past two-weeks', wherein respondents rated the frequency of every feeling (e.g., happy) or experience (e.g., that you had warm and trusting relationships) on a 6-point Likert scale ranging from 'Never' (0) to 'Every day' (5). Total scores can range from 0-70, with higher scores indicating positive mental health. High comprehension, internal validity and cross-cultural reliability has been shown for the MHC-SF (Lamers et al., 2011).

2.3 Data management and analysis

Raw data was transferred from SurveyMonkey software into the Statistical Package for the Social Sciences (SPSS, Version 25; IBM Corp, NY). The research team checked the data for invalid responses, missing data, and outliers. No outliers were present and following removal of missing data (described below) it was confirmed that all variables displayed acceptable skewness and kurtosis statistics to proceed with parametric statistical analysis The frequency of MS activities was dummy coded and categorised into four groups based on the WHO's (2020) guidelines. These were: (1) 0-days (i.e. no adherence); (2) 1-day (i.e., 'doing some' MS activity); (3) 2-days (i.e., adherence to public health guidelines), and; (4) $\geq$3-days (i.e., exceeding the guidelines). Duration of MS activities was calculated as total minutes for a typical session and, alongside intensity, was treated as a continuous variable. The GAD-7, PHQ-8, and MHC-SF were calculated as composite scores.

Mean scores and standard deviations were reported for both the full sample and MS frequency groupings and were included within a descriptive table. For descriptive purposes,

the prevalence of the sample classified as having clinically relevant anxiety and depression symptoms were reported through examining cut-off points of >10 for the GAD-7 and the PHQ-8 (Kroenke et al., 2009; Spitzer et al., 2006). Individuals classified as having the positive mental health condition of 'flourishing' in the MHC-SF were extracted through reporting of experiences 'everyday' or 'almost everyday' in at least seven of the symptoms, including one from hedonic dimension (Keyes, 2002). Adherence to the MS guideline of ≥2-days was reported, and prevalence statistics among genders were extracted.

For main analyses a multivariate regression model was specified with the three mental health outcome variables (GAD-7, PHQ-8, and MHC-SF) all simultaneously regressed on the seven predictor variables (age, gender, 'Intensity', 'Duration', and the three dummy coded variables representing 'Frequency'). The predictor variables were correlated, as were the residuals for the outcome variables. The model was specified and tested using Mplus 8.0 (Muthén & Muthén, 2018) with robust maximum likelihood estimation (Yuan & Bentler, 2000). The results are reported as unstandardized (B) and standardised (β) regression coefficients, and the R-squared was reported for each outcome variable.

3.0 Results

3.1 Descriptive statistics

Classification of the sample using PHQ-8 and GAD-7 cut-off points revealed that 24% and 22.8% were at the ≥10 threshold for having clinically relevant depression and anxiety symptoms. In raw scoring terms, means were 7.87 (*SD* = 5.75) for depression, and 7.34 (*SD* = 5.95) for anxiety suggesting mild levels on average across the sample. Furthermore, 31.4% of the participants were classified as having positive mental health or 'flourishing'. From a total possible score of 70, the sample's mean well-being score was 42.24 (*SD* = 13.88), that corresponds to an item average of 3.02 (*SD* = 0.99), suggesting the presence of well-being descriptors 'about once a week' to 'about 2 or 3 times per-week'.

In the MS activity questionnaire, 43.6% of the sample met the WHO's (2020) MS guideline of ≥2-days of activity, and split by gender, 55.8% of males met the guideline, compared to 35.3% of females. The mean minutes of engaging in a typical MS activity session was 64.13 with a large standard deviation of 68.08. The mean intensity levels were 2.72 (*SD* = 2.53), which is anchored to mean RPE/RIR levels of 'light effort' at 4-6 repetitions remaining. Table 1 outlines the mean scores and standard deviations for the full sample and for MS frequency categories.

3.2 Multivariate Regression Model

Exclusion of missing data for guideline reference categories resulted in a final analysis sample of 493 participants for the multivariate regression model. The results from Table 2 show that, after controlling for all other variables in the model, females were significantly higher in anxiety and depression and lower in well-being, and older age was associated with lower levels of depression and anxiety and higher well-being.

Despite a significant proportion of variance explained (i.e., 6%), $H_{1\text{-}3}$ for well-being were not supported, as only the statistical controls of age and gender exerted a statistically significant effect.

However, partially supporting H_1, and fully supporting H_3, MS frequency of 1 and $\geq$3 days, compared to no activity, were associated with significant decreases in depression. Unexpectedly, the effect for 1-day (B = -2.21*) was larger than 3 or more days (B = -1.67**), and the effect for 2 days (B = 0.24) was non-significant for depression. There was a significant negative association between intensity and depression (B = -0.61**), but not for MS duration (H_2), culminating in 10% of variance explained for depression.

For anxiety, and again partially supporting H_1, and fully supporting H_3, $\geq$3 or more days of MS (B = -1.51*) and higher intensity (B = -0.44*) were both associated with a significantly fewer anxiety symptoms. The proportion of variance explained for anxiety was 11%.

Table 1: *Descriptive statistics for the sample and Muscle Strengthening frequency categories of 0-days, 1-day, 2-days and ≥3-days*

Frequency category	***M/SD***	**Duration (minutes per typical session)**	**Intensity (Rate of Perceived Exertion/ Repetitions in Reserve)**	**Well-being**	**Depression**	**Anxiety**
0-days (*n* =190)	*M*	0.00	0.00	41.05	8.69	8.21
	SD	0.00	0.00	14.37	6.06	6.21
1-day (*n =41)*	*M*	91.46	3.17	43.52	7.42	7.03
	SD	25.71	1.70	13.99	5.29	6.94
2-days (*n* =66)	*M*	94.11	4.32	41.95	9.05	7.57
	SD	43.03	1.60	11.72	5.93	5.59
≥3-days (*n*= 196)	*M*	110.16	4.71	43.19	6.80	6.51
	SD	65.84	1.62	14.04	5.31	5.50
Sample (*n* = 493)	*M*	64.13	2.72	42.24	7.87	7.35
	SD	68.06	2.53	13.88	5.75	5.95

Table 2: *Regression Coefficients From Multivariate Regression Model Predicting Anxiety, Depression and Well-being.*

	Anxiety			Depression			Well-Being		
	B	**(se)**	**β**	**B**	**(se)**	**β**	**B**	**(se)**	**β**
Gender (female)	2.629***	(0.540)	0.222	2.113***	(0.522)	0.183	-4.979***	(1.331)	-0.178
Age	-0.081***	(0.021)	-0.178	-0.063**	(0.022)	-0.143	0.151**	(0.055)	0.141
MS Frequency - 1 day	-1.808	(1.168)	-0.088	-2.206*	(0.917)	-0.110	3.822	(2.534)	0.078
MS Frequency - 2 days	-0.736	(0.842)	-0.042	0.238	(0.917)	0.014	1.832	(1.860)	0.044
MS Frequency - 3 or more days	-1.512*	(0.642)	-0.126	-1.668**	(0.615)	-0.143	1.892	(1.574)	0.067
Intensity	-0.442*	(0.184)	-0.105	-0.609**	(0.184)	-0.148	0.379	(0.480)	0.038
Duration	0.007	(0.006)	0.049	0.003	(0.006)	0.025	0.004	(0.018)	0.011
R-squared	.11***			.10***			.06***		

4. 0 Discussion

The purpose of this study was to examine associations between MS frequency, intensity, and duration on mental health outcomes of anxiety, depression, and mental well-being. Through examining these MS factors together for the first time, the findings extend research on the 'forgotten' MS guidelines (Strain et al., 2016), and respond to recent calls (Shakespear-Druery et al., 2021) to broaden the scope and rigour of MS surveys in public health research. Overall, significant proportions of individuals were classified with likely anxiety and depression, while less than one third were 'flourishing' as per Keyes' (2002) definition. Further, a majority did not meet the MS public health guidance. Novel findings from the present study revealed some support for H_1 to the extent that 1-day and $\geq$3-days of MS activity over a 7-day period were protective against depression, and $\geq$3 days of MS activity was related to lower anxiety. Consistent with H_3, higher intensities of MS activity were associated with lower anxiety and depression. However, duration exerted a null effect (H_2), and frequency categories were not uniformly linearly related to mental health outcomes. While future longitudinal and intervention studies would need to confirm the direction of our associations, our study adds initial evidence to support the view that general physical activity guidelines may require further clarification and refinement for mental health outcomes (Teychenne et al., 2020).

Although mean score analysis showed mild levels of anxiety and depression across the sample, and the typical presence of regular well-being experiences, categorisation statistics revealed 22.8% and 24% were deemed likely to have clinically relevant anxiety and depression symptoms, and just 31.4% of the participants were classified as'flourishing'. While population rates of anxiety and depression vary, our statistics are somewhat lower, but likely within the margin of error with the 24.5% to 33.7% in anxiety, and 31.4% to 36.9% in depression, shown in recent large epidemiological studies in the US (Vahratian et al., 2021) and globally (Salari et al., 2020). While prevalence statistics of 'flourishing' are less well researched, nationally representative samples (e.g., Schotanus-Dijkstra et al., 2016) show estimates of 36.5 %, and demonstrate some consistency with our own data. Importantly, the aforesaid studies were conducted during Covid-19 social restrictions, while our study was conducted between January-April 2021 coinciding with relaxation of many restrictions (e.g., opening of leisure facilities, resumption of education and hospitality).

For MS activity, 43.6% of the sample met the WHO's (2020) guideline of $\geq$2-days of activity, which is markedly higher than the 30-31% presented by others (e.g., Bennie et al.,

2018; Strain et al., 2016). However, our sample's mean age was 30.92 years, and younger age groups (e.g., young adults, aged 18-24) show higher prevalence of MS guideline adherence (e.g., Bennie et al., 2018; De Cocker et al., 2020; Oftedal et al., 2019). Despite relatively high levels of MS activity in our sample, a majority of 56.4% were insufficiently active with regards to MS guidelines. Furthermore, consistent with research on aerobic activities (Biddle et al., 2014), gender analysis also showed a larger proportion of females (64.7%) than males (44.2%) did not meet the MS guidelines. Given that meta-analyses show decreases in physical activity behaviours between the ages of 18-30 years (Corder et al., 2017), and rapid declines during mid-to-late adulthood (Gow et al., 2017), our prevalence statistics reflect a broader public health challenge to increase MS activity amongst adult populations (Milton et al., 2018).

For those who engaged in some MS activity, mean levels of intensity were anchored to an RPE/RIR rating of 'light effort', with 4-6 repetitions remaining, while mean minutes of typical MS sessions were just over one hour (i.e., 64.13 mins). Although the ACSM's exercise prescription criteria recommended moderate-to-vigorous intensity as per RPE (Nelson et al., 2007), such criteria were initially formed on the basis of improving muscular strength outcomes. Hence, as a first step, we aimed to broaden the scope of current assessments to examine cross-sectional associations between MS variables and mental health outcomes (Shakespear-Druery et al., 2021), helping to highlight if appropriate adjustments to the physical activity guidance for mental health are worth consideration (Teychenne et al., 2017).

To this end, and based on multivariate regression modelling, support for H_1 was mixed, such that the $\geq$3 days per-week frequency category was inversely related to both anxiety and depression, but not related to well-being. Yet, 2-days per-week exerted a null effect across all mental health variables, while 1-day per week was inversely related to depression. Given a preponderance of studies show better mental health profiles among those meeting the MS guidelines compared to those who do not (e.g., Bennie et al., 2018; De Cocker et al., 2020; Oftedal et al., 2019), and whilst acknowledging the present data was cross-sectional, it was surprising that 1-day per-week predicted significantly fewer depressive symptoms than 2-days. However, given the established physical health benefits of MS activity, and fewer depression symptoms were found for 1-day, interventions designed to engage individuals with some MS activity are still strongly recommended. Such efforts may benefit from using a co-production model, wherein the population under focus exert a role as

key stakeholders, express preferences for MS activity frequency, intensity and duration based on practicality and feasibility, and socio-ecological factors (e.g., organisational context, barriers/facilitators) are incorporated into the design, implementation, and analyses (Mills et al., 2019). In this context, past research has shown those with severe mental illnesses (e.g., schizophrenia) tend to be disproportionately excluded from trials, with a healthy user bias found (Lally et al., 2018). Therefore, tailored recruitment strategies are needed for such populations (Hassan et al., 2022).

Furthermore, given the positive mental health effects found for both 1-day and ≥3-days, the present data support narrative reviews that suggest that depression symptoms may be reduced from both lower amounts of MS activity (Schuch et al., 2017a), and higher amounts of MS as per a meta-analysis of intervention trials (Gordon et al., 2018). Moreover, in this study, higher frequency of MS activity at ≥3 days resulted in significantly fewer anxiety symptoms, and the effect size for 1-day was larger than 2-days. A speculative u-shaped, quadradic, relationship could be argued from our data, wherein benefits are accrued from lower and higher frequencies. However, due to the cross-sectional methodology adopted, drawing conclusions for such relationships in the context of population health is far less convincing than findings from intervention studies (Reed & Ones, 2006).

Adding further complexity to the MS and mental health relationship, duration exerted a null effect across all mental health outcomes (H_2). A limitation of our measure of duration was that it was aligned to the length of a typical session, rather than accumulated over a total weekly period. Indeed, studies in the broader health domain have shown cumulative aerobic physical activity durations are as effective as continuous durations in establishing physiological health benefits (Murphy et al., 2019). Therefore, further study is required to establish the association between MS duration 'bouts' with mental health at an epidemiological level. Yet, such a study may be difficult to implement given the lack of validated objective wearable devices linked to MS activity (Shakespear-Druery et al., 2021). Moreover, it is likely that short bouts of MS activity occur in occupational-related activities rather than leisure-time physical activity where people tend to allocate extended periods to MS in a gym facility with specialised equipment (Biddle, 2022). Therefore, a more detailed MS questionnaire may be required to capture duration bouts and contexts(e.g., Armstrong & Bull, 2006).

Results from H_3 were largely supported, to the extent that higher MS intensities predicted s lower anxiety and depression symptoms, but not mental well-being. Harada et al. (2015) have established a likewise linear association between MS intensity and health-related quality of life. In aerobic physical activity research however, the exercise experience becomes increasingly unpleasant during an activity at supra-ventilatory threshold intensities (i.e., where the body relies to a greater extent on anaerobic metabolism for energy; Ekkekais et al., 2011), despite high-intensity interval training being a highly effective means of improving cardiorespiratory and metabolic function (Buchheit & Laursen, 2013). Additionally, many populations have difficulty establishing clarity with the exercise intensity terminology in public health guidance, leading to flawed prescriptions and exercise expectations (Hutchinson & Goosey-Tolfrey, 2021).

In view of behavioural adherence to aerobic physical activity in public health, there tends to be variability in the pleasantness experienced *close to* the ventilatory threshold, whereas; self-selected, rather than imposed, intensities tend to garner greater tolerance (Lind et al., 2008). While ventilatory threshold has little relevance to MS activity, emerging research (Cavarretta et al., 2018; Hutchinson et al., 2020) suggests a similar relationship may exist between MS intensity perceptions and affect, whereby ratings of RPE, intramuscular pH, percentage one-repetition maximum (1RM) or volume metrics may highlight where the transition to predominantly negative responses occurs.. Adding further support, recent studies using the Feeling Scale (FS; Emanuel et al., 2020), an 11-point scale characterising affective valence, showed that each one unit decrease in the FS corresponded to MS task failure between 11-14%. Therefore, it would appear prudent to recommend MS intensities at the moderate level between 5-8 RPE for both mental health and task competency, wherein at minimum, two repetitions are remaining in a given set. Additionally, individuals who self-select the load tend to gravitate toward moderate intensities, and such protocols have shown to increase resistance training self-efficacy, and higher intentions to participate in resistance training in the future (Focht et al., 2015).

Beyond the MS facets of frequency, intensity, and duration, the present study did not measure MS volume and its potential effects on mental health outcomes. While the WHO (2020) guidelines do not recommend a specific MS volume, the ACSM (Nelson et al., 2007, p. 1098) suggest a progressive ‘8–10 exercises be performed on two or more non-consecutive days per week using the major muscle groups”. In the context of intervention trials, volume has been calculated as a product of repetitions x sets x load (weight in Kg) (Fairman et al.,

2019), and may serve as a metric for future research. However, Fairman et al. (2019) acknowledged that relative volume (i.e., repetitions x sets x percentage of 1RM) as opposed to absolute volume (i.e., repetitions x sets x load) would improve accuracy in accounting for individual strength and body mass levels. Gaining accurate estimates of volume in the context of population health studies may be difficult however, and will depend upon the participants 1-RM experience and knowledge. Moreover, there may be differential mental health effects when MS frequencies, intensities, durations, and volumes, are accumulated through machine, free weights, plyometric exercises and/or resistance bands solely or in combination (Nilsen et al., 2018).

Study Limitations

While this study adopted the novel approach of assessing MS frequency, intensity and duration with multivariate mental health outcomes, limitations remain to address in future studies. Firstly, given the cross-sectional nature of the study, reverse causality is plausible. Longitudinal studies using latent difference score modelling (Muthén & Muthén, 2018) could improve knowledge on the protective and/or well-being enhancing effect of MS behaviours on mental health outcomes over time. Secondly, our sample composition included a younger profile of adults, likely due to their higher engagement in social media where recruitment took place. As such, this population are typically more engaged in MS than older populations. Future epidemiological research may consider a focused approach among middle-aged and older populations who are likely to experience an added benefit of MS activity on physical health outcomes (e.g., age-related sarcopenia) (Fairman et al., 2019; Nilsen et al., 2018). Relatedly, the sample's mean levels of anxiety and depression were classified as 'mild' and therefore the associations between MS activity and mental health cannot be extrapolated to groups with severe mental illness. Indeed, individuals with severe mental illness are less likely to participate in mental health research through various factors (e.g., motivation, pronounced negative symptoms) (Kline et al., 2018), and targeted recruitment and focused research on MS activity and mental health among such marginalised groups is much needed. Third, our assessment of duration could be extended beyond a typical MS session to total minutes accumulated across the previous week. Such measurement tools may consider capturing bouts within domain specific MS activities (e.g., occupational, leisure-time), and include assessments of total or relative volume (i.e., repetitions x sets x load/1RM). Moreover, while our study isolated MS activities to examine the relative effect of frequency, intensity, and duration, we did not concomitantly assess the same components within aerobic

physical activities (e.g., walking, running), and therefore excluded potential confounding variables. Lastly, given the timing of our study during a period of Covid-19 social restrictions in Ireland, opportunities to engage in one's typical leisure-time MS activity were likely impeded by the intermittent opening and closure of leisure facilities. Therefore, the prevalence statistics and mental health diagnostic estimates should be considered in context.

Conclusion

The present study showed a significant proportion of individuals with likely mental ill-being, sub-optimal well-being, and insufficient engagement in MS activity. Performing at least 1-day of MS activity protected against depression, whereas higher frequencies of ≥3-days was associated with lower anxiety and depression symptoms. Additionally, MS activity performed at higher intensities was associated with lower anxiety and depression. Given the cautionary considerations for aerobic exercise intensities for behavioural adherence (Ekkekais et al., 2011), and population difficulties in understanding exercise intensity terminology (Hutchinson & Goosey-Tolfrey, 2021), those communicating MS recommendations may be prudent to advise moderate intensities with self-selected loads and repetition ranges of MS activity, rather than imposed high intensities. Therefore, co-produced, evidence-based, MS interventions are recommended to help curb mental illness rates (Mills et al., 2019), and detailed tracking of MS activities is proposed to help identify at-risk groups and trends within physical activity surveillance (Shakespear-Druery et al., 2021). Longitudinal study designs replicating the present research are recommended, with the proposal of incorporating relative or total volume, total duration accumulated over a week, and capturing of domain-specific and/or type (e.g., free-weights, machine-based, bodyweight) of MS activities.

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