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Digital Phenotyping and Lifestyle Intervention in Patients With Myasthenia Gravis (DIG-MG): A Randomized Controlled Trial of Feasibility, Adherence, and Effects on Fatigue

Maja Norling[1] | Niclas Eriksson[2] | Elisabet Westerberg[3] | Ingela Nygren[4] | Klara Norman[1] | Julia Hedberg[1] | Sui H. Wong[5] | Susanna Jernelöv[6] | Pernilla Åsenlöf[7] | Anna Rostedt Punga[1,3]

[1]Clinical Neurophysiology, Department of Medical Sciences, Uppsala University, Uppsala, Sweden | [2]Uppsala Clinical Research Center, Uppsala University, Uppsala, Sweden | [3]Clinical Neurophysiology, Uppsala University Hospital, Uppsala, Sweden | [4]Neurology, Department of Medical Sciences, Uppsala University and Uppsala University Hospital, Uppsala, Sweden | [5]King's College, London, UK | [6]Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden | [7]Physiotherapy and Behavioral Medicine, Department of Women's and Children's Health, Uppsala University, Uppsala, Sweden

Correspondence: Anna Rostedt Punga (anna.rostedt.punga@uu.se)

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ABSTRACT

Introduction/Aims: Physical activity and sleep influence fatigue in myasthenia gravis (MG), and digital health technologies (DHT) enable objective monitoring of these behaviors in daily life. Using this approach, we evaluated whether a lifestyle intervention targeting physical activity or sleep hygiene could reduce fatigue in MG.

Methods: In this three-arm, randomized controlled trial (DIG-MG; NCT05992025), 72 MG patients completed 6 weeks of baseline monitoring with a DHT ring (OURA), followed by 12 weeks of (i) physical activity guidance, (ii) sleep hygiene education, or (iii) observation, and a 6-week follow-up. The primary outcome was the MG Activities of Daily Living (MG-ADL) score 1 week postintervention. Secondary outcomes included Fatigue Severity Scale (FSS) scores; exploratory outcomes were DHT-derived physical activity and sleep parameters.

Results: Baseline MG-ADL scores were similar (median: 5.0). Postintervention medians were 4.0 (physical activity), 3.5 (sleep hygiene), and 3.0 (control), with no significant differences ($p = 0.073$). Clinically meaningful MG-ADL improvement occurred in six, seven, and six participants, respectively. FSS scores showed no group differences ($p = 0.992$), with clinically relevant improvement in eight participants in each intervention group and five controls. Participants were more physically active than expected: 64.7% exceeded 600 MET-min/week at baseline. DHT adherence was excellent. REM sleep was lower than expected, while deep sleep was preserved. Self-reported data aligned with DHT measurements.

Discussion: Digital lifestyle interventions were feasible and well-accepted but did not improve MG-ADL or FSS in this unusually active population. However, DHT-based monitoring may support individualized follow-up, and reduced REM sleep warrants further investigation as a fatigue-related factor.

1 | Introduction

Myasthenia gravis (MG) extends beyond muscle fatigability and impacts broader aspects of daily functioning [1]. Fatigue, both generalized and physical (muscle), is one of the most common and debilitating symptoms in MG, and higher fatigue levels are typically associated with lower levels of physical activity and higher Myasthenia Gravis Activities of Daily Living (MG-ADL)

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scores [2, 3]. Physical activity is considered safe in stable MG and has been associated with improved muscle strength, function, and quality of life [4–7]. Despite this, many individuals with MG remain less active than recommended, with higher sedentary time than the general population [8]. Higher physical activity is associated with less fatigue, yet over half of patients report low physical activity [2]. While supervised exercise programs show benefit [4–7] and prevent co-morbidities [9], little is known about how patients engage in unsupervised every day activity, which is more relevant for long-term management. Barriers include fatigue, while facilitators include optimal treatment and social support [10]. Patients frequently report uncertainty about safe activity levels and a lack of MG-specific guidance [11].

Sleep is another important lifestyle factor that may contribute to fatigue in MG but remains understudied. MG patients report poorer sleep quality, more nocturnal disturbances, and daytime dysfunction [12, 13], all of which can exacerbate fatigue [14]. A small study suggests altered sleep architecture, including reduced REM sleep, increased deep sleep, and impaired oxygen saturation, in MG [15]. Sleep disturbance in MG may arise from respiratory muscle weakness and reduced ventilatory reserve during sleep, increasing vulnerability to sleep-disordered breathing, nocturnal hypoventilation, and CO_2 retention, especially during REM sleep [16]. Corticosteroid use may also disrupt sleep and reduce REM latency [17]. Another polysomnography study reported reduced light sleep and lower sleep efficiency in MG [18]. Taken together, lower physical activity, greater sedentary behavior, and impaired sleep are all associated with higher fatigue, though substantial individual variation suggests a need for personalized management strategies [19].

Digital health technologies (DHT) offer new opportunities to characterize lifestyle behaviors and support data-driven interventions in MG. Wearable DHT devices can provide validated continuous monitoring of physical activity, temperature [20], heart rate, heart rate variability [21, 22], and sleep patterns [23, 24], with good agreement with gold-standard measures (including electrocardiography and polysomnography). Such monitoring can itself promote positive behavioral change [25]. However, the utility of DHT-based lifestyle interventions in MG has not been evaluated.

The primary aim of this study was to determine whether a digital lifestyle intervention targeting physical activity or sleep hygiene could reduce muscle fatigue in MG. Secondary aims were to assess effects on fatigue and to characterize lifestyle patterns using DHT-derived data.

2 | Methods

2.1 | Inclusion of MG Patients

Patients diagnosed with MG in Sweden were recruited via the Swedish NEURO association's website, the Myasthenia Gravis Sweden Facebook group, and invitation letters sent to individuals followed at Uppsala University Hospital's Clinical Neurophysiology or Neurology Clinics.

Inclusion criteria were a confirmed diagnosis of ocular or generalized MG for ≥6 months, defined by characteristic clinical features and continuous neurology follow-up under ICD-10 code G70.0. To verify the MG diagnosis also for patients not regularly followed at our clinic, we confirmed clinical symptomatology and diagnosis through review of medical records and/or data from the Swedish MG Registry. Basic Swedish language proficiency was required. Patients self-reporting ≥150 min/week of moderate-intensity physical activity, defined as engaging in activity more strenuous than brisk walking, were excluded, as were those with disease duration <6 months, recent participation in another trial, or pregnancy. Additional exclusions included contraindications to physical activity (e.g., recent myocardial infarction, respiratory or cardiac failure, neuromuscular or disabling rheumatological disease, chronic pain, orthopedic conditions, recent hospitalization, anemia, or stroke within the past year). Eligibility was confirmed during baseline interviews.

2.2 | Study Design, Randomization, and Interventions

The *Digital Phenotyping and Lifestyle Intervention in Patients with Myasthenia Gravis (DIG-MG)* study was a prospective, three-arm, randomized controlled trial conducted entirely digitally via the secure platform *minforskning.se*, compliant with GCP-GAMP5 standards. Ethical approval was granted by the Swedish Ethical Review Authority (2023-01455-02, 2024-02423-02), and the study was registered at ClinicalTrials.gov (NCT05992025). All participants provided electronic informed consent.

The study included three phases:

- *Phase I*: 6-week *baseline* observation
- *Phase II*: 12-week *intervention*
- *Phase III*: 6-week postintervention *follow-up*

During Phase I, all participants wore the DHT ring (OURA Health Ltd., Oulu, Finland) to monitor sleep and physical activity. This acclimatization period ensured device compliance. Participants were blinded to their own DHT data throughout the study, ensuring unbiased observation and minimizing the risk of behavior change driven by self-monitoring in the control group. Baseline data were used to characterize lifestyle patterns.

Participants were then randomized (1:1:1) into the three arms:

Group 1: Control—Continued passive monitoring with no intervention or data access.

Group 2: Physical activity intervention—Received a 12-week structured digital program via a remote audio/video connection (Zoom Communications, San Jose, CA) in small groups (~6 participants), led by a certified health coach. Sessions were weekly (Weeks 1–4), every other week (Weeks 5–8), and once in Week 12 (7 sessions total). The goal was ≥150 min/week of moderate-intensity aerobic exercise (approximately 600 Metabolic Equivalent of Task [MET] minutes; see Table S1), primarily brisk walking, with alternatives like cycling or swimming. Intensity was self-monitored using the "singing test" (ability to talk in short phrases but not sing). Participants were encouraged to break up sedentary time with short activity breaks.

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Group 3: Sleep hygiene intervention—Followed a 12-week digital sleep program with the same session format. Focus areas included consistent sleep/wake times, reduced screen time and stimulants, and optimized sleep environments (see Table S1). Participants practiced techniques between sessions and tracked habits using a lifestyle diary. Coaching followed a standardized protocol.

All sessions used structured formats based on health behavior frameworks and included interactive elements like guided reflection and peer discussion.

2.3 | Adherence

Adherence in Groups 2 and 3 was defined as attending ≥70% of scheduled sessions. Participants in Groups 2 and 3 completed brief diaries. Group 2 recorded the type, duration, and effort of their physical activities as well as fatigue. Group 3 documented sleep times, sleep quality, and fatigue.

2.4 | Outcome Measures

The intention-to-treat analysis (ITT) incorporated primary, secondary, and exploratory outcomes to assess symptom burden and objectively measured health behaviors.

2.4.1 | Primary and Secondary Outcomes

The primary outcome was the *MG-ADL* score at Week 19 (range: 0–24); higher scores indicating greater impairment. Scores of 0–1 indicated minimal or no symptoms [26], 2–4 mild disease, and ≥5 moderate to severe disease [27]. A≥2 point reduction was considered the minimal clinically important difference (MCID) [26].

The secondary outcome was the Fatigue Severity Scale (FSS), a 9-item measure of fatigue impact (range: 9–63) [28]. A mean score ≥4.0 indicated clinically significant fatigue, and a≥0.45 point change represented the minimal important difference (MID) [29].

Assessments occurred at five time points:

- *T0*: Week 6 (baseline)
- *T1*: Week 11 (intervention Week 5)
- *T2*: Week 15 (intervention Week 9)
- *T3*: Week 19 (1 week postintervention)
- *T4*: Week 23 (5 weeks postintervention)

2.4.2 | Exploratory Outcomes

Exploratory measures included the Chalder Fatigue Scale (CFS; range: 0–33) [30], assessed at the same time points. Continuous data from the DHT ring included physical activity (moderate- and high-intensity activity, expressed in MET-minutes and sedentary time), sleep (total duration, deep and REM sleep), and sleep efficacy. Additional clinical data included antibody status, MG subtypes, and medication use (from medical records and the Swedish Myasthenia Gravis Registry).

2.4.3 | Validation of DHT Ring Data Against Self-Reported Physical Activity and Sleep

Objective activity data were compared with self-reported diaries. Entries were matched by date and duration; missing entries were treated as no activity. MET values were assigned using the 2024 Adult Compendium of Physical Activities [31], and multiplied by duration to calculate weekly MET-minutes. Self-reported weekly sleep duration was compared to DHT-derived "sleep duration" (defined as total sleep time, estimated by the DHT Ring using multimodal sensor data and calculated as the sum of light, deep, and REM sleep, excluding wakefulness). For all weeks with a minimum of 6 days of available data from both the sleep diary and the DHT Ring, the difference between the two measures and their mean value was calculated. Self-reported average weekly sleep duration (hours) was compared with the DHT ring–derived "sleep duration" (total time from going to bed to waking up) for the same participant and week. Only weeks with ≥6 days of valid data from both sources were included. Agreement between self-reported and DHT measures for activity and sleep was assessed using Bland–Altman plots.

2.5 | Hypothesis, Power Calculations, and Statistical Analysis

The primary hypothesis was that digital lifestyle interventions (physical activity or sleep hygiene) would yield a ≥30% reduction in MG-ADL score from baseline (T0) to postintervention (T3), compared to the control group. The secondary hypothesis was that a digital lifestyle intervention would yield a ≥30% reduction in FSS score over the same interval compared with the control group. The exploratory hypothesis was that digital lifestyle interventions would improve DHT-derived metrics (e.g., increased sleep duration, reduced sedentary time) when evaluated at T3 relative to baseline and compared with the control group.

2.5.1 | Power Calculation

Although our primary hypothesis focused on a proportional (30%) change in MG-ADL, no validated variance estimates or established MCID thresholds are available for percentage-based reductions in MG. To ensure a robust and clinically interpretable sample size estimation, we therefore based the power calculation on the well-established absolute MG-ADL MCID of 2 points, for which reproducible SD values (≈2.5) and data from prior trials are available. To detect a clinically meaningful 2-point difference in MG-ADL (SD = 2.5, $\alpha = 0.05$, power = 80%), 26 participants per group were required.

2.6 | Statistical Analysis

All randomized participants were included. Exclusions and deviations were recorded. The responsible statistician (N.E.) was blinded to group allocation to prevent analytic bias.

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The primary outcome (MG-ADL at T3) was analyzed via linear regression, including the treatment variable while adjusting for baseline MG-ADL. To maintain a family-wise type I error rate of 0.05, the overall ANOVA *F*-test for the treatment effect was used as the primary test. Pairwise comparisons were subsequently reported with point estimates, 95% confidence intervals, and *p*-values; however, if the overall ANOVA did not yield a $p \leq 0.05$, the corresponding *p*-values should be interpreted as nominal. Missing values were imputed using multiple imputation as a sensitivity analysis. Secondary outcome (FSS at T3) was analyzed analogously. Exploratory DHT-data were analyzed using linear regression adjusted for baseline and within-group changes via Wilcoxon signed-rank tests. Bland–Altman plots assessed agreement between self-reported and DHT measures [32]. Analyses were conducted in R (version 4.4.1) and Prism 10.5 (GraphPad, Boston, MA).

3 | Results

3.1 | Cohort Characteristics, Adherence, and Digital Monitoring

Of 103 screened patients, 81 were randomized to physical activity ($N = 26$), sleep hygiene ($N = 28$), and control ($N = 27$), with 72 completing the trial following withdrawals and diagnostic exclusions (Figure 1). The majority of patients (82%) received immunosuppressive therapy, primarily corticosteroids and rituximab (Table 1). Adherence to sessions was high: 68% in the physical activity group and 82% in the sleep group attended all sessions. Missed sessions were rare. DHT ring adherence was excellent across groups, with a median wear time of ~23 h/day and no significant differences between groups or study phases.

3.2 | Primary and Secondary Outcomes

3.2.1 | MG-ADL

MG-ADL scores were comparable across groups at baseline (Figure S1; Table 2). ANOVA adjusted for baseline showed no significant group differences at T3 ($p = 0.0727$). Pairwise comparisons gave the following effect estimates: physical activity versus control 1.12 (95% CI 0.10 to 2.14, $p = 0.04$) and sleep versus control 0.14 (95% CI −0.91 to 1.19, $p = 0.80$). Clinically meaningful improvement (≥2-point reduction) was observed in 6 participants in each of the physical activity and control groups, and 7 in the sleep group. Despite these individual-level improvements, there were no statistically significant changes in MG-ADL over time in the intervention groups compared to the control group (Table 2; Figure S2A–C). Sensitivity analysis with multiple imputation (eight imputed datasets, ~8% missing data) confirmed these findings (ANOVA $p = 0.1041$).

3.2.2 | Fatigue Severity Scale (FSS)

Fatigue levels also followed a similar trajectory across all groups (Table 2; Figure S2D–F). Clinically significant mean fatigue values (FSS ≥ 4.0) were present in 16 participants (64%) in the physical activity group, 12 (55%) in the sleep hygiene group, and 15 (60%) in the control group (Figure S2D-F). Clinically meaningful improvement occurred in eight participants each in the physical activity and sleep hygiene groups and five (20%) in the control group. No significant differences were found (ANOVA $p = 0.992$).

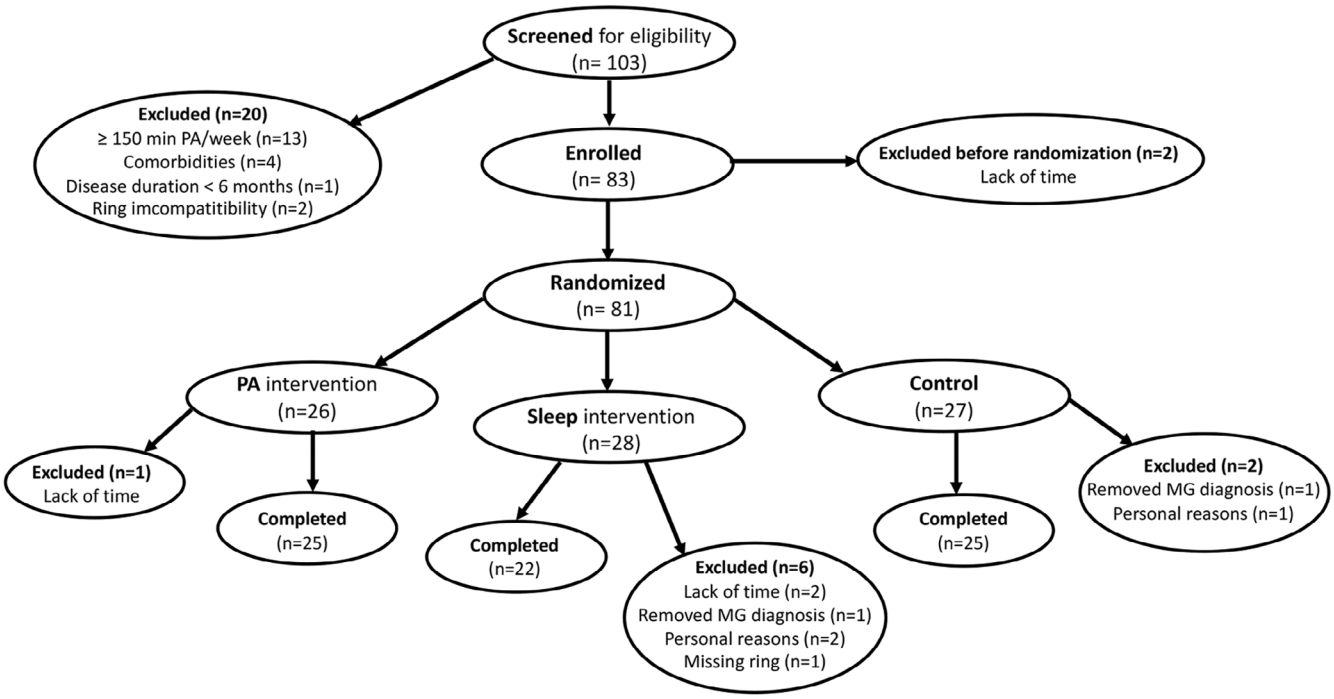

FIGURE 1 | Flow diagram of participant recruitment, exclusion, randomization, and study completion. Of 103 patients assessed for eligibility, 20 were excluded prior to enrollment. Eighty-three patients were enrolled, of whom two were excluded before randomization. Eighty-one participants were randomized to a physical activity intervention ($n = 26$), a sleep hygiene intervention ($n = 28$), or a control group ($n = 27$). The diagram details reasons for exclusion and the number of participants completing each study arm.

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TABLE 1 | Baseline characteristics of the 72 MG patients who completed the study.

	All MG ($N=72$)	Physical activity ($N=25$)	Sleep hygiene ($N=22$)	Control ($N=25$)
Age, years, median [IQR]	50 [38–65]	50.0 [40.0–60.0]	48.0 [38.5–60.5]	50.0 [38.0–68.8]
Age at onset, years	36 [25–56]	40 [23–57]	34 [24–49]	40 [28–66]
Disease duration, years, median [IQR]	6 [3–17]	6 [3–17]	9 [5–21]	3 [2–9]
Sex				
Male	16 (23%)	4 (17%)	5 (23%)	7 (28%)
Female	56 (78%)	21 (84%)	17 (77%)	18 (72%)
Antibodies				
AChR+	54 (75%)	20	16	18
MuSK+	2 (3%)	0	1	1
Seronegative	16 (22%)	5	5	6
Type of MG				
Ocular	5 (7%)	2 (8%)	1 (4%)	2 (8%)
Generalized	62 (86%)	22 (88%)	18 (82%)	22 (88%)
No symptoms	5 (7%)	1 (4%)	3 (14%)	1 (4%)
Disease severity				
Minimal symptoms (MG-ADL 0–1)	12 (17%)	5 (20%)	4 (18%)	4 (16%)
Mild (MG-ADL 2–4)	23 (32%)	7 (28%)	5 (23%)	11 (44%)
Moderate-high (MG-ADL ≥ 5)	37 (51%)	13 (52%)	13 (59%)	10 (40%)
Ongoing MG treatment				
Immunosuppression	59 (82%)	17 (68%)	19 (86%)	21 (84%)
Corticosteroids	27 (38%)	8 (32%)	7 (32%)	12 (48%)
Azathioprine	11 (15%)	2 (8%)	6 (27%)	3 (12%)
Tacrolimus	3 (4%)	1 (4%)	2 (9%)	0 (0%)
Rituximab	26 (36%)	8 (32%)	8 (36%)	10 (40%)
Methotrexate	3 (4%)	1 (4%)	1 (4%)	1 (4%)
Cyclosporine A	4 (6%)	0 (0%)	1 (4%)	3 (12%)
Efgartigimod	1 (1%)	0 (0%)	1 (4%)	0 (0%)
Only AChEI		4 (16%)	2 (9%)	3 (12%)
No medication		4 (16%)	1 (5%)	1 (4%)

Note: Several patients received more than one immunosuppressive treatment; therefore, the total number of treatments exceeds the number of patients.
Abbreviations: AChR+, acetylcholine receptor antibody seropositive; MuSK+, muscle-specific tyrosine kinase antibody seropositive; MG-ADL, Myasthenia Gravis Activities-of-Daily-Living; AChEI, acetylcholine esterase inhibitors.

3.3 | Exploratory Outcomes

3.3.1 | Chalder Fatigue Scale (CFS)

Baseline CFS was high and similar across groups (median: 28.0; IQR, 22.0–32.8). Group-specific medians were 27.0 (IQR, 22.0–33.0) in the physical activity group, 27.0 (IQR, 22.0–32.0) in the sleep hygiene group, and 29.0 (IQR, 24.0–33.5) in the control group. Postintervention, scores declined slightly (median: 26.0; IQR: 22.0–32.0) overall, indicating no significant between-group differences.

3.3.2 | Physical Activity and Sedentary Time (DHT Ring)

DHT data revealed that many participants were already meeting recommended physical activity levels at baseline (Table 3).

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TABLE 2 | Primary and secondary outcomes.

	All MG [*N* = 72]	Physical activity [*N* = 25]	Sleep hygiene [*N* = 22]	Control [*N* = 25]
MG-ADL baseline	5.0 [2.0–7.0] 0–12	5.0 [2.0–6.5] 0–12	5.0 [2.8–6.3] 0–9	3.0 [2.0–7.0] 0–12
MG-ADL T1	4.0 [2.0–6.0] 0–12	5.0 [2.0–5.0] 0–11	4.5 [1.8–6.0] 0–10	3.0 [2.0–6.0] 0–11
MG-ADL T2	3.5 [1.0–6.0] 0–12	3.0 [2.0–4.0] 0–11	4.0 [1.0–6.0] 0–9	3.0 [2.0–6.0] 0–12
MG-ADL T3	3.0 [2.0–6.0] 0–12	3.5 [2.0–5.8] 0–10	3.0 [1.0–4.8] 0–8	3.0 [2.0–5.0] 0–11
MG-ADL T4	3.0 [1.3–5.0] 0–13	4.0 [2.0–5.0] 0–10	3.0 [1.0–4.5] 0–13	3.0 [2.0–5.0] 0–11
FSS T0	43.0 [28.0–53.0] 10–63	42.5 [31.3–52.5] 16–63	38.5 [22.0–53.3] 14–60	46.5 [28.8–54.5] 17–63
FSS T1	43.5 [28.0–53.0] 10–68	44.0 [27.0–52.5] 10–68	40.0 [24.0–52.3] 12–57	44.0 [36.0–56.0] 15–63
FSS T2	41.5 [29.5–51.0] 9–54	42.0 [27.0–49.0] 9–62	38.0 [26.3–52.0] 12–59	42.0 [35.0–52.0] 11–63
FSS T3	41.0 [27.5–51.0] 11–63	44.0 [30.0–48.5] 12–62	37.5 [21.8–50.5] 11–59	42.0 [26.8–55.0] 24–63

Note: Data are shown as median [interquartile range, IQR] and range (minimum to maximum values).
Abbreviations: MG-ADL, MG Activities of Daily Living; FSS, Fatigue Severity Scale (total scores).

TABLE 3 | Number of patients achieving the requirement of the intervention regarding physical activity.

	Baseline	Intervention	Follow-up
Number of patients achieving at least 600 MET-minutes in MHPA/week.			
All	46/71 (64.7%)	50/71 (70.4%)	47/71 (66.2%)
Control	13/24 (54.2%)	14/24 (58.3%)	15/24 (62.5%)
Physical activity	17/25 (68.0%)	20/25 (80.0%)	17/25 (68.0%)
Sleep hygiene	16/22 (72.7%)	16/22 (72.7%)	15/22 (68.2%)
Mean time spent sedentary (hours/week)			
All	119.3 ± 23.3	120.7 ± 19.8	120.8 ± 18.5
Control	118.1 ± 33.7	121.7 ± 20.0	120.7 ± 21.2
Physical activity	116.9 ± 18.4	116.7 ± 24.8	118.5 ± 15.6
Sleep hygiene	123.2 ± 12.7	124.2 ± 11.8	123.5 ± 18.8

In the physical activity group, this increased to 80% during the intervention. Patterns of physical activity and sedentary time remained largely stable during the study, with no differences between groups or over time. (Figure S3).

3.3.3 | Sleep Parameters (Measured by DHT)

Total sleep time, sleep efficiency, and sleep stage proportions remained highly stable throughout the trial, with no differences observed between groups (Table 4; Figure S4). Deep sleep consistently accounted for approximately 10%–20% of total sleep, and 28% of participants showed reduced REM sleep. Although fewer participants in the physical activity group met the ≥ 7 h/night threshold at baseline, the proportion increased by T3 across all groups, with most participants achieving this level by the end of the intervention. Notably, REM sleep proportions were consistently lower than typical reference values, whereas deep sleep fell within expected ranges, and these patterns persisted through follow-up (Figure S5).

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TABLE 4 | Sleep data.

	Baseline	Intervention	Postintervention
Number of patients sleeping on average at least 7 h/24 h			
All	30/71 (42.3%)	31/71 (43.7%)	29/71 (40.8%)
Control	11/24 (45.8%)	11/24 (45.8%)	11/24 (45.8%)
Physical activity	8/25 (32.0%)	9/25 (36.0%)	13/25 (52.0%)
Sleep hygiene	9/22 (40.9%)	9/22 (40.9%)	4/22 (18.2%)
Total sleep time (hours/24 h)			
All	6.6 ± 1.1	6.7 ± 0.8	6.6 ± 0.8
Control	6.6 ± 1.1	6.7 ± 1.1	6.6 ± 1.0
Physical activity	6.7 ± 0.7	6.6 ± 0.6	6.7 ± 0.8
Sleep hygiene	6.7 ± 0.6	6.7 ± 0.6	6.6 ± 0.6
Light sleep (hours/24 h)			
All	4.2 ± 0.9	4.3 ± 0.6	4.3 ± 0.6
Control	4.1 ± 1.1	4.3 ± 0.7	4.2 ± 0.6
Physical activity	4.4 ± 0.7	4.4 ± 0.6	4.5 ± 0.7
Sleep hygiene	4.1 ± 0.7	4.2 ± 0.5	4.1 ± 0.5
Deep sleep (hours/24 h)			
All	1.1 ± 1.0	1.1 ± 0.9	1.1 ± 0.7
Control	1.0 ± 0.4	1.0 ± 0.4	1.0 ± 0.4
Physical activity	1.2 ± 1.5	1.1 ± 1.4	1.1 ± 1.0
Sleep hygiene	1.1 ± 0.4	1.1 ± 0.4	1.0 ± 0.40
REM sleep (hours/24 h)			
All	1.3 ± 0.3	1.4 ± 0.3	1.0 ± 2.3
Control	1.3 ± 0.4	1.4 ± 0.4	1.3 ± 0.4
Physical activity	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.3
Sleep hygiene	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.3
Sleep efficiency (%)			
All	81.7 ± 6.1	81.0 ± 4.5	81.3 ± 6.2
Control	80.9 ± 8.0	80.5 ± 7.4	80.4 ± 8.2
Physical activity	82.2 ± 4.1	80.9 ± 6.0	82.4 ± 4.4
Sleep hygiene	81.8 ± 5.7	81.7 ± 6.2	81.2 ± 5.4

Note: Number of patients achieving at least 7 h of total sleep per night/week, mean times in different sleep stages (hours/24 h), and sleep efficiency (%).

3.3.4 | Agreement Between Self-Reported and DHT Ring Data

In the sleep hygiene group, 211 paired weeks from 19 participants showed strong agreement between self-reported and DHT-measured sleep duration. Participants under-reported sleep by only 0.1 h on average, with no systematic bias, and Bland–Altman limits of agreement ranged from −1.51 to +1.71 h (Figure 2A). In the physical activity group, self-reported diaries underestimated activity compared with DHT data: (668 vs. 1229 MET-min/week), resulting in a mean difference of 561 MET-minutes. Discrepancies increased at higher activity levels, reflected in Bland–Altman limits of 800 to 1930 MET-minutes (Figure 2B).

4 | Discussion

This trial evaluated the impact of digital lifestyle interventions on fatigue in MG by targeting physical activity or sleep hygiene. Despite high adherence and excellent compliance with digital monitoring, no statistically significant differences were

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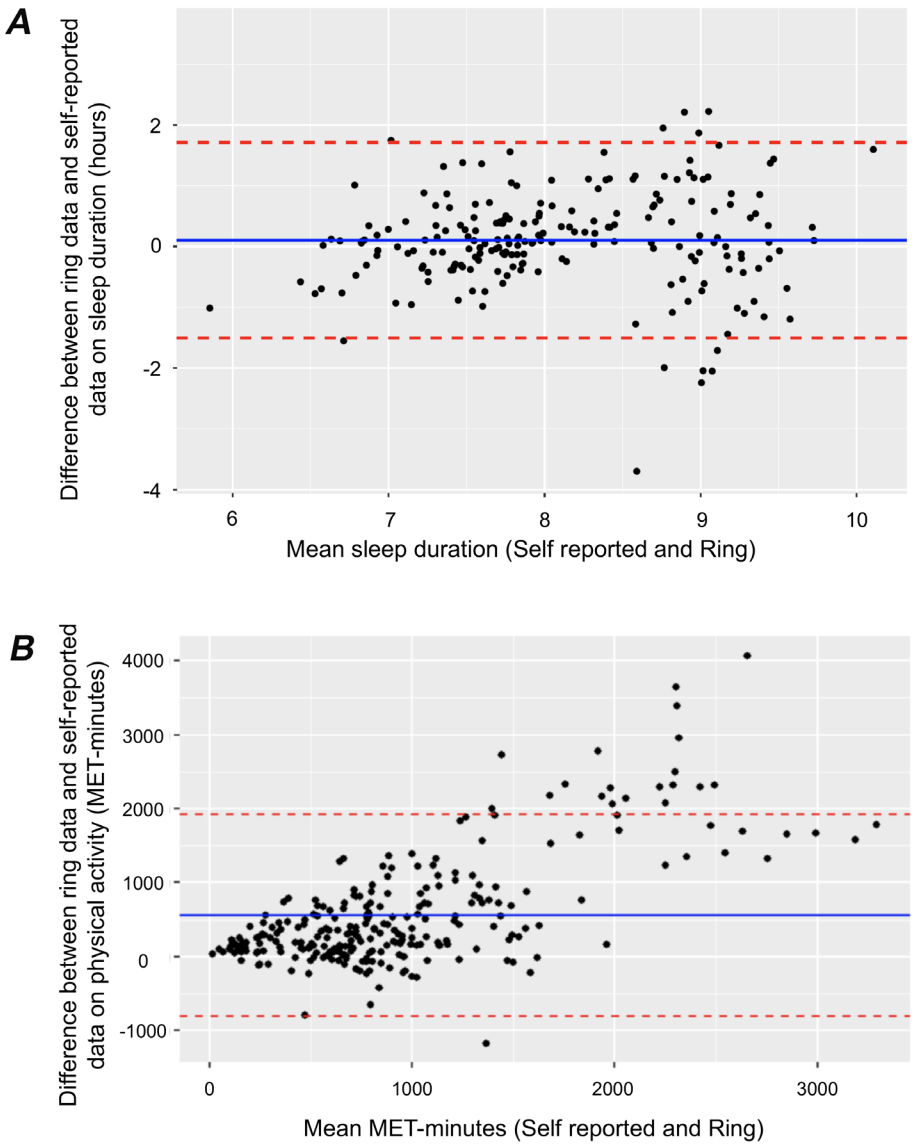

FIGURE 2 | Bland–Altman plots comparing self-reported and digital health technology (DHT) ring–measured outcomes: (A) nightly sleep duration and (B) weekly MET-minutes. Agreement was assessed between objective DHT ring measurements and subjective reports from daily digital diaries.

observed for primary (MG-ADL) or secondary (FSS) outcomes. Clinically meaningful improvements occurred in subsets across all groups, including controls, highlighting the challenge of detecting added benefits in a well-functioning MG population already receiving optimized treatment. Future studies should therefore prioritize individuals with greater unmet lifestyle needs and assess broader health outcomes, including comorbidity prevention.

A substantial proportion of screened patients were excluded because they already met physical activity guidelines, and nearly two-thirds of enrolled participants exceeded the recommended 600 MET-minutes/week during the introduction phase despite lower self-reported activity. This suggests that MG patients interested in lifestyle studies may already be highly active, aligning with Nordic guidelines and supporting the safety of exercise in MG [33]. High baseline activity and low MG-ADL scores likely contributed to the ceiling effects observed, limiting the measurable impact of the intervention.

From a public health perspective, our findings mirror previous work showing that Swedish MG patients are more likely to meet weekly physical activity recommendations [8] than those in Denmark [34], France [35], or Estonia [36]. An Australian cohort showed similarly high guideline adherence but prolonged sedentary time [37], consistent with sedentary patterns seen in Sweden [8]. Younger, digitally engaged, and less symptomatic individuals may be overrepresented in the present study, with disease severity and age known predictors of lower activity. About half of the participants had minimal or mild symptoms, further contributing to the limited detectable improvement [26].

Most participants met the recommended 7 h of sleep per night. Deep sleep generally reflected expected proportions of total sleep time, whereas REM sleep was frequently reduced, in line with observations from previous MG studies [15]. Corticosteroid use in over one-third of participants may have influenced sleep architecture, particularly REM latency [17]. Prior research also suggests sleep efficiency, rather than duration, is a stronger

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predictor of daytime sleepiness, especially in women [38]. These findings warrant further investigation into sleep efficiency and REM disturbances in MG, given their potential role in fatigue and quality of life.

Participant engagement and DHT compliance were high, supporting the feasibility of fully digital, remote interventions for MG self-management. Importantly, comparisons between self-reported diaries and DHT ring data showed strong agreement for sleep duration, and no systematic bias. This contrasts with prior studies showing self-reported sleep often overestimates duration by 20–30 min compared to polysomnography or actigraphy [39]. Physical activity, however, was consistently underestimated in diaries compared to DHT data, supporting the value of wearable-based monitoring in MG research and clinical care.

Several limitations must be acknowledged. First, although MG-ADL is clinically meaningful, it does not capture the multidimensional nature of fatigue, limiting sensitivity to detect fatigue-related changes. Second, recruitment through digital platforms and patient organizations likely favored highly active, health-literate, and mildly affected individuals, creating ceiling effects and increasing the risk of including cases with uncertain MG diagnoses; indeed, two seronegative participants were excluded after diagnostic reevaluation. Third, the remote design precluded inclusion of objective MG performance measures. Lastly, blinding participants to their DHT data may have reduced the potential for behavior change, as feedback is central to many digital interventions. While this approach minimized bias during the observation phase, it may also have limited the impact of the interventions. Feedback and self-monitoring are powerful tools for behavior change, and future studies might enhance efficacy by providing participants with tailored feedback from wearable devices. A key challenge remains sustaining self-management behaviors beyond the structured intervention period. While participants were motivated, long-term adherence is difficult without continued support, and future research should therefore explore scalable maintenance strategies, such as digital coping plans, peer support, and integration of digital tools into routine care [40].

In summary, digital lifestyle interventions were feasible, well accepted, and associated with high engagement in patients with MG but did not significantly improve fatigue or daily functioning in this highly active cohort. Future trials should incorporate objective pre-screening to identify less active individuals and broaden recruitment to better reach sedentary patients. Supporting self-regulation and coping strategies may also enhance long-term behavioral change. Digital interventions may be most effective when tailored to patients with lower baseline activity or impaired sleep. Finally, the observed reduction in REM sleep warrants further investigation as a potential contributor to fatigue and reduced quality of life in MG.

Author Contributions

A.R.P. and P.Å. conceived and designed the study. M.N. and A.R.P. enrolled patients and collected data. I.N. and S.W. contributed to the study design. N.E. served as the study statistician, responsible for analyzing and verifying the data reported in the manuscript. N.E., A.R.P., J.H., E.W., and K.N. performed data analyses. N.E., M.N., S.J., P.Å., I.N., and A.R.P. contributed to data interpretation. A.R.P. obtained funding and provided overall supervision. A.R.P., N.E., P.Å., and S.J. drafted the manuscript and prepared the revision. All authors critically reviewed the manuscript, contributed to its final version, and approved the submission.

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Ethics Statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

Conflicts of Interest

A.R.P. has received speaker or consultancy honoraria from Argenx, UCB, Alexion, Novartis, and Toleranzia, which are unrelated to this study. The other authors have no competing interests related to this study.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Group-level MG-ADL over time. MG-ADL scores for the physical activity (A; $n = 25$), sleep hygiene (B; $n = 22$), and control (C; $n = 25$) groups. Data are displayed as violin plots showing the distribution, mean, and range. MG-ADL, MG Activities-of-Daily-Living. **Figure S2:** Individual progression of MG-ADL and FSS scores during the intervention phase, stratified by group: (A–C) MG-ADL scores for the physical activity (A; $n = 25$), sleep hygiene (B; $n = 22$), and control (C; $n = 25$) groups. (D–F) Mean FSS scores for the physical activity (D), sleep hygiene (E), and control (F) groups. Each line represents an individual participant's score at four time points: baseline (T0), two mid-intervention assessments (T1 and T2), and two postintervention follow-ups (T3 and T4). Dashed lines indicate median scores at each time point. MG-ADL, MG Activities-of-Daily-Living; FSS, Fatigue Severity Scale. **Figure S3:** Physical activity and sedentary time over the study period. (A–C) Weekly minutes of moderate-to-high intensity physical activity expressed in MET-minutes, the physical activity (A), sleep hygiene (B), and control (C) groups. (D–E) Weekly sedentary time (minutes) for the physical activity (D), sleep hygiene (E), and control (F) groups. **Figure S4:** Total sleep duration over the study period. (A) Average total hours of sleep per night for the physical activity (A), sleep hygiene (B), and control (C) groups. **Figure S5:** Proportion of time spent in REM and deep sleep over the study period. (A–C) Percentage of total time spent in REM sleep for the physical activity (A), sleep hygiene (B), and control (C) groups. (D–E) Percentage of total sleep spent in deep (N3) sleep per night weekly in the physical activity (D), sleep hygiene (E), and control (F) groups. **Table S1:** Intervention instructions in the Physical Activity and Sleep Hygiene group, respectively.

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