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Effect of Time after COVID on Standing Postural Control

Langenderfer Joseph E.[1,*], Ustinova Ksenia I.[2]

[1]School of Engineering and Technology, Central Michigan University, United States
[2]Doctoral Program in Physical Therapy, Central Michigan University, United States

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Abstract This study investigated whether individuals exhibited changes in standing postural control following diagnosis of COVID infection and monitored the extent of alterations during multiple sessions over a 12 week period. Twenty post-COVID recovering individuals participated in three testing sessions. Center of pressure (COP) was recorded with a force plate while participants stood in a quiet posture and also while engaged in relatively low-level tasks representing activities expected to challenge posture. Participants quit a testing session if standing or the tasks became too difficult. Standard COP measures (path, RMS, path velocity and power spectrum in low and high frequency ranges) were calculated and task and session test times were recorded. Even 12 weeks post-COVID some individuals were able to endure the complete test by completing all tasks, while others exhibited decreased endurance as they were unable to complete all tasks and stand for the duration of a session. For later test sessions, endurance was increased, as more participants were able to complete the tasks and stand for a greater time. However, the greater endurance demonstrated by these individuals was acquired at a cost of decreased postural control as indicated by increased postural oscillations. Results suggest that a 12 week post-COVID recovery period may not be sufficient to fully regain postural control. Improvements in postural endurance could be just compensatory reactions of postural control.

Keywords Fatigue, Postural Stability, Endurance

1. Introduction

Myriad symptoms have been documented in patients infected with COVID. These symptoms have been shown to be related to the effects of COVID on many organ systems [1-3]. Among the reported symptoms include those associated with, to varying degrees, disorders of neurological, and musculoskeletal systems [4-7]. Moreover, individuals encountering COVID seem to have a bi-, or multi-modal distribution of clinical presentation, with the duration of COVID illness varying greatly, typically from one to several weeks [7-9]. Most patients experience asymptomatic to mild symptoms and thus are relatively functional for the period immediately following diagnosis. For others, symptoms can be moderate to severe, resulting in a fair degree of incapacitation effectively requiring mandatory bed-rest. The most severe cases require higher level medical care in the form of hospitalization.

For mild to moderate cases, following a period of some degree of outright symptomatic manifestation, recovery from overt symptoms typically occurs within a period of 2-3 weeks. However, some patients experience, to a varying degree, prolonged symptoms [9, 10]. Although not shown to be serious in terms of long-term effects, evidence has emerged that covert decrements in biomechanical or motor-control related measures may exist in presumably COVID recovered individuals. These potentially secondary neuromusculoskeletal effects of COVID include reductions in postural stability for individuals with decreased olfactory function or respiratory dysfunction [8], increased gait asymmetry in mild-moderately COVID-recovered patients [11], and altered ground reaction forces and muscle activations during running [12]. One limitation to the current understanding of these longer-term effects, is that the changes in neuro-biomechanical capabilities were found relatively soon after COVID diagnosis, e.g. 2-4 weeks [8], or ~ 8 weeks following COVID [12]. Improved understanding of any potential neuromusculoskeletal changes due to COVID over an even longer time-period, during which gradual and eventual recovery might be expected to occur, would be quite useful in planning and determining rehabilitation and therapeutic intervention.

Maintenance of stability during standing posture is an important function required for activities of daily living, personal hygiene and manual labor [13-16]. Extensive literature has documented alterations in center of pressure (COP) measures in individuals with neurological and musculoskeletal impairments, e.g. [17-20]. Having such information for compromised individuals is useful to suggest potential treatment modalities. In general, longer-term studies of the effects of COVID virus are still limited in number. While prior studies have documented alterations in ground reaction forces while running [12], it is possible similar effects are present for the simpler task of standing posture. Therefore, it would be useful to know the extent of any deficits in standing postural stability following COVID and how the deficits change over time since symptom onset and subsequent presumed recovery.

Therefore, the purpose of this study was to measure alterations in standing postural control following diagnosis of COVID infection and to monitor the extent of these alterations over a 12-week period. Based on observations of previous studies it was hypothesized that COVID would affect stability of standing posture. More specifically, it was expected that COVID, and the relatively low-level tasks employed here to moderately increase difficulty of standing, would reduce postural stability as assessed by COP measures. Furthermore, it was expected that postural stability would improve over the course of three testing sessions beginning less than 4 weeks after onset of COVID symptoms, spaced 4 weeks apart, and ending 12 weeks after initial COVID.

2. Materials and Methods

This study assessed standing posture in a longitudinal design over the course of three, 30-minute testing sessions. The first test session occurred 4-weeks after the diagnosis of COVID. The second and third sessions occurred at 4 week intervals following the preceding session. In each test session, participants stood on a force plate while engaged in simple quiet standing or standing while performing relatively low-exertion, but more difficult than simple standing tasks designed to challenge ability to maintain an upright posture.

2.1. Participants

Twenty COVID-recovered individuals (age: range 18-52, mean 26.6, S.D. 9.2 years) (2 Male, 18 Female) (Height: range: 1.58-1.79, mean: 1.67, S.D. 70.1 meters, Weight: range: 52.6-104.5, mean: 72.5, S.D. 15.6 kg) from university community-setting self-selected for inclusion in the study. The individuals demonstrated a variety of symptoms typical of COVID (Table I). None of the individuals were hospitalized or spent any time in resident medical care. After being informed of the nature, purpose and risks of the study, participants granted consent to enroll in the study as required for approval by the institutional review board (Central Michigan University IRB 2021-003).

Table 1. COVID symptoms for participants

Symptom	Number of participants
Fever	10
Upper respiratory congestion	18
Gastrointestinal distress	5
Loss of taste and/or smell	9
Sinus Congestion	5
Muscle and joint pain	8
General Fatigue	10

2.2. Procedure and Data Collection

Ground reaction forces and moments were measured with a six-degree of freedom force plate (AMTI-OR-6-7, Watertown, MA) (Figure 1). From the ground reactions, center-of-pressure (COP), which is a reflection of the neuromuscular response to alterations in center of gravity, was calculated. Test time for each session was 30 minutes duration while performing up to eight tasks of quiet standing and relatively low-exertion tasks that were of higher demand than simple bipedal quiet standing (Table 2). Task order, and the interspersing of tasks, were designed to gradually increase difficulty of standing over session duration in a comfortable manner representative of daily activities, rather than requiring highly difficult tasks overtly designed to challenge standing posture.

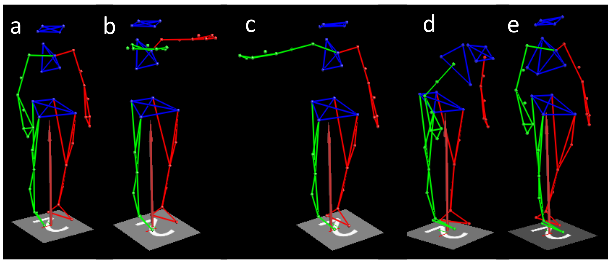

Figure 1. Standing on force plate. (a) Tasks 1, 3, 5, 8, quiet standing; (b) Task 2, arms outstretched horizontally to front; (c) Task 4, dominant hand holding 1 lb weight; (d) Task 6, trunk flexed 30 degrees; (e) Task 7, semi-tandem foot position.

Table 2. Tasks performed in each session.

Task (order)	Task	Time (minutes)
1	Quiet standing	3
2	Arms horizontal front	4
3	Quiet standing	4
4	1-lb weight horizontal lateral	4
5	Quiet standing	4
6	Trunk flexion	4
7	Semi-tandem foot stance	4
8	Quiet standing	3

For the quiet standing tasks (tasks 1, 3, 5, 8), participants stood with feet a self-selected approximately shoulder-width distance apart. For the second task (arms horizontal front), participants stood in the same position as quiet standing but with both arms outstretched to the front approximately shoulder width apart and parallel to the ground. For the fourth task (1 lb weight horizontal lateral), participants held a 1 lb (455 gram) exercise weight in dominant hand with arm abducted laterally at shoulder height. During the 4th task, there generally was some downward vertical movement of the weight, but the task was allowed to continue as long as participant actively resisted the load while maintaining at least 45 degrees of lateral shoulder abduction. For the sixth task (trunk flexion), participants stood with feet shoulder-width apart and the trunk flexed at 30 degrees and arms hanging toward the ground. For the seventh task, subjects stood in a semi-tandem foot position with arms hanging at the side of trunk. Between each task within a session there was less than a 30-second pause in data collection to transition between tasks and to ensure the participant was able to continue before data collection for the next task was re-initiated. During this pause, participants were required to remain in a standing posture although were free to move about rather than remain stationary. At any time during the 8 tasks within each session, participants were free to quit the session if unable to continue. If participants quit the session, test time ended and they were given a break to rest and recover before being invited to schedule a subsequent test session.

2.3. Data Processing and Analysis

The force plate signal was acquired at 1000 Hz in Nexus 2.9 (Vicon Motion Systems, Centennial, Colorado, USA). Following collection, data were analyzed with custom-written scripts in Matlab (Math Works Inc.). The anterior-posterior and the media-lateral coordinates of COP were calculated from forces and moments measured by the force plate. The COP data were filtered with a fourth-order, 8 Hz low-pass Butterworth filter and were centered by subtracting the mean from each time series. In order to minimize the effects of task initiation on measurements, the first minute of each trial was omitted from the analysis and calculation of COP measures.

For each trial, COP path was calculated as the Euclidean norm of the two-dimensional COP coordinates. Root-mean-square (RMS) and mean velocity were calculated for COP path. Mean COP velocity was determined by dividing the total COP path by the total time interval. RMS and velocity were normalized by participant height (Cattagni et al., 2014), and thus are expressed as a percentage of participant height. To assess the frequency components of COP oscillations, the power spectral density (PSD) of COP path was calculated for each trial. PSD was estimated by the Welch periodogram with a resolution of 0.05 Hz. A Hann window with 50% overlap was used with subtraction of the best linear regression. The area under the PSD was calculated in order to determine power contained in COP oscillation in two frequency ranges: 0.05-0.5 Hz “low frequencies” and 0.5–2.0 Hz “high frequencies” [21]. As mentioned in [22], these ranges were selected because in the low-frequency range (LF), the COP power spectrum approximates the center of gravity [23], while the frequency range that encompasses 99% of the total power of the COP signal during stance is bounded by the upper limit of the high-frequency (HF) band (2Hz) [24].

2.4. Statistical Analysis

Two-way ANOVA was used to compare the duration of the testing time for the 3 testing sessions and the 8 tasks with the testing session considered as a repeated-measure. Each session test time was compared against the expected session time (30 minutes), and each task test time was compared against the expected task test time [25]. Expected task test times were 3 minutes for tasks 1 and 8, and 4 minutes for tasks 2 through 7. After completion of the testing session, participants were divided into two groups: those who quit the session before all tasks were complete (Quit), and those completing all eight tasks (Complete). Each COP outcome measure was evaluated with two-way repeated measure ANOVA to assess if there were differences between testing session and the baseline condition of the first standing posture trial of the first session (testing session was a repeated-measure). The significance level was set at $\alpha=0.05$, with t-tests for pairwise comparisons between conditions and Bonferroni adjustment to guard against Type I errors.

3. Results

3.1. Session Completion and Time

Not all participants completed all eight tasks for each of the three sessions. For Session 1, 12 participants quit before completing all tasks (Figures 2 and 3). For sessions 2 and 3, 8 and 7 participants respectively, quit before completing all tasks. Consequently, the average test times when all tasks were not completed were 12.4, 14.6, and 16.7 minutes for sessions 1, 2 and 3, respectively (Figure 3). Significant reductions in test time for quit compared to completed sessions were found ($p<0.0001$ for all sessions). Although a different number of participants completed the tasks, no significant difference in test time was determined between the quit sessions. However, for the quit participants, there was a trend toward a significantly increased test time for later sessions compared to the earlier sessions resulting from all participants increasing their endurance during later sessions.

3.2. Center-of-Pressure Path (Temporal-Spatial and Frequency Analysis)

RMS COP demonstrated differences for Task Quit/Complete when compared to Baseline (Figure 4) ($F_{6,54}$ =6.12, $p< 0.0001$). RMS COP for Quit in Session 3 was significantly increased (0.014) compared to Baseline (0.006) ($p<0.0001$). There was a trend ($p=0.024$) toward increased RMS COP for Quit in Session 2 (0.010) compared to Baseline. No differences were found for Complete in any session compared to Baseline, or between sessions.

There were no differences in velocity of COP path when comparing Task Quit/Complete to Baseline (Figure 5) ($F_{6,54}$ =0.81, $p=0.57$). A significant main effect of Quit/Complete was found for Low frequency PSD area (Figure 6) ($F_{6,54}$ =4.15, $p=0.0017$). Low frequency PSD area for Quit in Session 3 was significantly increased (13.7 mm^2) compared to Baseline (1.75 mm^2) ($p=0.0004$). Also, low frequency PSD area for Quit in Session 3 was significantly increased compared to Complete Session 2 (1.01 mm^2) ($p=0.0017$) and Complete Session 3 (1.33 mm^2) ($p=0.0015$).

For High frequency PSD area (Figure 7) a significant main effect of Quit/Complete was found ($F_{6,54}$ =4.15, $p< 0.0017$). High frequency PSD area for Quit in Session 3 was significantly increased (42.2 mm^2) compared to Baseline (5.40 mm^2) ($p=0.0005$). Additionally, high frequency PSD area for Quit in Session 3 was significantly increased compared to Complete Session 2 (3.1 mm^2) ($p=0.0019$) and Complete Session 3 (4.09 mm^2) ($p=0.0017$).

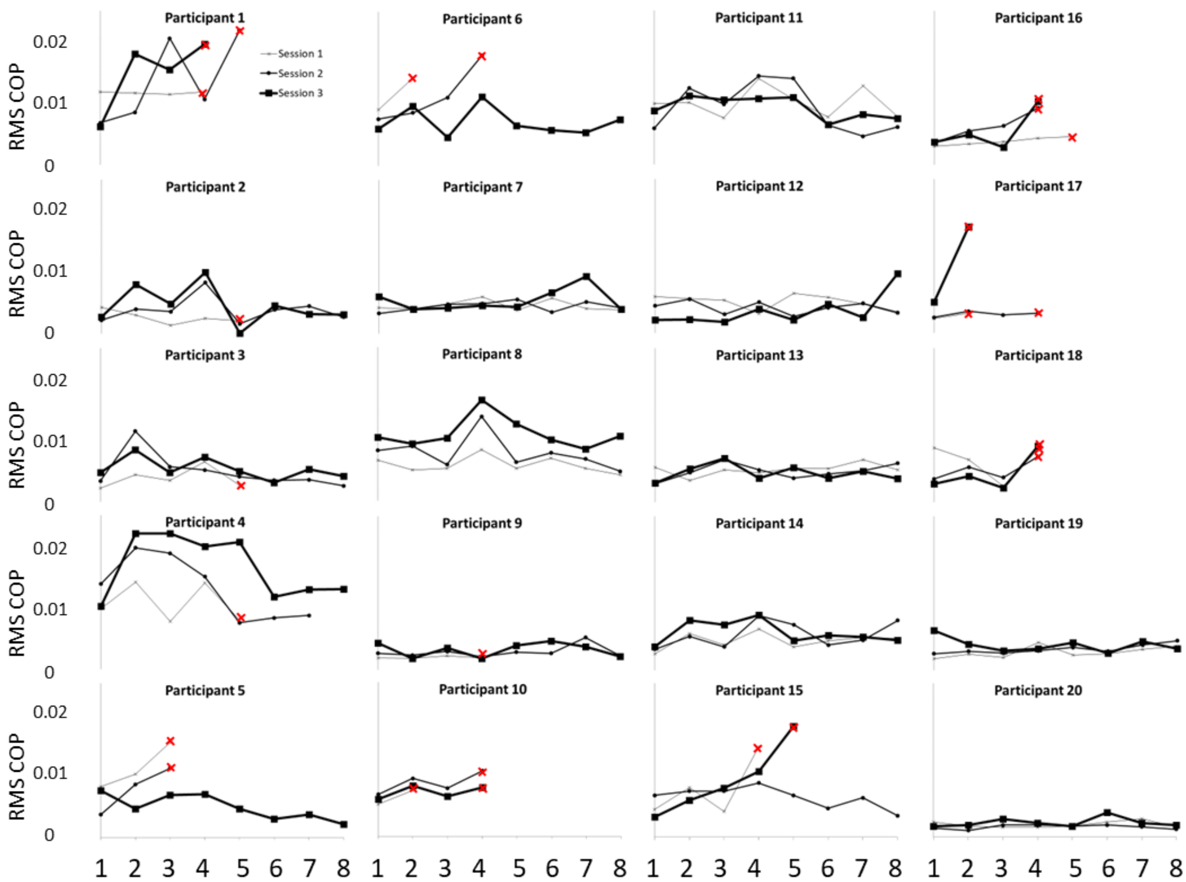

Figure 2. Root-mean-square (RMS) of center of pressure (COP) path for each participant for each of 8 tasks for the three sessions. (other outcome measures not shown). Trials with red cross-mark denote Quit where participant did not complete test session.

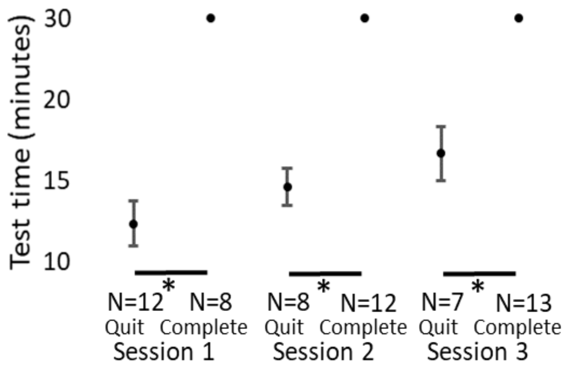

Figure 3. Test time (mean and standard error) for the three testing sessions for the number of participants who Quit and Completed each Session. Expected time was 30 minutes for each session. * Test time for quit was significantly less than expected test time ($p<0.00001$)

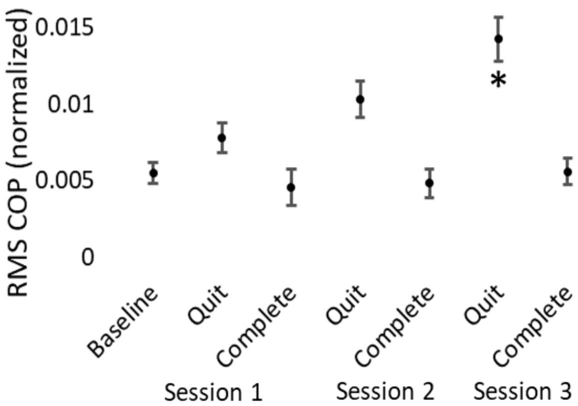

Figure 4. Root mean square (RMS) Center of pressure (COP) path (mean and standard error) for Trial 1, Session 1 (Baseline) and Quit and Task 8 (Complete) for the three sessions. * Significant difference from Baseline. RMS normalized to participant height.

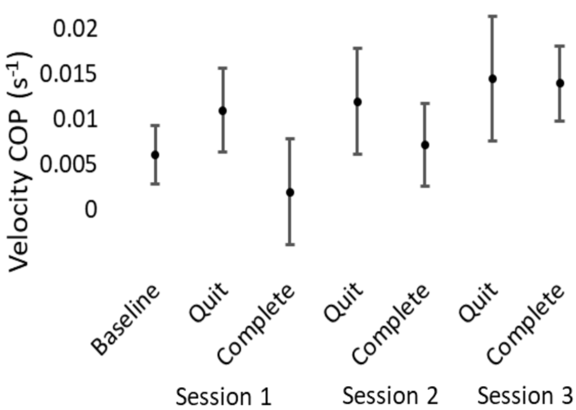

Figure 5. Velocity of Center of Pressure (COP) path (mean and standard error) for Trial 1, Session 1 (Baseline) and Quit and Task 8 (Complete) for the three sessions.

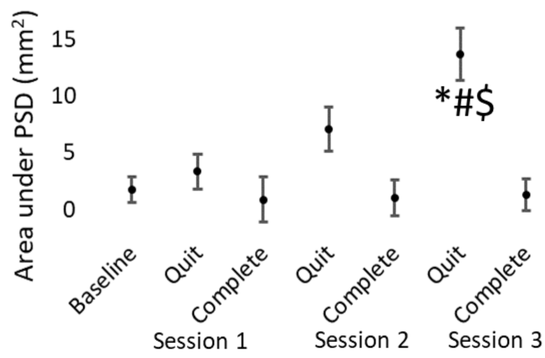

Figure 6. Low frequency area under PSD (mm^2) (mean and standard error) for Trial 1, Session 1 (Baseline) and Quit and Task 8 (Complete) for the three sessions. * Significant difference from Baseline. # Significant difference from Complete Session 2. $ Significant difference from Complete Session 3.

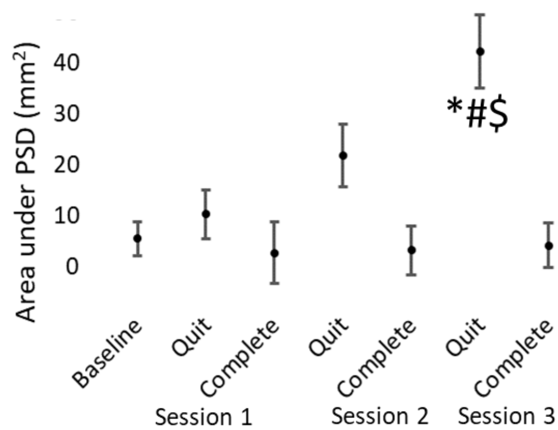

Figure 7. High frequency area under PSD (mm^2) (mean and standard error) for Trial 1, Session 1 (Baseline) and Quit and Task 8 (Complete) for the three sessions. * Significant difference from Baseline. # Significant difference from Complete Session 2. $ Significant difference from Complete Session 3.

4. Discussion

The present study measured alterations in standing postural control in individuals diagnosed with COVID and monitored these alterations in multiple test sessions over a twelve-week period following symptom onset and diagnosis. The test sessions involved a series of tasks interspaced between simple quiet standing that were designed to gradually challenge individuals' ability to maintain postural stability in a manner replicating activities encountered during daily activities and light manual labor. The expectation was that COVID would cause a reduction in postural stability as measured by COP and that the tasks would cause some relatively low level of additional physical load to challenge participants' postural control.

As expected, the tasks were challenging to a degree that some individuals were able to completely endure all tasks within a session, while others demonstrated reduced endurance as they were unable to complete all tasks and stand for the duration of a session. Furthermore, for later test sessions, overall endurance was increased, as a greater number of participants were able to complete the tasks, and for a longer period of time, on average. Likewise, the individuals who were unable to complete all tasks during later test sessions also demonstrated increased endurance. The increased endurance though cannot be used as a strong indicator of full COVID recovery. Inability to stand and perform operative tasks for 30 minutes can be interpreted that some individuals may require a longer period of recovery for postural control systems. It is rather speculative, as we cannot compare it with post-COVID level of performance. However, 30-40 min of standing while performing is a typical/minimum time duration in fatigue studies [26, 27].

If not fully recovered, it is not surprising that the greater endurance demonstrated by these individuals was acquired at a cost of decreased postural control as indicated by increased postural oscillations. Individuals who were unable to complete all tasks likely quit earlier due to fatigue. However, it is interesting that their CNS preferred to give rather than compromise postural stability. Second, during subsequent sessions (sessions 2 and 3), most participants increased their standing time. This finding can be interpreted as the ability to tolerate more physical load with increasing time since COVID. However, all these trial duration improvements were at the cost of increased postural oscillations. This explanation is rather speculative, assuming that increased COP oscillations in healthy individuals are viewed as equivalent to decreased postural stability. However, this occurrence may be a compensatory reaction of the human body after having a severe illness, when some functions are compromised (balance) at the advantage of other functions (endurance). This finding of increased COP oscillations and potentially decreased postural stability can be interpreted as a sign that the body was not recovered yet at that time despite the fact these phenomena occurred quite sometime after the typical symptomatic period.

Increases in some components (vertical and medial-lateral) of ground reaction forces have been detected in running for individuals post-COVID when compared to healthy controls [12] and these increased forces were related to alterations in lower-extremity muscle activations. Alterations to ground reaction forces have been associated with an increased likelihood of running related injury [28, 29]. Altered muscle force generation has been related to impairment of function rather than damage of tissue [30]. Based on the results found here in present study, and elsewhere [8], such impairment of function could possibly also exist not only for running, but while engaged in standing posture and during the relatively simple tasks performed while standing.

The alterations in measures of postural stability as indicated by COP measures presented here are similar to findings of an earlier study of standing posture in COVID recovering individuals [8], which used a rambling-trembling analysis of center-of-pressure [31]. In this prior study, COVID recovering participants demonstrating olfactory abnormalities were more likely to have increased sway range and RMS of COP trembling component in sagittal direction. Additionally, for those with respiratory abnormalities, the length and mean velocity of rambling and trembling components as well as range and RMS of trembling components, were increased in the sagittal plane where it was suggested that COVID may cause similar neurodegenerative outcomes as aging as the alterations in COP measures parallel those found in studies of older individuals [32]. Results of the present study agree with those from other studies of postural stability in neurological or musculoskeletal compromised persons. Decreased postural stability has been measured over several-month periods in several groups including Parkinson's disease [33], chronic ACL tear [34] and injured athletes following season-end [35], as well as adults who had bacterial meningitis as children or adolescents [36].

There are a few limitations of this study that warrant mentioning. The number of participants was relatively small. While COVID can have varying degrees of damage, primarily to the respiratory system which then affects physical condition, no accounting for this variability was made in this study. Additionally, there was no accounting for differences in treatment protocols, including pharmaceutical interventions which might have different side effects on participants. The protocol was designed to challenge individuals to an extent similar to that experienced during daily activities rather than specifically causing subjects to quit the study spontaneously due to fatigue. Participants were compensated when any portion of a testing session was completed rather than tying the compensation to the duration in which individuals completed the session. Consequently, the bimodal presentation where some individuals completed each session of the study while others quit the sessions may have reflected some other factors such as motivation, rather than simply effects due to COVID.

5. Conclusions

In summary, this study measured alterations in standing postural control in COVID recovering participants over a 12-week period. Alterations in COP measures were detected when participants were unable to complete an entire protocol for a testing session designed to cause loading in a manner consistent with activities of daily living. While for participants who were able to complete the testing session protocol, no alterations in COP measures were found. In addition, it is unknown if the apparent effect of COVID on increases in postural oscillations, which seems to be the cost of increased endurance for some subjects, would be chronic or lingering for a period beyond the time scope of this study. Future studies of any potential long-term effects of COVID can be conducted to clarify likelihood of this outcome.

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