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ORIGINAL RESEARCH

The associations between training and match demands of male professional football players over a season

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Abstract

This study had two objectives: (i) to analyze the between-position differences in training:match load ratios and (ii) to test the relationships between the weekly training and match demands of male professional football players over a season. A cohort study lasting 43 weeks was performed. Nineteen professional football players (age: 27.5 ± 4.6 years old) used a 15-Hz global positioning system (GPS) unit integrating a 100-Hz tri-axial accelerometer. Total distance (TD), metabolic power average (MPA), new body load (NBL), accelerations (ACC), and decelerations (DEC) were considered. The training:match ratio was obtained for all the external load measures. Significant between-position differences were found only for DEC. Moderate correlations between the weekly training and match demands were found for NBL (r = 0.343 (0.19; 0.48); $p < 0.008$) and DEC (r = 0.472 (0.327; 0.595); $p < 0.001$). Moderate correlations between the mean training intensity and match demands of the same week were found for NBL (r = 0.454 (0.313; 0.575); $p < 0.001$) and DEC (r = 0.451 (0.304; 0.577); $p < 0.001$). This study did not show significant position differences for the overall training:match ratios. Significant position differences were revealed for left-back players compared to all other positions. Fullbacks performed four times more DEC during training sessions than during matches. It was revealed small to moderate associations between both the volume and intensity of the overall external load measures and their respective match running demands. However, such correlations are too weak to suggest a cause-and-effect relationship.

Keywords

Athletic performance; Sports training; Football; Running demands

1. Introduction

The quantification of external training volume and intensity is an increasing area of study within sports sciences and is of great interest among technical support staff and strength and conditioning coaches [1]. There are two dimensions of training load quantification [2]: (i) external load (the demands of a given exercise imposed on athletes) and (ii) internal load (the responses to the imposed external load). While subjective and objective measures can quantify internal load, the external dimension is usually quantified by positioning or accelerometry-based data (global positioning systems (GPSs) and inertial sensor units (IMUs)) [3]. Training load quantification allows coaches to identify players' status variations during training and matches. It is also a promising approach for ensuring that the training principles (individualization, progressive overload, and variation) are being followed [4].

Owing to the exponential development of the above-mentioned technologies, modern GPSs or local positioning systems include IMUs in the devices, allowing the quantification of three levels of GPS data [5, 6]. The first level contains the distances covered at different velocity thresholds (*e.g.*, high-speed running and sprinting), and the second level contains all the actions associated with changes in velocity, such as accelerations, decelerations, and change-of-direction. Meanwhile, the third level encompasses all actions derived from inertial measurement units (IMU) (*e.g.*, player load, impacts, and stride) [5]. While levels 1 and 2 are commonly associated with players' tactical roles and field positions, level 3 GPS measures are dissociated from players' activities on the pitch. They are more applicable to monitoring fitness and fatigue dynamics [7].

The systematic monitoring of external load can ensure that relevant training principles, such as progressive overload and individualization, are considered during training [8]. Football players must cope with high running demands during training and matches [9]. Power-based measures (level 3 GPS data) are position-dependent, with central defenders having the lowest metabolic power values, while central midfielders present the highest values of all field positions [10]. Moreover, when comparing the halves of a football match, the lowest and highest metabolic power values were associated with central defenders and midfielders, respectively [10].

Weekly external training demands can be relativized according to the demands of the preceding match [11], which is the ratio of a week's training load divided by the match intensity of the same week. According to the training:match ratio (introduced by Clemente *et al.* [12]), a value below 1 means that the accumulated external load of a given week was less than the match demands of the same week. Meanwhile, a value above 1 indicates a more significant accumulated load than match demands. The training:match ratios for the overall external load can vary between ~2 to 4 arbitrary units, except when considering high-speed running and sprint distances, which seem relatively low [12]. Total distances, new body load (NBL), accelerations (ACC), and decelerations (DEC) can be 1.8 to 3.5 times greater than match demands within the same training microcycle [12].

Coaches and practitioners may benefit from understanding positional differences, as this knowledge could help them accumulate an adjusted training load. This, in turn, could improve players' resilience to cope with match running demands and limit injuries. Naturally, this ratio tends to increase as the number of training sessions increases. Still, this ratio improves the control of weekly load progressions. It also allows coaches to delineate the training load volume individually while considering the needs of each athlete. Eventually, it can also help coaches differentiate the load needs between positions, especially when considering the heterogeneity of positional roles on the field.

Examining the relationships between external training load measures and match can give coaches a greater understanding of the training dose that must be imposed on athletes during the training week before the match. Thus, it can improve players' resilience to match demands by adjusting the planned external load during a training week [13]. Professional football players show weekly high-speed running and acceleration training volume and the mean training intensity (m/min) had significant moderate correlations (r = 0.366 to 0.498; $p < 0.001$) with match demands for the same measures [13]. These findings suggest that the associations between training and match demands depend on the types of external load measures analyzed, as no significant correlations were found for level 2 GPS data [13]. However, another study revealed that both level 1 and level 2 GPS data exhibited that weekly training volume of high-speed running, accelerations/decelerations, and high-metabolic load distances had significant relationships with match running demands for the same measures [14].

Despite the abovementioned inconsistencies in the associations between weekly training and match demands, coaches seem to promote volume over intensity during training sessions [15]. One study has attempted to examine both weekly training volume and mean intensity (in meters or number per minute, depending on each external load measure) [13]. However, this study considered only levels 1 and 2 of GPS data. The possible dependencies between the training and match volume and intensity of level 3 GPS measures remain unknown. Together with this fact, the contradictory evidence regarding the associations between training and match-related levels 1- and 2-related GPS data highlight the need for this study. Therefore, the study aimed to analyze between-position differences in training:match ratios and to determine the dependencies between weekly external training dimensions and match demands of professional football players.

2. Materials and methods

2.1 Experimental approach and procedures

In this study, an observational analytic cohort design was used to collect the data. An adult professional football team was observed for 43 weeks (from June 2021 to April 2022). Each player was observed during all sessions and official matches using a GPS unit. Based on the GPS data, the following measures were considered for analysis: (i) total distance (TD); (ii) metabolic power average (MPA), which is an estimate of the energy consumed per second (W/kg); (iii) new body load (NBL) (iv) ACC (>4.0 m/s^2); and (v) DEC (>4.0 m/s^2). Only 21 weeks were considered for further analysis. A descriptive analysis regarding training:match ratios were conducted, and the between-position differences for training:match ratios were tested. The characterization of the observation period is reported below in Table 1.

2.2 Participants

Nineteen adult football players (age: 27.5 $\pm$ 4.6 years old; height: 182 $\pm$ 6.0 cm; body mass: 73.5 $\pm$ 6.3 kg), participated in the study. The inclusion criteria were based on: (i) being present at all sessions and the match of the same week for all weeks; (ii) not being injured in the two weeks preceding match participation. Players who were absent for more than two weeks were excluded from the sample.

2.3 External load quantification

All athletes were monitored during the observational period using a 15 Hz GPS unit with a 100 Hz tri-axial accelerometer, a 50 Hz magnetometer, and a 16 G tri-axial impact tracker from a GPSports System (Canberra, Australia) [16, 17]. The GPSports System was previously considered valid and reliable for measuring distances in tennis players [18]. However, there is no study conducted on football players to corroborate the GPSports System validity and reliability. Each player used his attributed GPS unit during both training and matches. For each session recorded, these were the measures extracted: (i) total distance (TD); (ii) new body load (NBL, forces quantified by a 100 Hz tri-axial accelerometer); (iii) accelerations (>4.0 m/s^2) (ACC); (iv) decelerations (>4.0 m/s^2) (DEC), and (v) metabolic power average (MPA). The MPA measure is calculated as follows [19]:

$$Metabolic\,Power\,(MP) \;=\; metabolic\,energy \times running\,velocity$$

The weekly training (wt) was considered as the sum of the external load of weekly training sessions without considering the match. That is, the weekly training load is the total number of actions/meters covered that were quantified by the GPS, and performed during a training week by each player. The weekly mean training intensity (mt) was also considered. That is, the mean number of actions/meters performed or covered, during

TABLE 1. Characterization of the included weeks, number of training sessions, matches, and eligible players.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May	Jun
Week (n)	4, 6	7, 9, 10	12, 14	16, 17	20, 21, 22	23, 26	30	32	35, 38	39	40, 41
Training Sessions (n)	8	12	9	8	12	6	4	3	11	4	9
Matches (n)	2	3	2	2	3	2	1	1	2	1	2
Players Eligible (n)	23	23	14	14	26	15	7	6	11	7	11

TABLE 2. Weekly training load, weekly intensity training load and match intensity load.

Weekly training		Mean training		Match Intensity		T:M	
	Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD
wtTD (m)	18896.5 ± 6052.9	mtTD (m/min.)	62.4 ± 12.1	MiTD (m/min.)	117.5 ± 175.9	TD	3.6 ± 3.8
wtMPA (AU)	22.8 ± 9.1	mtMPA (m/min.)	0.1 ± 0.7	MiMPA (m/min.)	0.3 ± 0.4	MPA	1.7 ± 1.3
wtNBL (AU)	519.4 ± 263.3	mtNBL (AU/min.)	1.7 ± 0.8	MiNBL (AU/min.)	3.2 ± 4.2	NBL	4.0 ± 4.9
wtACC (n)	9.9 ± 10.8	mtACC (n/min.)	0.7 ± 2.9	MiACC (n/min.)	3.1 ± 16.1	ACC	3.7 ± 7.4
wtDEC (n)	13.9 ± 16.6	mtDEC (n/min.)	0.1 ± 0.1	MiDEC (n/min.)	0.1 ± 0.2	DEC	2.4 ± 3.2

wtTD: weekly total distance; wMPA: weekly metabolic power average; wNBL: weekly new body load; wACC: weekly acceleration; wDEC: weekly deceleration; mt: mean training intensity, Mi: match intensity; T:M: training:match ratio.

a training week by each athlete relativized per minute, without considering the match. Then, all the analyzed external loads were relativized per minute to quantify the match intensity. The training:match ratio was obtained by the division of the weekly external load by the match demands, as previously recommended [12].

2.4 Statistical procedures

Descriptive statistics are represented as mean ± standard deviation (SD). After using the Kolmogorov-Smirnov and Levene tests, it was revealed that data was not normally distributed. As such, to examine the dependencies between training and match demands, Spearman's correlation was conducted. The observed correlations were reported as: [20]: 0.0–0.1 (trivial); 0.1–0.3 (small); 0.3–0.5 (moderate); 0.5–0.7 (large); 0.7–0.9 (very large); and >0.9 (nearly perfect). For the position differences of external measures training:match ratios, the Kruskal Wallis and Mann-Whitney tests were conducted. The statistical procedures were conducted on the statistical SPSS software (v25.0, IBM, Armonk, NY, USA) for a $p < 0.05$.

3. Results

The weekly training, mean training intensity, and match demands are listed below in Table 2.

The position differences for each training:match ratio can be found in **Supplementary material**.

Small correlation coefficients were found between weekly training and match demands for MPA (r = 0.143 (−0.018; 0.297); $p < 0.026$), and ACC (r = 0.170 (−0.004; 0.334); $p < 0.049$). Also, moderate correlation coefficients were found for NBL (r = 0.343 (0.19; 0.48); $p < 0.008$), and DEC (r = 0.472 (0.327; 0.595); $p < 0.001$). No significant correlation coefficient was found for TD measure (Figs. 1,2).

4. Discussion

The position differences in external load training:match ratios, and the associations between training load and the match running demands of each week among professional football players were the objectives of this study. The main findings showed significant position differences for the DEC training:match ratio of left-back players compared to all other positions. The overall external load measures (volume and intensity) had small-to-moderate positive relationships with match demands of the same week.

Studies conducted on football players demonstrated weekly TD training volumes between 22,454 m and 23,126 m, while in the present study, a lower TD volume was reported (18,896 m) [11, 13]. The weekly TD training intensity in the above-mentioned studies was between 58.4 m/min and 61.9 m/min, while in the present study, the training intensity for TD was 62.4 m/min [11, 13]. Steven *et al.* [11] might have shown higher TD volume and lower TD intensity than our study as the training duration of each session was greater in the present study.

When considering accelerometer-based measures, a study on 12 professional football players analyzed very high-

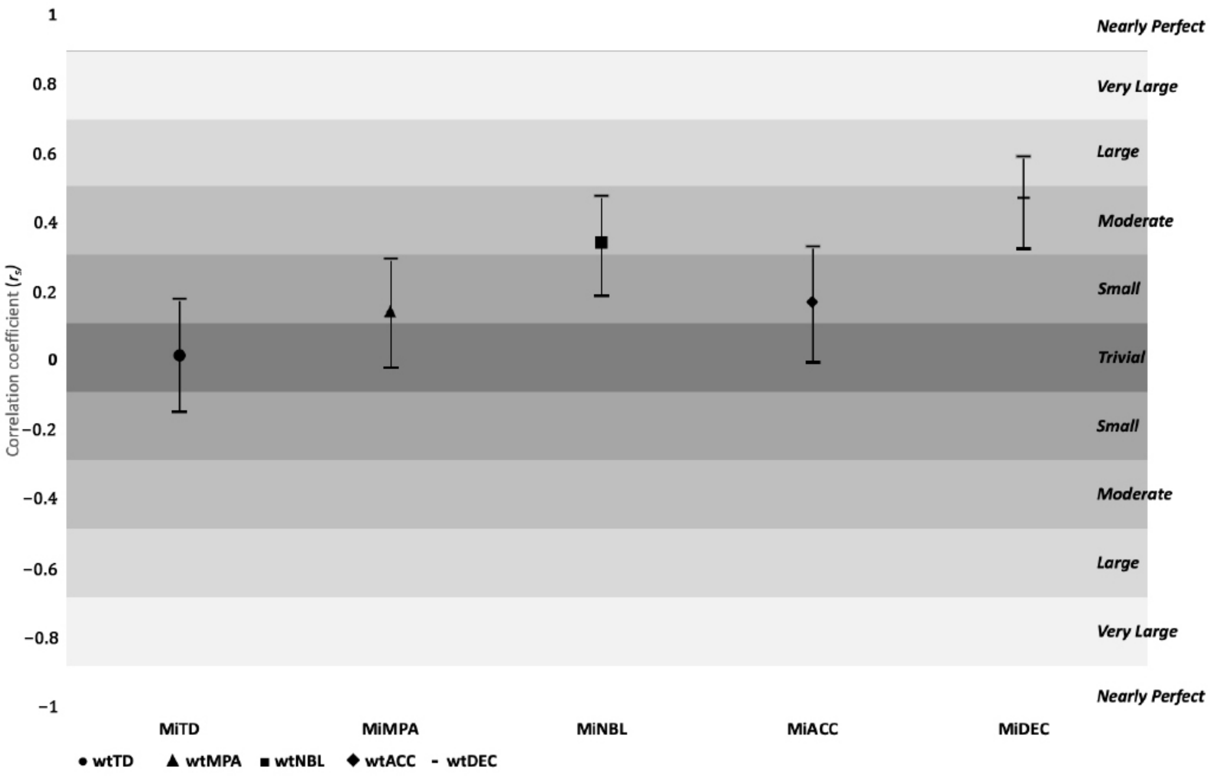

FIGURE 1. Correlations between training volume and match demands. wtTD: weekly training total distance; wtMPA: weekly training metabolic power average; wtNBL: weekly training new body load; wtACC: weekly training acceleration; wtDEC: weekly training deceleration; Mi: match intensity.

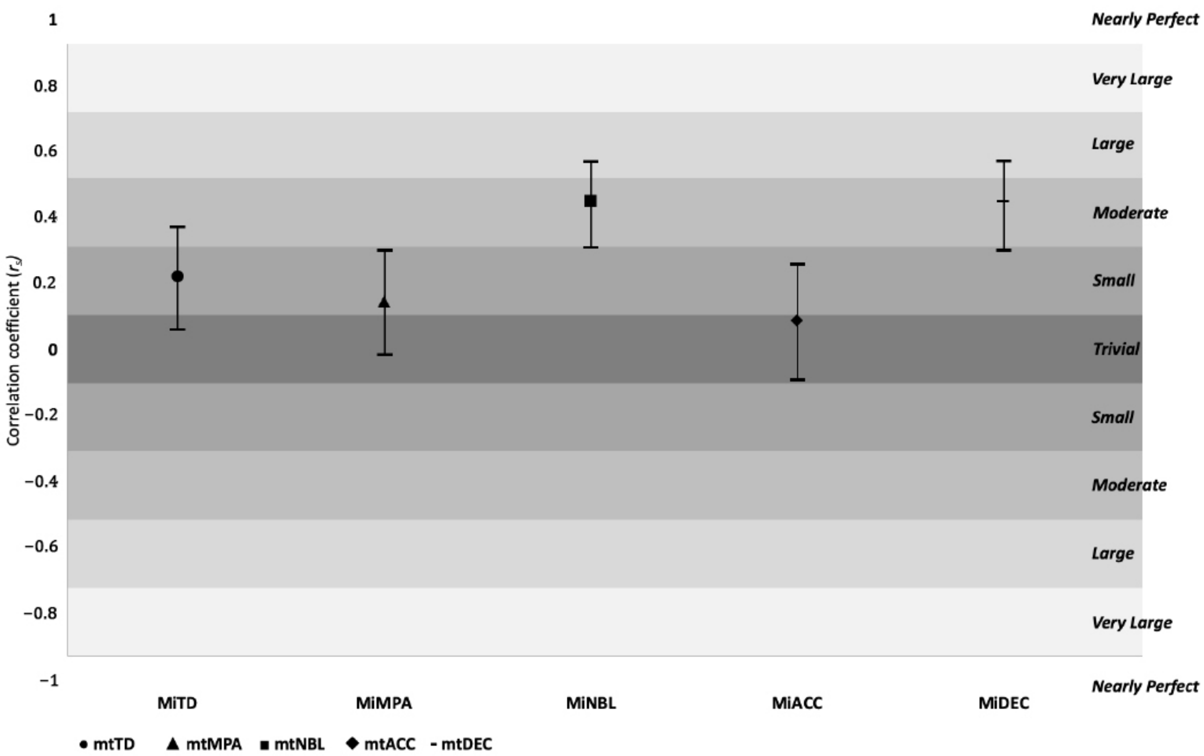

FIGURE 2. Correlations between mean training intensity and match demands. mtTD: mean training total distance; mtMPA: mean training metabolic power average; mtNBL: mean training new body load; mtACC: mean training acceleration; mtDEC: mean training deceleration; Mi: match intensity.

intensity ACC and DEC values (above 4 m/s^2) and showed that players completed a total of 4.4 n of ACC and 8.4 n of DEC during a football match [21]. It must be noted that both the ACC and DEC used in the present study were above 4 m/s^2, following Nobari *et al.* [21]. Another study on 12 professional football players from the German Bundesliga reported MPA values of 8.5 (W/kg) during a football match [1]. However, given the lack of studies reporting the volume and intensity values of both MPA and NBL during training sessions among professional football players, it is difficult to make comparisons with the values reported in the present study [21]. As the MPA measure considers the running speed, acceleration, and deceleration, it was expected lower values than those recorded in other studies that used higher velocity thresholds.

Our study presented similar training:match ratios to those reported by Clemente *et al.* [12] for TD (3.8 ± 1.6), ACC (4.1 ± 1.6), and DEC (3.4 ± 1.9). In that study, TD and the number of high ACC and DEC at training were three to four times greater than the match running demands, depending on the frequency of training. That is, training:match ratios were higher during the weeks with five training sessions than those with three sessions.

Although describing training:match ratios was out of the scope of this study, the results show that football coaches tend to impose higher weekly training demands on players compared to the weekly match demands that players experience. However, the values of the last-mentioned ratio may depend on the methodology imposed by each coach. For example, when coaches use only small-sided games during training, lower values of sprint and high-speed running are recorded, while higher values of accelerations and decelerations are recorded. Meanwhile, coaches who combine ecological and analytical training approaches usually present long high-intensity running distances [22].

No study has examined the position differences of external load training:match ratios. Interestingly, left-back players were the only positional group who obtained a significantly greater DEC training:match ratio than other positions. Previous studies have reported significant between-position differences for external load measures in professional football players [23–25]. For example, central defenders were found to cover the shortest TD, while external defenders, wingers, and forwards executed more high-intensity ACC and DEC above 3 m/s^2 compared to the central defenders and central midfielders [26].

In terms of power-based measures, our findings showed no significant positional differences for the metabolic power average measure, which contrasts a recent study that reported significantly lower metabolic power values for central backs and was higher for central midfielders compared to the overall positions [10]. However, a study on 12 football players from the German Bundesliga reported no significant position differences for metabolic power measures [27]. Such discrepancies may be related to the different tactical roles of each playing position, as well as the training methodologies imposed. That is, due to the central role between the offensive and defensive areas of central midfielders, they have to cope with more power events on the football pitch. Also, wingers perform more power actions given their attacking tactical roles [10].

Previous studies have examined the relationships between weekly training load and match demands [11, 12, 14, 28]. The small but significant correlation between weekly training TD and match TD found in the present study contrasts a previous study that found a non-significant trivial correlation (r = 0.030 (−0.09; 0.15); $p = 0.691$) [12]. Trivial-to-moderate associations between ACC and DEC training volume and their respective match intensities were also reported [13, 14]. For instance, Clemente *et al.* [12] found small correlations for ACC (r = 0.292 (0.17; 0.40); $p = 0.001$) and DEC (r = 0.236 (0.11; 0.35); meanwhile, the present study revealed trivial correlations for ACC and small correlations for DEC.

Concerning NBL, the same study [12], also revealed a small correlation between weekly training and match player loads (r = 0.250 (0.13; 0.36); $p = 0.001$), which conflicts with the moderate correlation reported in the present study. Thus, the available evidence shows that the external dimensions of training imposed on football players are not related to that experienced during matches [11, 12, 14, 28]. This may be explained by the interference of the contextual factors inherent to matches and the training process [12]. For instance, if a football team is losing by one goal or more, its central defenders tend to cover more high-intensity distances than the players from the same position on the leading team [29]. Also, tactical formation influences the match-running demands of professional football players. That is, offensive tactical formations represent approximately 40% greater high-intensity running demands than defensive tactical formations [30]. This explanation indicates non-linearity due to the complexities of training and competitions, which may limit the observation of stronger dependencies between training volume and match demands.

To our current knowledge, only one study [13] examined the dependencies between the imposed relative external measures and match demands. The authors found that the mean training intensity of ACC had a moderate positive correlation (r = 0.366; $p < 0.01$) with its respective match demands, while only a small correlation was found for DEC (r = 0.283; $p < 0.01$) [13]. Of note, even contextual factors, such as weekly relative MPA, NBL, ACC, and DEC, increase as match demands increase. However, analysis of the dependencies between training and match MPA and NBL, is still lacking. Therefore, further studies are needed to generalize the present findings.

This study has limitations to be addressed. One of the most notable was the small sample size. Still, this is a common difficulty among football contexts. Only players participating in all training and match of the same week, were considered. Furthermore, our study did not consider both subjective and objective internal load measures. Therefore, future studies should replicate the present study using objective internal load measures.

Despite these limitations, this study has relevant practical implications. For instance, the present study corroborated previous findings indicating considerably superior weekly external training measures compared to the match demands of the same week. Although the volume and intensity of the external load measures had small-to-moderate relationships with the match demands, the power of such correlations is too weak to suggest a cause-and-effect relationship. Moreover, this study analyzed training:match ratios, which provides insights that coaches can consider regarding the training volume imposed compared to the match demands for each position. Specifically, coaches should analyze the left back players data, who showed significant differences compared to all other positions.

5. Conclusions

This study revealed that significant between-position differences are mainly present for left back players regarding DEC. Given that the number of DECs above 4 m/s^2 at training was more than four times greater than the demands of the match for fullbacks, coaches should adjust the exposure of DEC according to each player's needs. Despite the small-to-moderate relationships revealed in this study, it may not be appropriate to use the volume and intensity of external load measures to infer the following match's running demands.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated in this study are available from the first author or the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

RMS, FMC, and JMC-C—Conceptualization, writing—original draft; RMS—formal analysis, investigation; RMS, FMC, JMC-C, AFS, HN and GB—writing—review & editing; FMC, JMC-C—Validation, Supervision. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. The study protocol was approved by a scientific council of the local university (CTC-ESDL-CE005-2021 | date: 03/06/2021) and followed the ethical standards of Declaration of Helsinki for the study in humans.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Georgian Badicu is serving as one of the Editorial Board members of this journal. We declare that Georgian Badicu had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DC.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1663417040405184512/attachment/Supplementary%20material.docx.

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