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Working from home during the COVID-19 pandemic. The role of physical activity to counteract the workers' oxidative stress. A pilot study

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Abstract

Objective: Office workers spend typically more than two-thirds of their working time sitting and this negative behaviour could have been increased during the pandemic. Low levels of Physical Activity (PA) can have detrimental effects on health, well-being, and Quality of Life (QoL), as well as on the oxidative stress burden. Our aim was to evaluate the role of moderate PA remotely administered in modulating the bio-molecular profile and the QoL of a group of workers during the COVID-19 pandemic.

Methods: The 26 subjects recruited were sampled at the beginning of the study (T0), after 3 months of remotely administered training (T1), and 3 months after the suspension of the online workouts (T2). Each of the three times, subjects filled out a questionnaire and provided a spot urine sample for the quantification of oxidative stress (15-F2t-Isoprostane, Thiobarbituric Acid Reactive Substances (TBARS), and Total Antioxidant Power (TAP)) and inflammatory biomarkers (Interleukin (IL)-6 and IL-10).

Results: The PA administration resulted in a significant decrease in 15-F2t-Isoprostane ($p = 0.02$) and TAP ($p = 0.019$). A significant increase in TAP was observed between T1 and T2 ($p = 0.044$).

Conclusion: A PA-based health promotion strategy could be a valuable intervention in the working environment to promote the well-being of an ageing workforce, especially for white collars.

Keywords

exercise, inflammation, oxidative stress, psychological well-being, quality of life, working conditions

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Introduction

The COVID-19 pandemic and the restrictions to contain the virus spread led to the sudden implementation of a wide variety of changes in lifestyle and in the way working activity had been conceived until then. In Italy, individual mobility was variously limited according to the different stages of the pandemic, up to the almost full limitation during the toughest phases. This scenario introduced the temporary suspension of several working activities and the promotion of working from home in a large number of sectors and occupations, leading to an increase in the proportion of people usually working from home in Italy, from 3.6% in 2019 to 12.2% in 2020 (Eurostat, 03.10.22. http://appsso.eurostat.ec.europa.eu/nui/submitModifiedQueryWai.do).

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According to a recent Eurostat e-survey, over 60% of respondents would have welcomed the maintaining of the teleworking or the hybrid mode, even after the lifting of restrictions.[1]

Office workers, during a typical working day, spend more than two-thirds of their waking time sitting[2] and are at high risk of developing several chronic diseases (e.g. musculoskeletal disorders, obesity, cardio-metabolic diseases, and metabolic syndrome) associated with a general reduction of Quality of Life (QoL) and with both lost productivity and increasing health care needs.[3] In these settings, Physical Activity (PA) can be implemented in well-being interventions for the management and prevention of many work-related chronic diseases.[3,4] Working from home may exacerbate this situation and was found to be negatively associated with PA.[5]

Low levels of PA and the sedentary behaviour can have detrimental effects on the health, well-being, and QoL.[6] This was even more evident during the pandemic, when the increasingly restrictive containment measures made harder maintaining a healthy and varied diet, as well as a regular exercise.[7]

The abrupt reduction or interruption of PA can induce a number of detrimental effects at both physical and mental levels, in the short and long term.[8] Moreover, physical inactivity was recognized as a strong risk factor for severe COVID-19 outcomes.[9]

The large reduction in PA during the pandemic and the increase in sedentary time, especially in screen time, was associated with a reduction in mental health in a survey on US adults.[10] Respondents who met the WHO guidelines before the pandemic (i.e. at least 150 min of moderate PA[6]) decreased their PA on average by 32%, with those in self-isolation by 43%. Those no longer active reported worse mental health than those maintaining their activity level.[10] Indeed, the regular practice of a structured moderate-to-vigorous intensity exercise can reduce negative moods, depression, and anxiety symptoms, and improve cognitive functions.[11] People who exercised daily during lockdowns reported fewer somatization symptoms, lower stress levels, more normal sleep, and a general reduction in depression and anxiety symptoms than those who did not exercise.[12] Even though the biological mechanisms underlying this process have not been completely elucidated yet, long-term exercise seems to be involved in the modulation of neuroendocrine and oxidative stress biomarkers' concentrations, as well as in the modulation of cortical activity.[13] Mental health benefits may also be related to psychological implications, via increasing social support, reducing social isolation, and improving self-esteem and body image.[11]

All these elements can result in a different perception of QoL, defined by the World Health Organization (WHO) as '*a person's perception of his/her position in life within the context of the culture and the value system in which he/she lives and in relation to his/her goals, expectations, standards, and concerns*'.[14] Encouraging workplace interventions matching measurements of both biological and psychological aspects could provide interesting insights into the development of health promotion strategies to implement workers' well-being.[15]

In this perspective, the bio-molecular profile may represent a biological signature of individuals' life experiences, giving information on the pathways involved in the translation of the balance between stressors and positive behaviour into health outcomes.[16]

WEB-based tools had been widely and successfully employed to target modifiable behavioural health risk factors to prevent obesity, and other non-communicable diseases.[17,18] Dietary risk factors and physical inactivity were estimated in 2010 to account for 10% of all deaths and Disability-Adjusted Life Years (DALYs) globally, while a high Body Mass Index (BMI) for 3.8% of DALYs 21, revealing the need for effective intervention strategies applicable at large-scale.[18,19]

The restrictions in force during the lockdowns exacerbated the use of web-based tools such as applications, videos, and social media, engaging people in remote online training sessions.[20] In this peculiar condition, digital-PA represented a valuable tool from a physical, psychological and social perspective, being able to overcome a number of limitations and representing key factor in preventing the isolation and the lack of social support.[17,21] Despite the undeniable positive role of digital technologies in enhancing PA training, especially in inactive people, these tools seem to be promising in short term but less effective in long term.[22] Among the issues related to these tools, the absence of a complete understanding of the users' needs was highlighted.[22] However, the restrictions in force during the pandemic represented a peculiar scenario in which the digital-PA was found to play a pivotal role in supporting the different facets of well-being as a coping strategy to manage the stress induced by the pandemic.[21]

The aim of the present pilot study is to evaluate the role of web-based moderate-intensity workouts during the pandemic in shaping the workers' bio-molecular profile and QoL, promoting the well-being of those working from home.

Methods

This research is a pilot study to test the impact of a web-based PA program on both the bio-molecular profile and the QoL perception of the participants and propose a possible multidisciplinary approach for further research. It involved a sample of Italian workers enrolled in a company located in Piedmont (Italy) and was performed between March and September 2021.

Epidemiological sample

The participation was extended to all the workers employed in a Company involved in the information technology sector, regardless of their sex, age, and task. All workers willing to take part in the study were included since no exclusion criteria had been a priori established. Each volunteer received a detailed description of the project and signed up a written informed consent form. The study was approved by the University of Turin ethics committee (Prot. N. 335619, 22.07.2020) and was in line with the ethical standards reported in The Code of Ethics of the World Medical Association (Declaration of Helsinki, 2013).

Due to the small number of subjects participating in the study, we preferred to not further allocate participants to a control and an intervention group, considering also the risk of potential dropouts. However, we analysed the trend in the selected outcomes during the project in the whole sample and in two subgroups identified ex-post according to the attendance to the training lessons. The poor-attendance subgroup, in this case, was considered a control group.

All measurements were performed at the beginning of the study, to assess the baseline values and obtain information regarding lifestyle and habits (March 2021–T0), after 3 months of remotely guided PA training (June 2021–T1) to observe the eventual effects of the intervention, and at the end of the summer (September 2021–T2), to investigate an eventual trend to the restoration of the baseline values. Each subject filled out a questionnaire, underwent the assessment of anthropometric measurements, and provided a spot of urine for the quantification of biomarkers. Data were pseudonymised immediately after collection.

Questionnaire

The questionnaire aimed to collect information on demographic variables (sex, age), concern for the pandemic, lifestyle and habits (food frequency consumption of fruits and vegetables, red meat, and fish), smoking status, QoL, and PA. All the questionnaires employed are freely available online and a copy of the questionnaire is available in the Supplementary Material. The questionnaire was self-administered by the Lime Survey platform (2012, Hamburg, Germany). The link was made available during the sampling day.

Quality of Life

The workers' QoL was measured by the Italian version of the World Health Organization Questionnaire–Bref (WHOQOL-Bref).[23] Even though the questionnaire is available online, we were further granted permission to use it in our research by the copyright holder. The score of each domain ranges between 0 and 20, with higher values revealing a better QoL in that area. The Cronbach's α was > 0.7 for all domains, except for the social relationship domain in T0.

Additionally, we administered the three questions of the four-item set of Healthy Days core questions (CDC HRQOL– 4)[24] concerning physical health, mental health, and activity limitation reference respondents' health during the previous 30 days.[25] We chose a 14-day cut point to discriminate frequent physical and psychological distress and frequent activity limitation.[26]

Physical Activity

The PA level was evaluated by the Italian version of the International Physical Activity Questionnaire - Short Form (IPAQ-SF).[27]

Physical Activity Administration

The online workout lessons started on the 12th of April 2021. Due to the restrictions in force in Italy to limit the spread of the pandemic, the lessons of PA were delivered remotely, via web meeting, by a trainer having a degree in physical education and specialized in 'adapted physical activity'. Each subject was proposed to participate in two 1-h weekly sessions, for a total of 23 sessions, at the end of the working day (between 18.00 and 20.30) from their homes.

Each lesson was organized as follows: (a) general warm-up exercises (10–15 min), (b) warm-up specific for the later activities (10–15 min), (c) metabolic exercises, aerobic activities, metabolic training, full-body strength workout, posture exercises, balance and flexibility exercises (15–25 min), and (d) stretching and cool-down exercises (10 min).

Each participant was recommended to complete the training with at least 30 min of unsupervised outdoor fit walking to meet the weekly threshold of 150 min of moderate PA proposed by the WHO.

We deliberately choose to administer a moderate-intensity workout in order to meet the needs of the vast majority of the potentially eligible subjects, making our intervention as inclusive as possible, even for a heterogeneous population. The schedule was defined in accordance with the participants, which preferred evening lessons ensuring better management of personal and professional life tasks.

Anthropometric measurements

The height of each subject was measured by an altimeter (Seca, Hamburg, Germany) at the T_0. Weight was measured by a segmental body composition scale (TANITA BC-545N, Amsterdam, The Netherlands) at all three times. The BMI was calculated by the formula $(Weight\ [kg]) / (Height\ [cm])^2$.

Biological assessment

Each subject provided a spot urine sample at each of the three sampling times (T0, T1, and T2) to assess the bio-molecular profile alteration in response to the intervention. Assuming the PA being able to exert its role by the regulation of oxidative stress and inflammation, we measured the array of biomarkers summarized in Table 1, to highlight an eventual modulation of these pathways. Samples were immediately aliquoted and refrigerated after collection and stored at −80° C until analyses.

Statistical analysis

Statistical analyses were performed by SPSS Statistics 28 (IBM SPSS Statistics, New York, NY, USA) and STATA 17.0 (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC).

Aiming at performing a pilot study, we did not calculate the sample size. Categorical variables have been reported as frequency (n) and percentage (%), while continuous variables have been reported as median and interquartile range. Measurements of Thiobarbituric Acid Reactive Substances (TBARS) under the limit of detection (LOD) have been calculated as LOD/2. Due to the small number of subjects, the analyses have been conducted with non-parametric tests. Specifically, Wilcoxon's Signed-Rank Test was employed to compare ordinal data and continuous variables between the beginning and at the end of the intervention (T0 vs T1) and data between the end of the intervention and the end of the following 3-month period with no longer training (T1 vs T2).

Ordinal data were compared by Wilcoxon test. To partly overcome the absence of a control group, we re-run analyses splitting the epidemiological sample in two groups, including workers who took part to <60% and >60% of PA lessons, respectively. Graphs were created by R Studio (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA, USA) and by using GraphPad Prism version 9.4.1 for Windows, GraphPad Software, San Diego, California USA, www.graphpad.com.

To explore the effect of the PA intervention over time, we used Linear Mixed Models with participants ID as random intercept and time as random slope. Single-biomarker models were specified using log-transformed biomarkers (ln), as outcome variable, and adjusting by key potential confounders, namely age, sex, and BMI. In addition, we controlled for the PA attendance (i.e. the number of training sessions) and included the time variable in the model. The model was fitted via the Maximum-Likelihood method and using an unstructured variance-covariance structure. Statistical significance was set at $p < 0.05$. The goodness of fit was tested using likelihood ratio test and by verifying the assumptions underlying the model.

Results

Among the 51 employees, 26 subjects decided to voluntarily take part in the study (participation rate = 51%).

Table 2, Table 3, and Table A.1 (Appendix A) summarize the characteristics of workers involved in the study, obtained by the answers to questionnaires and biological analyses. Eight subjects followed less than 60% of the training lessons.

Table 4 and Figures 1 to 4 display the variation in QoL and biomarkers at the three sampling points in subjects attending more than 60% of the training, subjects attending less than 60% of the training, and in the whole participants' group.

Comparisons among the three sampling times in the whole epidemiological sample

From a biological point of view, in the whole epidemiological sample, the comparison between T1 and T0 resulted

Table 1. Description of the selected biomarkers and of the analytical methods employed.

Biomarker	Description	Analytical method	LOD
Creatinine (crea)	Normalization of the urinary biomarkers' concentration	Kinetic Jaffé procedure	
15-F2t-Isoprostane (15-F2t-IsoP)	Oxidative stress (Lipid peroxidation)	Enzyme-linked immunoassay (EA85, Oxford biomedical, MI, USA)	0.08 ng/mL
Thiobarbituric Acid Reactive Substances (TBARS)	Oxidative stress (Lipid peroxidation)	Colorimetric assay (FR40, Oxford biomedical, MI, USA)	0.5µM
Total Antioxidant Power (TAP)	Antioxidant response	Colorimetric assay (TA02, Oxford biomedical, MI, USA)	0.125 mM
Interleukin (IL)-6	Pro-/anti-inflammatory cytokine	Enzyme-linked immunoassay (HS600C, R&D Systems, MN, USA)	0.09 pg/mL
Interleukin (IL)-10	Anti-inflammatory cytokine	Enzyme-linked immunoassay (EHIL10, Thermo Fisher Scientific, MA, USA)	<3 pg/mL

LOD: limit of detection.

in a significant reduction in BMI and 15-F2t-IsoP, Total Antioxidant Power (TAP), Interleukin (IL)-6, and IL-10. After the summer period (T2 vs T1), we could observe only a significant rise in TAP, whose median concentration three months after the end of the intervention was similar to the one observed in T0. The comparison between the values measured at the end and at the beginning of the study (T2 vs T0) revealed the persistence of lower values in 15-F2t-Isop and IL-10. No significant differences were highlighted in terms of QoL comparing T1 and T0, with the only exception of a reduction in the WHOQOL-Bref psychological domain, although we observed an improvement concerning the lowest values recorded in T0 (Figure 2). After the summer period (T2 vs T1), we observed a significant increase in the physical (WHOQOL-Bref) and psychological (Healthy Days) domains and in the total number of Healthy Days. The comparison between the values reported at the end and at the beginning of the study (T2 vs T0) revealed a significant increase in the psychological domain

Table 2. Basic characteristics of the population.

	n (%)
Sex	
Male	19 (73.1%)
Female	7 (26.9%)
	Mean ± SD
Age (years)	43.15 ± 11.85

Table 3. Comparisons among the three sampling points concerning QoL, BMI, and biomarkers in the whole participants' group.

	T0 Median (IQR)	T1 Median (IQR)	T2 Median (IQR)	T0 vs T1 *p*-value	T1 vs T2 *p*-value	T0 vs T2 *p*-value
Quality of Life (QoL)						
WHOQOL-Bref-physical domain	16.00 (3.00)[a]	16.00 (3.37)[b]	16.57 (4.00)[d]	0.760	**0.034**	0.600
WHOQOL-Bref-psychological domain	14.33 (3.33)[a]	14.00 (3.00)[b]	14.67 (2.66)[d]	**0.010**	0.880	**0.002**
WHOQOL-Bref-social relationship domain	14.67 (4.00)[a]	14.67 (3.33)[b]	14.67 (4.00)[d]	0.674	0.142	0.342
WHOQOL-Bref-environmental domain	15.00 (2.13)[a]	15.00 (3.00)[b]	15.00 (2.00)[d]	0.134	0.981	0.345
Healthy Days-physical aspect	29 (2)[a]	29 (3)[b]	30 (2)[d]	0.885	0.384	0.487
Healthy Days-psychological aspect	27.5 (5)[a]	28 (5)[b]	29 (3)[d]	0.715	**0.014**	**0.011**
Healthy Days-usual activities	30 (0)[a]	30 (3)[b]	30 (1)[d]	0.278	0.065	0.673
Healthy Days-total	27 (5.50)[a]	26 (7)[b]	28 (4)[d]	0.984	**0.012**	**0.038**
BMI	25.50 (6.09)[a]	25.00 (6.05)[b]	25.28 (5.57)[d]	**0.002**	0.131	0.075
Biomarkers						
15-F_{2t}-IsoP [ng/mg crea]	3.55 (1.90)[b,h]	2.64 (0.91)[a]	2.67 (1.39)[d]	**< 0.001**	0.064	**0.005**
TBARS [μmol MDA/mmol crea]	0.08 (0.06)[b,h]	0.05 (0.08)[a]	0.06 (0.10)[d]	0.326	0.144	0.935
TAP [mmol Trolox equivalents/mmol crea]	0.46 (0.19)[a]	0.37 (0.16)[a]	0.46 (0.15)[d]	**0.004**	**0.029**	0.574
IL-6 [pg/mg crea]	1.49 (1.47)[a]	1.17 (0.85)[a]	1.09 (1.11)[d]	**0.012**	0.605	0.125
IL-10 [pg/mg crea]	1.49 (4.78)[a]	0.72 (1.05)[c]	0.94 (2.07)[d]	**0.018**	0.808	**0.019**

[a]26 subjects; [b]25 subjects; [c]24 subjects; [d]23 subjects; [e]22 subjects; [f]20 subjects; [h]an outlier value has been removed.
TBARS: Thiobarbituric Acid Reactive Substances; TAP: Total Antioxidant Power; IL: Interleukin; BMI: Body Mass Index; IQR: Interquartile Range. Significant differences (p<0.05) are highlighted in bold face.

Table 4. Comparisons among the three sampling points concerning QoL, BMI, and biomarkers in subjects attending more and less than 60% of the training lessons.

Subjects attending > 60% of the training lessons (n = 18)						
	T0	T1	T2	T0 *vs* T1	T1 *vs* T2	T0 *vs* T2
	Median (IQR)	*Median (IQR)*	*Median (IQR)*	*p-value*	*p-value*	*p-value*
Quality of Life (QoL)						
WHOQOL-Bref-physical domain	16.00 (3.00)[a]	16.00 (3.14)[b]	16.57 (3.86)[c]	0.806	0.244	0.608
WHOQOL-Bref-psychological domain	14.34 (3.33)[a]	14.00 (3.00)[b]	14.67 (2.50)[c]	0.166	0.209	**0.013**
WHOQOL-Bref-social relationship domain	14.67 (4.00)[a]	14.67 (4.00)[b]	14.67 (3.67)[c]	0.403	0.121	0.812
WHOQOL-Bref-environmental domain	15.00 (2.38)[a]	15.50 (2.75)[b]	15.00 (1.88)[c]	0.278	0.843	0.293
Healthy Days-physical aspect	29.00 (1.25)[a]	29.00 (2.50)[b]	29.50 (2.00)[c]	0.916	0.765	0.968
Healthy Days-psychological aspect	27.00 (4.00)[a]	28.00 (4.50)[b]	29.50 (2.75)[c]	0.777	**0.007**	**0.009**
Healthy Days-usual activities	30.00 (0.00)[a]	30.00 (1.50)[b]	30.00 (0.75)[c]	0.458	0.236	0.655
Healthy Days-total	26.50 (4.75)[a]	26.00 (6.00)[b]	28.50 (3.50)[c]	1.000	**0.019**	0.058
BMI	25.55 (6.09)[a]	25.00 (5.61)[b]	25.28 (5.19)[b]	**0.003**	0.301	0.058
Biomarkers						
15-F_{2t}-IsoP [ng/mg crea]	3.54 (1.90)[a]	2.51 (0.89)[a]	2.53 (1.50)[b]	**0.002**	0.193	0.010
TBARS [μmol MDA/mmol crea]	0.08 (0.08)[b]	0.05 (0.06)[a]	0.05 (0.11)[b]	0.185	0.136	0.959
TAP [mmol Trolox eq./mmol crea]	0.45 (0.15)[a]	0.35 (0.17)[a]	0.46 (0.15)[b]	**0.019**	**0.044**	0.394
IL-6 [pg/mg crea]	1.58 (1.42)[a]	1.33 (1.16)[a]	1.12 (0.93)[b]	0.122	0.795	0.149
IL-10 [pg/mg crea]	1.33 (3.71)[a]	0.98 (1.14)[b]	0.94 (2.15)[b]	0.149	0.501	0.185
Subjects attending < 60% of the training lessons (n = 8)						
	T0	T1	T2	T0 *vs* T1	T1 *vs* T2	T0 *vs* T2
	Median (IQR)	*Median (IQR)*	*Median (IQR)*	*p-value*	*p-value*	*p-value*
Quality of Life (QoL)						
WHOQOL-Bref-physical domain	16.86 (4.28)[d]	16.00 (4.40)[d]	16.57 (4.57)[e]	0.345	**0.042**	0.892
WHOQOL-Bref-psychological domain	13.34 (4.17)[d]	14.67 (4.50)[d]	12.67 (4.67)[e]	**0.011**	**0.041**	0.068
WHOQOL-Bref-social relationship domain	14.00 (2.67)[d]	14.67 (2.00)[d]	14.67 (4.00)[e]	0.071	1.00	0.194
WHOQOL-Bref-environmental domain	14.75 (2.13)[d]	14.75 (4.00)[d]	14.00 (3.50)[e]	0.325	0.786	0.931
Healthy Days-physical aspect	29.00 (3.00)[d]	30.00 (4.50)[d]	30.00 (2.00)[e]	1.000	0.285	0.102

(continued)

Table 4. Continued.

Subjects attending > 60% of the training lessons (n = 18)	T0 Median (IQR)	T1 Median (IQR)	T2 Median (IQR)	T0 *vs* T1 *p-value*	T1 *vs* T2 *p-value*	T0 *vs* T2 *p-value*
Healthy Days–psychological aspect	29.00 (5.00)[d]	28.50 (4.75)[d]	29.00 (7.00)[e]	1.000	0.705	1.000
Healthy Days–usual activities	30.00 (1.00)[d]	30.00 (3.75)[d]	30.00 (2.00)[e]	0.461	0.180	1.000
Healthy Days–total	27.50 (8.75)[d]	25.50 (7.75)[d]	28.00 (10.00)[e]	0.916	0.244	0.416
BMI	25.22 (8.82)[d]	24.94 (8.54)[d]	26.41 (6.88)[f]	0.401	**0.345**	0.753
Biomarkers						
15-F_{2t}-IsoP [ng/mg crea]	4.25 (2.25)[e]	2.99 (1.53)[d]	3.39 (1.48)[f]	**0.043**	0.116	0.345
TBARS [μmol MDA/mmol crea]	0.07 (0.03)[d]	0.08 (0.24)[d]	0.08 (0.10)[f]	0.889	0.752	0.917
TAP [mmol Trolox eq./mmol crea]	0.56 (0.30)[d]	0.42 (0.20)[d]	0.53 (0.23)[f]	0.093	0.249	0.753
IL-6 [pg/mg crea]	1.34 (1.45)[d]	0.86 (0.90)[d]	1.00 (1.60)[f]	**0.025**	0.600	**0.046**
IL-10 [pg/mg crea]	2.90 (4.95)[d]	0.62 (0.74)[e]	0.78 (1.78)[f]	0.063	0.345	0.249

[a]18 subjects; [b]17 subjects; [c]16 subjects; [d]8 subjects; [e]7 subjects; [f]6 subjects.
TBARS: Thiobarbituric Acid Reactive Substances; TAP: Total Antioxidant Power; IL: Interleukin; BMI: Body Mass Index; IQR: Interquartile Range. Significant differences (p<0.05) are highlighted in bold face.

scores (WHOQOL-Bref and Healthy Days) and in the total number of Healthy Days.

Other significant modifications observed were a decrease in red meat consumption over time and a reduction in the concern for the pandemic between T1 and T0.

Comparisons among the three sampling times according to the attendance to the training lessons

The comparisons among the three sampling points according to the different attendance to the training lessons provided some interesting insights. From a biological point of view, the comparison between T0 and T1 revealed that the significant decrease in 15-F2t-Isop could be measured in both subgroups, while the significant decrease in BMI and TAP was measured only in those attending more than 60% of the training. On the contrary, a significant decrease in IL-6 was observed only in the poor-attendance subgroup. After the splitting, the difference in IL-10 median values pre- and post-intervention was no longer significant in any subgroup. The comparison between T2 and T1 highlighted that the significant increase in TAP was significant only in the high-attendance subgroup, while the poor-attendance subgroup reported a rise in the BMI score. The comparison between T2 and T0 revealed that the significant reduction in 15-F2t-Isop observed in the whole group was confirmed only in subjects performing more than 60% of the lessons. In subjects attending less than 60% of the training, we observed a significant decrease in IL-6, while the significant difference in IL-10 measured in the whole group was no longer significant in any subgroup.

Concerning the QoL, in the comparison between the T0 and T1, the significant reduction in the WHOQOL-Bref psychological domain was not confirmed in the high-attendance subgroup, while, on the contrary, a significant increase was observed in the poor-attendance group. The comparison between T1 and T2 confirmed the significant increase in psychological health (Healthy Days) and in the total number of Healthy Days in subjects attending the workout. In the poor-attendance subgroup, we could observe an increase in the physical and in the psychological domains (WHOQOL-Bref). The comparison between T0 and T2 confirmed the significant increase in the psychological domain (WHOQOL-Bref and Healthy Days) in the high-attendance group.

The effect of PA intervention over time

Independently from sex, age, BMI, and participation we observed a significant decrease in log-transformed 15-F2t-IsoP (15-F2t-IsoP geometric mean = 3.02 ng/mg crea) both between T0 and T1 ($\beta = -0.33$; 95% C.I.

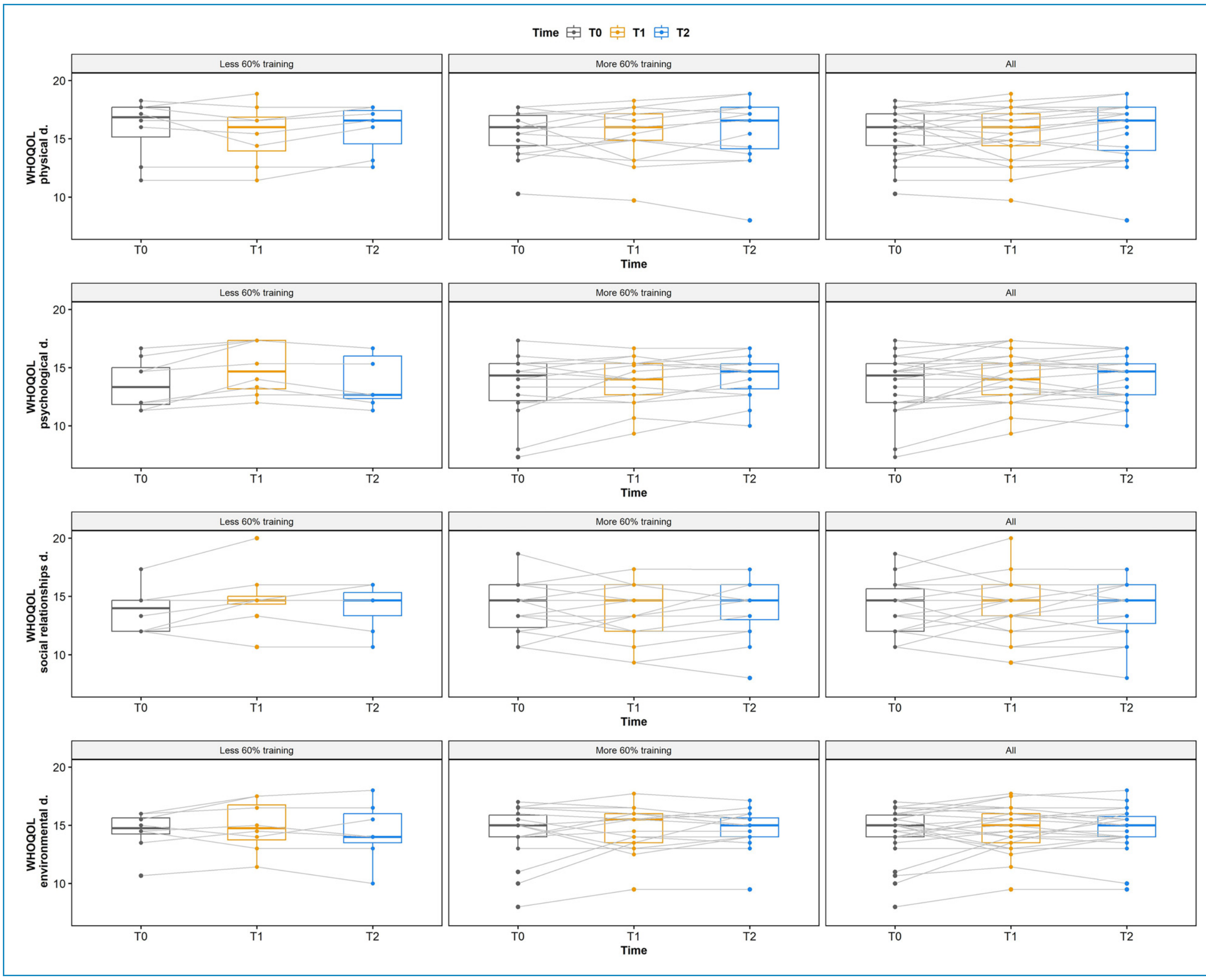

Figure 1. QoL (WHOQOL-Bref) among participants at the three sampling points, T0, T1, and T2. The first two faces include subjects according to different attendance to the training lessons (more and less than 60%), while the last includes the whole participants' group. Each boxplot shows the median, the 1st, and the 3rd quartiles. Jitters represent the data of each individual, grey lines join data of the same subjects. QoL: Quality of Life.

(−0.461, −0.201), $p < 0.001$) and between T0 and T2 (β = −0.21; 95% C.I. (−0.343, −0.069), $p = 0.003$). This decrease was further affected by the participation (β = −0.02; 95% C.I. (−0.032, −0.008), $p = 0.001$). On the contrary, the analysis did not reveal any significant variation in log-transformed TBARS (TBARS geometric mean 0.42 μmoL MDA/mmoL crea), which was only affected by sex, with higher values in males (β = −0.89; 95% C.I. (0.224, 1.564), $p < 0.009$). We also observed a significant decrease in log-transformed TAP (TAP geometric mean = 0.24 mmoL Trolox eq./mmol crea) only between T0 and T1 (β = −0.22; 95% C.I. (−0.359, −0.077), $p = 0.002$). Concerning the inflammatory profile, we observed a significant reduction in log-transformed IL-6 (IL-6 geometric mean = 1.24 pg/mg crea) between both T0 and T1 (β = −0.343; 95% C.I. (−0.620, −0.066), $p = 0.015$) and T0 and T2 (β = −0.260; 95% C.I. (−0.544, 0.023), $p = 0.072$). As well, in log-transformed IL-10 (IL-10 geometric mean = 1.10 pg/mg crea) between both T0 and T1 (β = −1.04; 95% C.I. (−1.677, −0.404), $p = 0.001$) and T0 and T2 (β = −0.96; 95% C.I. (−1.681, −0.244), $p = 0.009$). The variation of β coefficients is reported in Figure 5.

Discussion

The purpose of our study is to analyse the potential benefit of a WEB-based workout program in office workers, aiming to suggest, whether possible, key elements to be implemented in sustainable strategies to promote workers' well-being. The analysis of different modalities of online training revealed that only livestream groups with the supervision of an experienced trainer seem to be related to an increase in cardiovascular variables in addition to the increase in muscular fitness.[20]

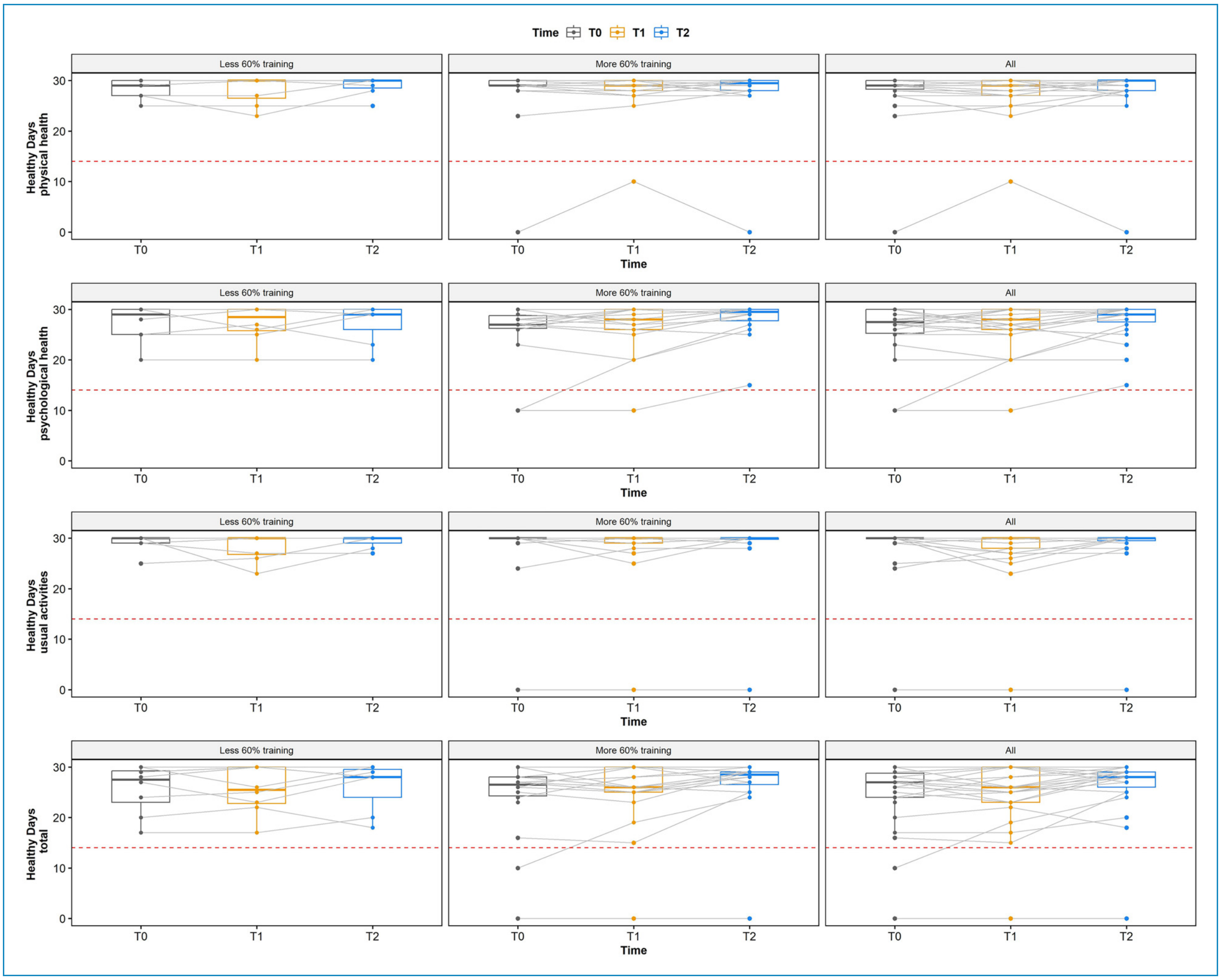

Figure 2. QoL (Healthy Days) among participants at the three sampling points, T0, T1, and T2. The first two faces include subjects according to different attendance to the training lessons (more and less than 60%), while the last includes the whole participants' group. Jitters represent the data of each individual, grey lines join data of the same subjects. The red dashed lines represent the cut-off of 14 days. QoL: Quality of Life.

We did not observe any significant variation in the QoL perception after the intervention, except for a reduction in the median scores of the WHOQOL-Bref psychological domain, even if not confirmed in the high-attendance group. This fluctuation could be likely related to the small number of subjects enrolled, emphasizing the lowering of the scores in some subjects. The significant improvement observed, instead, after the summer period, could be likely related to a more relaxing and maybe healthier lifestyle typical of the holiday period.

PA can exert its beneficial role in influencing various bio-molecular pathways, including oxidative and inflammatory status that are interdependent pathophysiological processes associated with several chronic diseases, including diabetes, hypertension, and cardiovascular diseases, neurodegenerative diseases, cancer, and ageing.[28]

We analysed thus the urinary concentration of multiple biomarkers as a proxy of the PA role in modulating these molecular mechanisms. As expected, the bio-molecular profile revealed a clearer effect of the PA administration. Indeed, in T1 we observed a significant reduction in both the 15-F2t-IsoP and TAP concentration. Considering the different training attendance, while the decrease in 15-F2t-IsoP was detected in both subgroups, the decrease in TAP was observed only in the high-attendance subgroup. Three months after the end of the intervention we assisted in a significant increase in TAP, confirmed only in subjects having performed more than 60% of the training lessons. This relationship was no more significant when tested in the multivariable regression analysis. Our results are in line with our previous work,[29] reporting that, while vigorous PA is related to an increase in oxidative stress, the

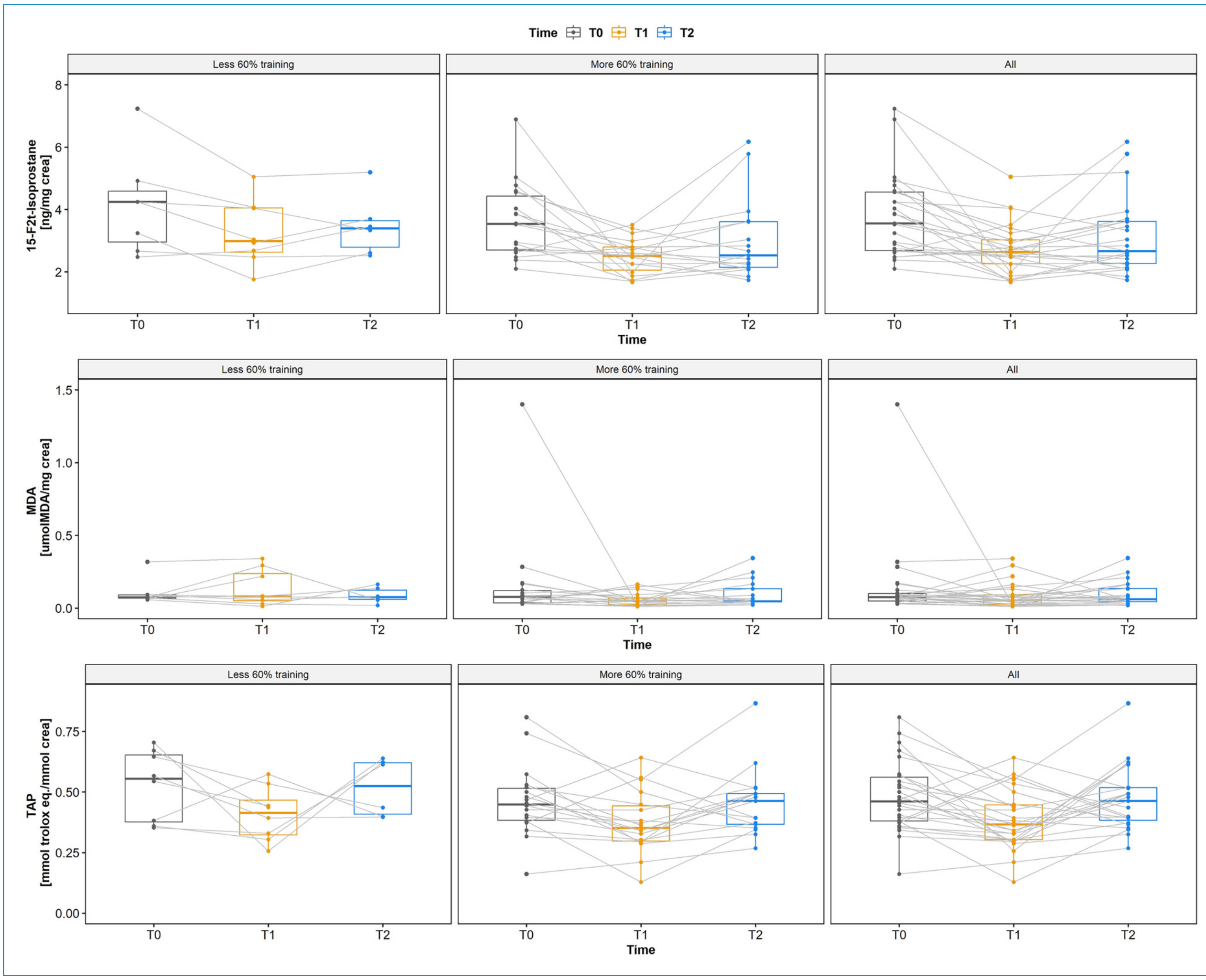

Figure 3. Urinary concentration of oxidative stress biomarkers at the three sampling points, T0, T1, and T2. The first two faces include subjects according to different attendance to the training lessons (more and less than 60%), while the last includes the whole participants' group. Jitters represent the data of each individual, grey lines join data of the same subjects.

regular practice of moderate PA is able to reduce the oxidative burden.

The similar trend between the concentration of 15-F2t-IsoP and the antioxidants in the high-attendance subgroup was unexpected, even if reported in the literature.[30] A possible explanation might be the evolution of adaptive molecular pathways such that common processes responsible for an increase in pro-oxidants (e.g. PA and critical illness) that can lead to the activation of the Nuclear factor erythroid 2-related factor 2 (Nrf2), a transcription factor playing a key role in enhancing the antioxidant production to maintain the redox homeostasis.[30] Nrf2 can also induce its own expression, resulting in positive feedback activation of its transcriptional network.[31]

We might thus hypothesize that the prolonged exercise is able to trigger a general rebalancing of the oxidative status, with a reduction in the oxidative burden confirmed by the reduction in the antioxidant concentration. This relation seems to be supported by the reverse in the biomarkers' concentration after the end of the intervention. The significant increase in TAP may be interpreted as an attempt to re-establish a redox balance due to a possible increase in pro-oxidants. The data reported in T2 could have been affected in many ways by the changes in lifestyle, either positive or negative, due to the summer life.

Concerning the inflammatory status, we focused our attention on IL-6, a pro-/anti-inflammatory cytokine involved in the response to several stimuli, including exercise, and IL-10, an anti-inflammatory immune-suppressive cytokine. At T1, in the whole sample, we observed a significant reduction in both biomarkers, even if these differences disappeared in the high-attendance subgroup. This reduction in both IL-6 and IL-10 was instead confirmed in the multivariable regression analysis.

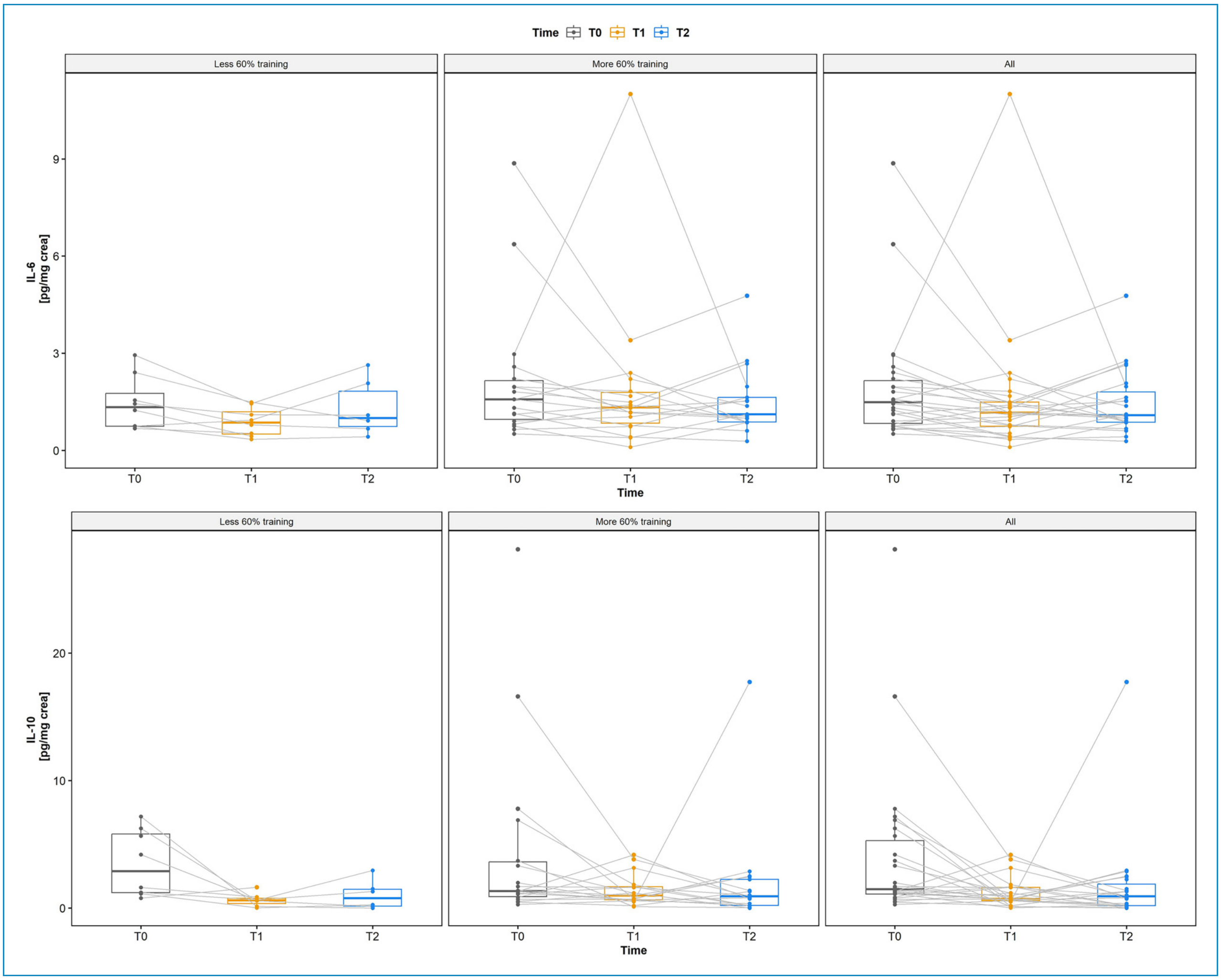

Figure 4. Urinary concentration of inflammatory biomarkers at the three sampling points, T0, T1, and T2. The first two faces include subjects according to different attendance to the training lessons (more and less than 60%), while the last includes the whole participants' group. Jitters represent the data of each individual, grey lines join data of the same subjects.

The role of PA on the immune system these days assumes a pivotal role, being PA one of the behavioural factors associated with an enhanced vaccine response.[32] Active people are indeed more likely to experience a better immune response, with higher efficacy in regularly trained subjects who had an exercise session shortly before inoculation.[33] The recent COVID-19 pandemic shed light on the importance of immunization campaigns, and the PA is proving once more to be essential in the promotion of health and well-being.

The main strength of the study consists in the proposal of key elements to implement workers' well-being promotion strategies, with a demonstrated biological efficacy, as evidenced by the improvement in the oxidative and inflammatory status. Secondly, the adoption of a WEB-based intervention was and easy to implement for a huge number of workers, even when they are working from home. This last point is even more valuable to improve also social support among workers, especially from the perspective of a foreseeable change in the work organization after the pandemic. Thirdly, the PA sessions were supervised by a skilled trainer, strengthening the importance of the presence of professionals with extensive knowledge in ergonomics and biomechanics in the working environment to prevent musculoskeletal injuries.[34]

At the same time, several weaknesses could be identified. First of all, the low sample size and the uneven sampling, challenging the possibility to consider those results as reliable and representative. The absence of a sample size calculation represents a further limit for the generalization of the results obtained. Indeed, since this is a pilot study, thus more focused on suggesting a possible approach in addressing a problem than in testing hypotheses, we did not calculate the sample size, but we included any subjects willing to participate. Concerning the choice of the company, limiting the sampling to a single company could have likely introduced a selection bias and affected the gender ratio. The adoption

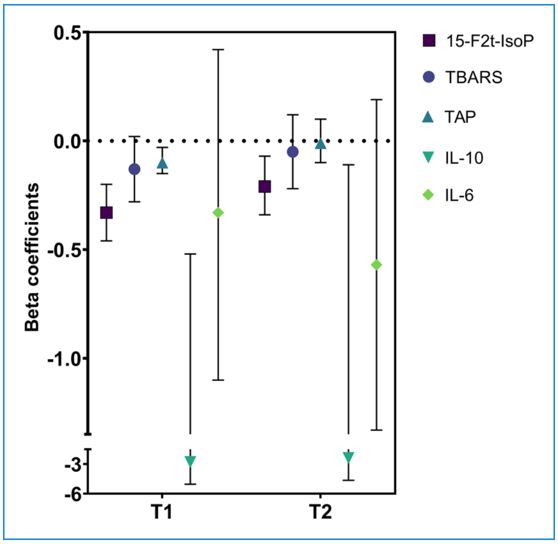

Figure 5. The effect of Physical Activity intervention over time
Footnote: All estimates are derived from Multivariable Linear Mixed Models with participants IDs and random intercept and time as random slope. Single-biomarker models were fitted controlling for age, sex, BMI ad participation to PA. The number of observations was n = 73, n = 74, n = 74, n = 72 and n = 74 for model including 15-2t-IsoP, TBARS, TAP, IL-10, and IL-6 as the outcome variable, respectively. PA: Physical Activity; TBARS: Thiobarbituric Acid Reactive Substances; TAP: Total Antioxidant Power; IL: Interleukin; BMI: Body Mass Index.

of self-reported questionnaire, moreover, could have introduced a response bias not further investigated in our study. Consequently, the eventual generalization of these results should be carefully considered.

Further studies would be desirable to create standard protocols which could be employed in the different working environments as a routine part of health promotion programs, with a particular focus on the specific needs of an ageing workforce. Further researches implementing the ambulatory assessment of PA[35] could allow to obtain interesting results concerning the relationship between PA and the bio-molecular profile.

Conclusions

The present study highlights once more the importance of PA as a constituent element of health promotion initiatives, especially as copy strategy to deal with the distinctive conditions characterizing the pandemic. The adoption of PA-based health promotion strategies could be a valuable intervention in the working environment, especially for office workers spending most of their working time sitting and, in general, to promote the well-being of an ageing workforce.

Declarations of conflicting interests: The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Appendix A

Table A.1. Characteristics of workers enrolled, and measurements obtained by questionnaire.

	T_0	T_1	T_2	T_0 *vs* T_1	T_0 *vs* T_2
	n (%)				
Working years					
0–5 years	8 (30.8%)				
5–10 years	3 (11.5%)				
10–15 years	3 (11.5%)				
15–20 years	7 (26.9%)				
> 20 years	5 (19.2%)				
Physical activity level					
Low	7 (26.9%)				
Moderate	11 (42.3%)				
High	8 (30.8%)				
	n (%)	*n (%)*	*n (%)*		
Concerning for the pandemic					
None	0 (0%)	4 (16.7%)	2 (8.7%)	**0.009**	0.782
Very mild	5 (19.2%)	7 (29.2%)	7 (30.4%)		
Mild	10 (38.5%)	6 (25.0%)	7 (30.4%)		
Moderate	8 (30.8%)	6 (25.0%)	6 (26.1%)		
Severe	3 (11.5%)	1 (4.2%)	1 (4.3%)		
Vegetable and fruit consumption (n. of times/week)					
1–2	2 (7.7%)	1 (4.0%)	0 (0.0%)	0.317	0.564
3–4	2 (7.7%)	3 (12.0%)	3 (13.0%)		
≥ 5	22 (84.6%)	21 (84.0%)	20 (87.0%)		
Read meat consumption (n. of times/week)					
None	0 (0%)	1 (4.0%)	0 (0.0%)	**0.046**	0.317
1–2	18 (69.2%)	19 (76.0%)	18 (78.3%)		
3–4	8 (30.8%)	5 (20.0%)	5 (21.7%)		

(continued)

Table A.1. Continued.

	T_0	T_1	T_2	T_0 *vs* T_1	T_0 *vs* T_2
≥ 5	0 (0.0%)	0 (0.0%)	0 (0.0%)		
Fish consumption (n. of times/week)					
None	4 (15,4%)	2 (8.0%)	2 (8.7%)	0.157	0.317
1–2	21 (80.8%)	22 (88.0%)	20 (87.0%)		
3–4	1 (3.8%)	1 (4.0%)	1 (4.3%)		
≥ 5	0 (0%)	0 (0%)	0 (0%)		
Sleep (h/night)					
< 6	5 (19.2%)	4 (16.0%)	3 (13.0%)	0.317	1.000
≥ 6	21 (80.8%)	21 (84.0%)	20 (87.0%)		

Significant differences (p<0.05) are highlighted in bold face.