Recent COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in physically active healthy people

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Running Title: Exercise responses after COVID-19 vaccination

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Abstract

Athletes are advised to receive the COVID-19 vaccination to protect them from SARS CoV-2 infection during major competitions. Despite this, many athletes are reluctant to get the COVID-19 vaccine due to concerns that symptoms of vaccinosis may impair athletic performance. **OBJECTIVE**: To determine the effects of COVID-19 vaccination on the physiological responses to graded exercise. **METHODS**: Healthy physically active participants completed a 20-minute bout of graded cycling exercise at intensities corresponding to 50, 60, 70 and 80% of the pre-determined $\dot{V}O_{2max}$ before and ~21 days after receiving the COVID-19 vaccine (2 dose Pfizer mRNA or 1 dose Johnson&Johnson). **RESULTS**: Vaccination had no effect on a large number of physiological responses to exercise measured in blood (e.g. lactate, epinephrine, cortisol) and by respiratory gas exchange (e.g. oxygen uptake, CO_2 production, ventilation, respiratory exchange ratio, predicted $\dot{V}O_{2max}$, ventilatory threshold) ($p>0.05$). We did, however, find significant elevations in heart rate (~5 bpm) and norepinephrine (p = 0.006 and 0.04, respectively) in response to vigorous (e.g. 70-80% $\dot{V}O_{2max}$) intensity exercise after vaccination, particularly in those that received the two shot Pfizer mRNA vaccine regimen. These findings held true when compared to demographically matched controls who completed identical bouts of exercise several weeks apart without receiving a vaccine; delta values for heart rate ($p=0.03$) and norepinephrine ($p=0.01$) were elevated in the second trial for those that received the Pfizer mRNA vaccine compared to the controls at the 70% and 80% $\dot{V}O_{2max}$ stages, respectively. **CONCLUSION**: Recent COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in physically active healthy people. The small elevations in cardiovascular and neuroendocrine responses to exercise after the Pfizer mRNA vaccine regimen could have implications for athletes at the elite level and warrants investigation.

Keywords: SARS-CoV-2; athletes; metabolic response; Pfizer; Johnson & Johnson; physical activity

New and Noteworthy

- Recent COVID-19 vaccination does not affect a large number of physiological responses to graded exercise, indicating that vaccination is unlikely to impair exercise capacity in normal healthy people
- Small but significant elevations in heart rate and norepinephrine responses to exercise were found after the Pfizer mRNA vaccination but not controls
- The small elevations in cardiovascular and endocrine responses to exercise after recent COVID-19 vaccination could have implications for athletes performing at the elite level
- How COVID-19 vaccination affects metabolic responses to exercise and performance in elite athletes warrants investigation, particularly because booster shots or new vaccines may be required for continuous protection against SARS-CoV-2 and its evolving variants

Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS–CoV-2) - etiological agent of coronavirus disease 2019 (COVID- 19)- was first identified in December 2019 in Wuhan, China, before being declared a global pandemic in March 2020 (1). As of November 2021, more than 250 million people worldwide have been infected with SARS CoV-2, which has resulted in ~5.1 million deaths. The rapid production and distribution of mRNA (e.g. Pfizer and Moderna) and viral vector-based vaccines (e.g. Johnson&Johnson and AstraZeneca) was initiated in November 2020 and has greatly limited the spread of COVID-19 (2), with 40% of the world's population now fully vaccinated (3). Several clinical trials have

demonstrated the safety and efficacy of the current COVID-19 vaccines (4–6), with reported side-effects such as body aches, fever, arm soreness, malaise and flu-like symptoms usually mild and typically resolving within 48h (7). However, reports are emerging that COVID-19 vaccination in a minority of patients has been associated with more severe and longer lasting symptoms including myocarditis fatigue, shortness of breath, cough, joint and chest pain (8,9).

Athletes are recommended to receive all necessary vaccines prior to competition due to increased risks of viral exposure (10). A recent study in elite German athletes found that the quadrivalent inactivated influenza vaccine evoked a strong immune response with no reported side-effects or loss of training (11). However, due to emerging reports (albeit mostly anecdotal) of adverse symptoms associated with COVID-19 vaccines, there is a growing concern among the athletic community that vaccination might hinder athletic performance. This has resulted in many athletes refusing to get vaccinated prior to or during competition, leaving them susceptible to SARS-CoV-2 infections during major sporting events. Indeed, during current/recent sporting events such as the 2021 European Championship and Copa America international soccer tournaments, as well as the Tokyo Olympic Games, there were multiple incidences involving players/athletes having to miss games/competition due to contracting SARS-CoV-2, or having been in contact with infected individuals.

In order to alleviate or confirm concerns regarding the potential negative effects of COVID-19 vaccination on athletic performance, there is a critical need to determine if recent COVID-19 vaccination affects physiological responses to various intensities of exercise. Here we investigated the effects of recent COVID-19 vaccination on metabolic and physiological responses to graded cycling exercise in physically active healthy individuals. We report that COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in healthy people, although small increases in the cardiovascular and neuroendocrine response to vigorous exercise that were observed after vaccination could have implications for athletes at the elite level.

Methods

Participants

A total of eighteen (9 females, 9 males) healthy individuals between the ages of 24-43 years participated in this study. Baseline anthropometric and cardiovascular characteristics are shown in Table 1. Twelve participants received a COVID-19 vaccine during the study period [Pfizer mRNA vaccine (n=9), Johnson&Johnson viral vector-based vaccine (n=3)] while six participants, who were involved in a parallel non-vaccine related research study in our laboratory, served as controls. Prior to their enrollment, each subject completed an AHA-ACSM preparticipation screening questionnaire and medical history survey (12) to verify that they had not been previously diagnosed with any cardiovascular, metabolic, renal, liver, pulmonary, asthmatic, rheumatic, or other inflammatory disease/condition and were not currently under the administration of medication known to alter their inflammatory or metabolic profiles. All participants were additionally screened for physical activity participation to ensure the enrollment of active individuals – physical activity rating score $>$ 4 (13). Moreover, research participants were non-users of tobacco products and consumed ten or less standard alcoholic beverages per week on average. Participants were asked to abstain from alcohol, caffeine, and physical activity 24h prior to exercise trials and complete an overnight (minimum 8h and maximum 12h) fast prior to each laboratory visit. Adherence to these pre-testing procedures were confirmed verbally with the participants upon their arrival to the laboratory. All participants provided written informed consent and all procedures were performed in accordance with the ethical guidelines provided by the

Belmont Report. The Institutional Review Board (IRB) of the University of Arizona granted ethical approval (#2102477676) and the trial was registered at www.clinicaltrials.gov (NCT05019456).

Experimental Design

The study required participants to visit the laboratory on three separate occasions. Visit 1 involved a pre-screening procedure to verify that participants were eligible for the study and healthy enough to perform vigorous intensity exercise and to provide written consent (ACSM/AHA questionnaire). Eligible participants then completed a submaximal graded exercise test on a cycling ergometer (Velotron, Quarq Technology, San Diego, CA) to determine predicted maximal oxygen consumption ($\dot{V}O_{2max}$). Blood samples were also collected during this visit to confirm serological status against SARS-CoV-2 using a commercially available ELISA kit (SARS-CoV-2 Spike S1 Human IgG; Biolegend, San Diego, USA). Visit 2 occurred 1-3 weeks after the first visit and required the participants to complete a continuous 20-minute graded cycling exercise with multiple blood collections from an intravenous catheter. Visit 3 required participants to perform the exact same trial that was performed during Visit 2 at 1-3 weeks after receiving the final COVID-19 vaccine dose via their own health care provider. This corresponded to an elapsed time of 5-7 weeks between Visit 2 and Visit 3. Participants arrived at our laboratory at the exact same time of day across all trials, which were performed between 06:00-09:00 local time.

Submaximal Exercise Testing Procedure (Visit 1)

Upon arrival at the laboratory, participants were briefed regarding the nature of the testing protocol, and height, weight and resting blood pressure measurements were collected. Each participant was assessed for appropriate apparatus sizing (e.g., metabolic cart face mask) and cycling ergonomics (e.g., saddle height, handlebar reach, etc.) and these were recorded so they could be replicated during subsequent visits. Prior to initiating the test, all participants performed 3-5 minutes of seated rest on the cycling ergometer) for the collection of resting heart rate and respiratory gas exchange data. This was followed by a 5-minute warm-up period of cycling at 50 watts (W). Thereafter resistance was increased by 15 watts every minute and participants were asked to maintain a consistent cycling cadence throughout the entire exercise bout (≥60rpm). Exercise continued until the participant reached 85% of age-predicted maximum heart rate (220-age). Estimated $\dot{V}O_{2max}$ was determined using the built-in algorithm contained within the metabolic cart software (Quark CPET, COSMED, Pabona di Albona Laziale, Italy). Heart rate and rating of perceived exertion (RPE; Modified BORG 0-10 scale - (14)) were recorded during the final 15 seconds of each exercise stage. Individual linear regression equations were established for each participant and used to determine cycling power outputs corresponding to various percentages of the $\dot{V}O_{2max}$for the main exercise trials performed during Visit 2 and Visit 3.

Main Exercise Trial (Visit 2 and 3)

During Visit 2 and Visit 3, participants' weight was re-recorded, and an indwelling catheter (BD, Franklin Lakes, NJ, USA) was inserted to an antecubital vein so that serial blood draws could be collected before, during and after exercise. The catheter was flushed with isotonic saline after each blood draw and a 2mL volume was drawn and discarded prior to collecting the blood sample used for analysis. Blood was collected into a 6mL vacuum tube containing a serum separator gel (BD Vacutainer® blood collection tubes). Participants were then asked to complete a 5-minute warm up at 50W before cycling continuously for an additional 20-minutes at graded intensities. The 20-minute trial consisted of four incremental 5-minute stages with power outputs corresponding to 50%, 60%, 70%, and 80% of the individual predicted $\dot{V}O_{2max}$. Participants again were asked to maintain a consistent cycling cadence throughout the entire exercise session (≥60rpm) and heart rate and respiratory gas exchange were measured throughout with RPE being recorded during the final 15 seconds of each exercise stage. To reduce the influence of a respiratory lag phase at the beginning of each incremental stage of the

exercise protocol, the heart rate and breath-by-breath respiratory data obtained during the final 3-min of each stage was averaged and processed for analysis (15).

Blood samples were collected at 4 separate time points during these visits: (i) at rest; (ii) during the 60% $\dot{V}O_{2max}$ stage; (iii) during the 80% $\dot{V}O_{2max}$ stage; and (iv) at 1h after exercise cessation. An exception to this was the control participants who performed identical exercise protocols as part of a parallel but separate research study in our laboratory but had blood collected at rest and during the 80% $\dot{V}O_{2max}$ stage only. To maintain consistency, the absolute cycling power outputs for each individual were identical during Visit 2 and Visit 3. During Visit 3, the resting serum sample was also used to confirm that all vaccinated individuals had seroconverted and presented with a positive SARS-CoV-2 IgG titer. To exclude the possibility of including participants that had been infected naturally between laboratory visits, whole blood samples collected in two LH tubes was stimulated with overlapping peptide pools spanning the breadth of the spike, membrane and nucleocapsid antigens (10µg/mL; Miltenyi) prior to measuring IFN-γ in plasma by ELISA (R&D Systems; Minneapolis, MN, USA) following methods we recently described (16). No responses to membrane or nucleocapsid antigen were found post-vaccine in the participants who had not been infected naturally (not shown)(17).

Assessment of Serum Biomarkers

Blood collected into vacutainers containing a serum gel separator were allowed to rest for 30 minutes and subsequently centrifuged at 1500 RCF for 10 minutes. Serum was then collected and stored at -80°C until future analysis of cortisol (EIAHCOR, INVITROGEN®, Frederick, MD, USA), lactate (MAK064, SIGMA-ALDRICH®, St Louis, MO, USA), and catecholamine release (BA E-6500R, LDN®, Nordhorn, Germany) by standard enzyme-linked immunosorbent assay (ELISA) kits according to the manufacturer's instructions.

Statistical Analysis

All data are presented as the mean ± standard deviation (SD) unless otherwise stated. All statistical analyses were completed using GraphPad Prism 8.0. Linear mixed models (LMM) or repeated measures ANOVA were used to analyze all metabolic and blood data, with Sidak post hoc test to determine differences between trials and groups. The model included main effects for group (vaccinated vs control), time (exercise workload) and trial (Pre vs Post vaccine, or Trial 1 vs Trial 2 in the controls) and interaction (Group x Time x Trial) effects. Main effects for Time and Trial and interaction effects (Time x Trial) were also determined within each group. Paired sample T-tests were used to detect differences in predicted $\dot{V}O_{2max}$ and time to ventilatory threshold between the trials performed during Visit 2 and Visit 3. Significance was set at $p < 0.05$

Results

COVID-19 vaccination is associated with an elevated heart rate and norepinephrine response to graded cycling exercise in healthy individuals

To determine if COVID-19 vaccination is associated with changes in the physiological responses to exercise, we first of all compared pre and post vaccine exercise responses in the entire vaccinated cohort (n=12) regardless of SARS CoV-2 exposure status or vaccine type (Figure 1). Overall, the physiological responses to exercise were similar between trials but we did find significant interaction (Time x Trial) effects for heart rate (HR) and serum norepinephrine levels, with were elevated during exercise after vaccination. Post-hoc analysis revealed that HR was elevated at the 60% and 70% $\dot{V}O_{2max}$ stage ($p = 0.02$ and 0.0005 respectively) and norepinephrine levels were elevated at the 80% $\dot{V}O_{2max}$ stage ($p=0.002$) compared to the pre-vaccine trial. The RPE tended to be lower post vaccine at the 50%

$\dot{V}O_{2max}$ stage (p = 0.06) but not at the other exercise intensities. We found no pre-to-post vaccine differences for ventilation (VE), oxygen uptake (VO_2), CO_2 production (VCO_2), respiratory exchange ratio (RER), ventilatory equivalents of oxygen uptake ($\dot{V}E/\dot{V}O_2$), carbon dioxide production ($\dot{V}E/\dot{V}CO_2$), stroke volume (SV), cardiac output (Q), predicted $\dot{V}O_{2max,}$ time to ventilatory threshold (VT), rating of perceived exertion (RPE), serum lactate, serum epinephrine or serum cortisol (p>0.05).

Elevations in heart rate and norepinephrine responses to graded exercise were found in those receiving the Pfizer mRNA COVID-19 but not controls.

As the majority of our vaccinated participants received the Pfizer mRNA vaccine (9/12), we decided to test if the increased heart rate and norepinephrine responses to exercise after vaccination were unique to this cohort. We found that the elevation in HR at the 70% $\dot{V}O_{2max}$ stage and norepinephrine response at the 80% $\dot{V}O_{2max}$ stage was still significant (p = 0.006 and 0.04, respectively) (Figure 2). As with the entire cohort, we did not find differences in any other physiological endpoint post vaccine. As this study was not randomized, we decided to include data collected from a parallel study being performed in our laboratory whereby two bouts of graded exercise were performed by healthy participants ~5-weeks apart (i.e., similar to the time elapsed between Visit 2 and Visit 3 for the vaccinated cohort) without receiving a vaccine. All participants in the control group were found to be seronegative for SARS-CoV-2 at the time of testing (Visit 2 and Visit 3) and the exercise bouts performed by these control participants were identical to the vaccinated cohorts described here. When the control participants and the Pfizer mRNA vaccine cohort were included in the same LMM, we found no Group x Time x Trial interactions for HR or norepinephrine (p>0.05). However, due to the preliminary nature of this study and the fact we had only 6 control participants to compared with 9 vaccinated participants, we were concerned that our small sample size and variability across groups could be causing a type II statistical error. To address this, we decided to compare delta values (Trial B – Trail A) between the vaccine and the control cohorts for heart rate and norepinephrine and analyzed these in the same LMM (Figure 3). In doing this, we found that both HR (p=0.03) and norepinephrine (p=0.01) was elevated in the second trial for those that received the Pfizer mRNA vaccine compared to the controls at the 70% and 80% $\dot{V}O_{2max}$ stages, respectively.

Discussion

Vaccination is strongly recommended to safeguard athletes from infection during training and competition (10). Several major sporting events (e.g., UEFA European and Copa America Soccer Championships, Tokyo Olympic Games) have been held during the COVID-19 pandemic, increasing the risk of SARS-CoV-2 infection for non-vaccinated athletes. While both vaccination (18) and natural immunity (e.g. from prior infection) (19) can protect against COVID-19 disease, non-vaccinated athletes are at an increased risk of contracting SARS-CoV-2 during training and competition. This could cause athletes to miss major sporting events and initiate isolation protocols for other athletes they were in close contact with. Despite this risk, anecdotal reports have emerged of athletes refusing the COVID-19 vaccine due to perceived negative impacts it may have on both their health and performance.

This is the first study, to our knowledge, to report on physiological responses to exercise before and after COVID-19 vaccination. We found that recent COVID-19 vaccination in a group of physically active healthy individuals had no impact on a large number of physiological endpoints measured in blood and by respiratory gas exchange during graded cycling exercise. Principally, reliable markers of metabolism and aerobic capacity including blood lactate, oxygen uptake, carbon dioxide production, time to ventilatory threshold and predicted $\dot{V}O_{2max}$ were unaffected by recent COVID-19 vaccination. These

findings indicate that COVID-19 vaccination is unlikely to affect exercise capacity in normal healthy people and should alleviate concerns regarding potential negative effects of vaccination on the ability to carry out daily physically demanding tasks or in meeting recommended physical activity guidelines. We did, however, find significant elevations in heart rate (~5 bpm) and norepinephrine responses to vigorous (e.g. 70-80% $\dot{V}O_{2max}$) intensity exercise after vaccination, particularly in those that received the two dose Pfizer mRNA vaccine regimen. Neither heart rate or norepinephrine changed in demographically matched control participants who completed identical bouts of exercise several weeks apart without receiving a vaccine. Although it is possible that these effects are due to reduced physical activity levels after vaccination (e.g., due to symptoms of vaccinosis), we deem a detraining effect unlikely as, despite reporting many of the common symptoms associated with COVID-19 vaccination, our participants did not report significant changes to their physical activity levels during the study period. The mechanisms by which recent COVID-19 vaccination might increase cardiovascular responses to graded exercise in healthy people are not known, although the elevated heart response after vaccination may have been driven by the concomitant elevation in the norepinephrine response to exercise (20). A more detailed examination of the cardiovascular and neuroendocrine responses to graded exercise after COVID-19 vaccination would be illuminating.

Despite finding that most physiological responses to exercise were unaffected by recent COVID-19 vaccination in these physically active healthy people, it should be noted that the small increases in heart rate and norepinephrine response to exercise after vaccination could have implications for athletic performance at the elite level. Repeating this work in a group of elite athletes with an additional performance measure (e.g., cycling time trial or peak power test) is warranted. We also acknowledge that our study is not randomized, but it would have been unethical to administer a placebo or prevent eligible individuals from receiving a vaccine during a global pandemic. Our small sample size also restricted us from stratifying the exercise response by SARS CoV-2 infection history and vaccine type, and may have prevented us from detecting other physiological shifts during exercise after vaccination. We also do not know how long the increased heart rate and norepinephrine responses to exercise lasts beyond 2-3 weeks post vaccination. We purposefully tested our participants 2-3 weeks after vaccination as this is within the timeframe for neutralizing antibody production and SARS-CoV-2 T-cell detection (21), and because athletes are often vaccinated in close proximity to competition (10). Finally, we acknowledge that our $\dot{V}O_{2max}$ assessments were made using submaximal as opposed to maximal tests, which may have affected the accuracy of the exercise intensity prescriptions. This was to alleviate concerns associated with maximal exercise testing in naturally infected and/or vaccinated individuals with undiagnosed myocarditis (22).

We conclude that recent COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in physically active healthy people. However, small elevations in the cardiovascular and neuroendocrine responses to exercise observed after the Pfizer mRNA vaccine could have implications for athletes and more consideration should be given when it comes to administering vaccines in close proximity to major sporting events. Future studies are required to determine if these effects of COVID-19 vaccination will impact athletic performance at the elite level, particularly because booster shots or new vaccines may be required for continuous protection against SARS-CoV-2 and its evolving variants (23).

Figure 1. The physiological responses to graded exercise before (Pre) and after (Post) COVID-19 vaccination (n=12). Endpoint measures include: (A) $\dot{V}O_2$, (B) $\dot{V}CO_2$, (C) RER, (D) Predicted $\dot{V}O_{2max}$, (E) VE, (F) $\dot{V}E/\dot{V}O_2$, (G) $\dot{V}E/\dot{V}CO_2$, (H) Time to VT, (I) HR, (J) SV, (K) Q, (L) RPE, (M) Lactate, (N) Cortisol, (O)

Epinephrine, and (P) Norepinephrine. Data are mean ± SD. Significant difference from the Pre-trial indicated by *** ($p<0.001$), ** ($p<0.01$) and * ($p<0.05$).

Figure 2. The physiological responses to graded exercise before (Pre) and after (Post) vaccination in the Pfizer mRNA vaccine cohort (n=9) and non-vaccinated controls tested on two separate occasions (n=6). Endpoint measures include: (A) $\dot{V}O_2$, (B) $\dot{V}CO_2$, (C) RER, (D) Predicted $\dot{V}O_{2max}$, (E) VE, (F) $\dot{V}E/\dot{V}O_2$, (G) $\dot{V}E/\dot{V}CO_2$, (H) Time to VT, (I) HR, (J) SV, (K) Q, (L)RPE, (M) Lactate, (N) Cortisol, (O) Epinephrine, and (P) Norepinephrine. Data are mean ± SD. Significant difference from the Pre-trial indicated by ** ($p<0.01$) and * ($p<0.05$).

Figure 3. Delta (Trial B – Trial A) HR and norepinephrine responses during exercise trial 1 (pre-vaccine) compared to trial 2 (post-vaccine) for the Pfizer vaccine cohort (n=9) vs non-vaccinated controls tested on two separate occasions (n=6). Data are mean ± SD. Significant difference from controls indicated by * ($p<0.05$).

Table 1. Participant demographic data (n=18). Vaccinated participants received either the two dose Pfizer mRNA regimen (n=9) or the single dose Johnson & Johnson vaccine (n=3). The remaining participants served as controls (n=6). Median ± SD

	Total (*n*=18)	**Pfizer Cohort (*n*=9)**	**Controls (*n*=6)**
Female	9/18	5/9	3/6
Age (yrs)	29 ± 5.4	29.1 ± 3.9	28 ± 8.4
Height (cm)	173.9 ± 11	170.1 ± 11	177.5 ± 11.7
Weight (kg)	67.4 ± 13.6	68.1 ± 10.9	70.2 ± 11.5
Resting HR (bpm)	70 ± 5.7	71.2 ± 5.6	70 ± 5.9
Resting Systolic Blood Pressure (mmHg)	115 ± 8.2	115.4 ± 6.4	119 ± 7.9
Resting Diastolic Blood Pressure (mmHg)	77 ± 6.7	75.7 ± 5.5	77 ± 4
Predicted VO_{2max} (mL/kg/min)	40.7 ± 9.9	42.7 ± 7.2	44.1 ± 8.1
Time between main exercise trials (days)	52.5 ± 21.6	54.6 ± 15.7	26 ± 185.2
Time between final vaccine dose and last exercise trial (days)	14 ± 10.1	14.9 ± 6.5	N/A

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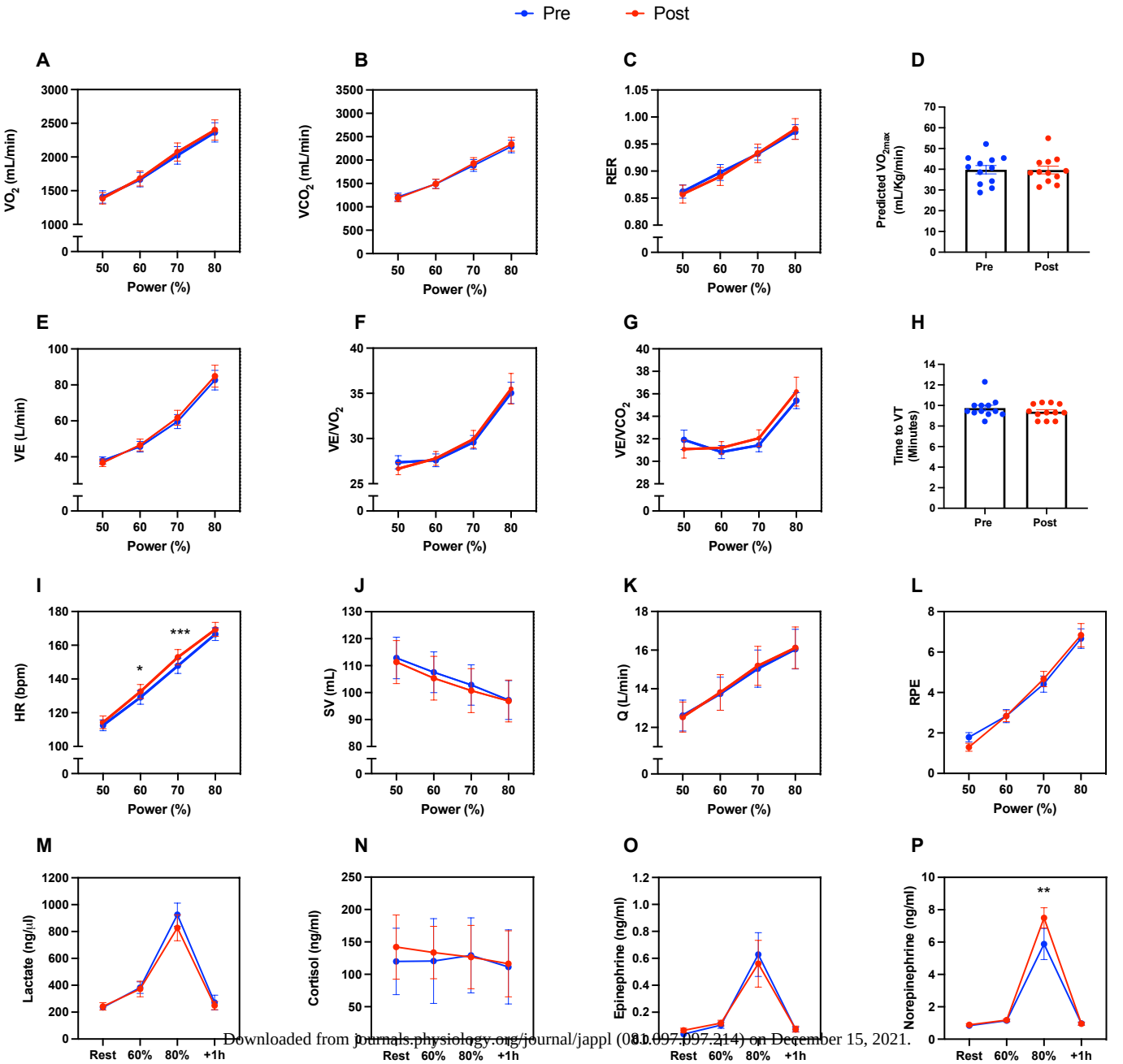
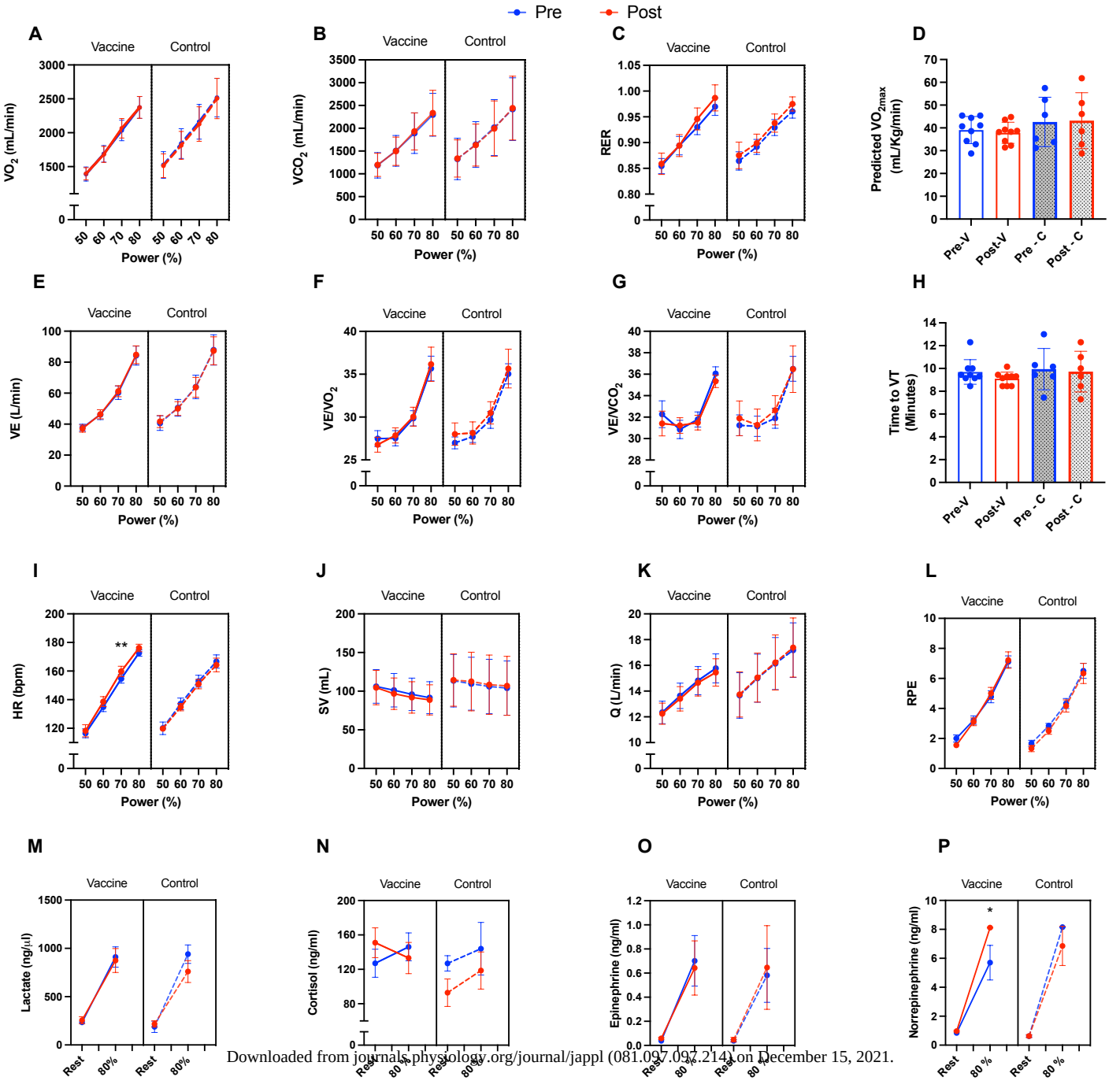




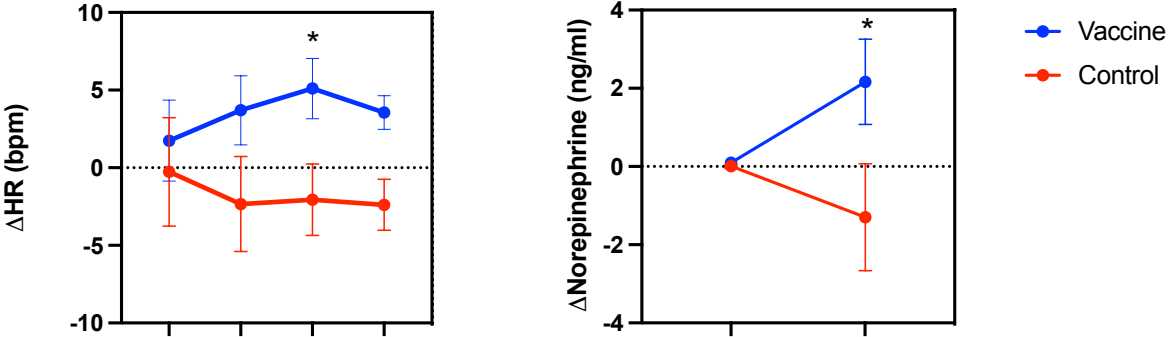
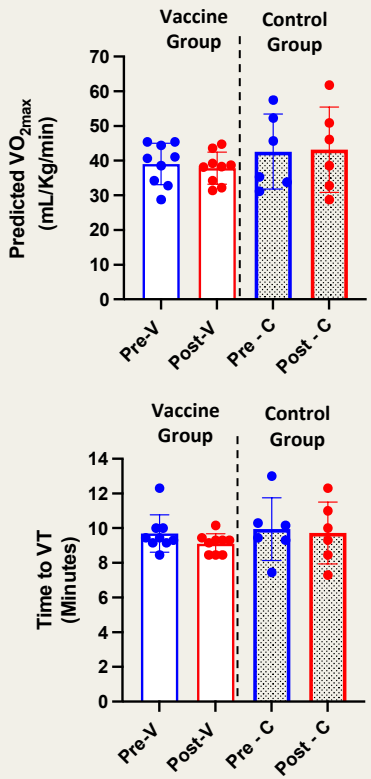


Table 1. Participant demographic data (n=18). Vaccinated participants received either the two dose Pfizer mRNA regimen (n=9) or the single dose Johnson & Johnson vaccine (n=3). The remaining participants served as controls (n=6). Median ± SD

	Total (*n*=18)	**Pfizer Cohort (*n*=9)**	**Controls (*n*=6)**
Female	9/18	5/9	3/6
Age (yrs)	29 ± 5.4	29.1 ± 3.9	28 ± 8.4
Height (cm)	173.9 ± 11	170.1 ± 11	177.5 ± 11.7
Weight (kg)	67.4 ± 13.6	68.1 ± 10.9	70.2 ± 11.5
Resting HR (bpm)	70 ± 5.7	71.2 ± 5.6	70 ± 5.9
Resting Systolic Blood Pressure (mmHg)	115 ± 8.2	115.4 ± 6.4	119 ± 7.9
Resting Diastolic Blood Pressure (mmHg)	77 ± 6.7	75.7 ± 5.5	77 ± 4
Predicted VO_{2max} (mL/kg/min)	40.7 ± 9.9	42.7 ± 7.2	44.1 ± 8.1
Time between main exercise trials (days)	52.5 ± 21.6	54.6 ± 15.7	26 ± 185.2
Time between final vaccine dose and last exercise trial (days)	14 ± 10.1	14.9 ± 6.5	N/A

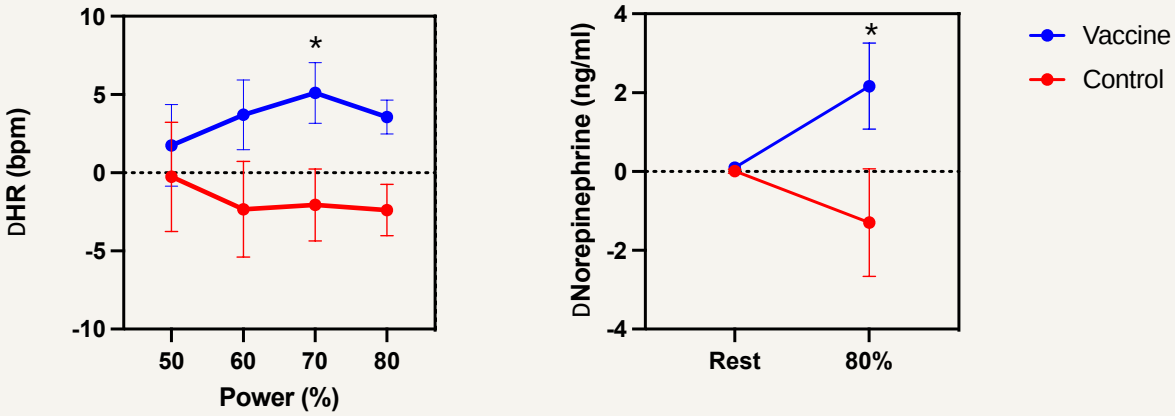
Recent COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in physically active healthy people

METHODS



Physiological Responses to graded cycling exercise were compared before and after COVID-19 vaccination and in controls.

RESULTS



COVID-19 vaccination had no effect on a large number a large number of physiological endpoints in response to graded cycling exercise at various percentages of the VO2max.

Small elevations in the heart rate (HR) and norepeinephrine response to vigorous exercise (70-80% VO_{2max}) were observed after vaccination (Pfizer mRNA) but not controls.

CONCLUSION

Recent COVID-19 vaccination has minimal effects on the physiological responses to graded exercise in physically active healthy people. The small elevations in cardiovascular and neuroendocrine responses to exercise after the Pfizer mRNA vaccine regimen could have implications for athletes at the elite level.

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