Gender governs the relationship between exercise intensity and growth hormone release in young adults

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Abstract:

We previously reported that in young adult males growth hormone (GH) release is related to exercise intensity in a linear dose-response manner (Pritzlaff et al. *J Appl Physiol* 87: 498–504, 1999). To investigate the effects of gender and exercise intensity on GH release, eight women (24.3 ± 1.3 yr, 171 ± 3.2 cm height, 63.6 ± 8.7 kg weight) were each tested on six randomly ordered occasions [1 control condition (C), 5 exercise conditions (Ex)]. Serum GH concentrations were measured in samples obtained at 10-min intervals between 0700 and 0900 (baseline) and 0900 and 1300 (Ex + recovery or C). Integrated GH concentrations (IGHC) were calculated by trapezoidal reconstruction. During Ex, subjects exercised for 30 min (0900–0930) at one of the following intensities [normalized to the lactate threshold (LT)]: 25 and 75% of the difference between LT and rest, at LT, and at 25 and 75% of the difference between LT and peak O_2 uptake. No differences were observed among conditions for baseline IGHC. To determine whether total (Ex + recovery) IGHC changed with increasing exercise intensity, slopes associated with individual linear regression models were subjected to a Wilcoxon signed-rank test. To test for gender differences, data in women were compared with the previously published data in men. A Wilcoxon ranked-sums two-tailed test was used to analyze the slopes and intercepts from the regression models. Total IGHC increased linearly with increasing exercise intensity. The slope and intercept values for the relationship between total IGHC and exercise intensity were greater in women than in men. Deconvolution analysis (0700–1300 h) revealed that, regardless of gender, increasing exercise intensity resulted in a linear increase in the mass of GH secreted per pulse and summed GH production rate, with no changes in GH secretory pulse frequency or apparent half-life of elimination. Exercise reduced the half-duration of GH secretory burst in men but not in women. Gender comparisons revealed that women had greater basal (nonpulsatile) GH secretion across all conditions, more frequent GH secretory pulses, a greater GH secretory pulse amplitude, a greater production rate, and a trend for a greater mass of GH secreted per pulse than men. We conclude that, in young adults, the GH secretory response to exercise is related to exercise intensity in a linear dose-response pattern. For each incremental increase in exercise intensity, the fractional stimulation of GH secretion is greater in women than in men.

Article:

Acute exercise is a powerful stimulus to growth hormone (GH) release (2-5, 15, 17, 20, 32, 33). Previous research has suggested that exercise intensity plays a key role, wherein a particular threshold of exercise intensity must be exceeded to elicit GH release (3-5). However, recent data from our laboratory indicate that, in young men, the magnitude of GH release rises with increasing exercise intensity in a linear dose-response relationship (as opposed to a threshold relationship) (20). Whether females have similar GH responses to varying exercise intensities is not known.

GH release at rest is greater in young women than in comparably aged men (7, 26, 30, 34). This gender difference is accounted for by a twofold greater mass of GH secreted per burst in young women (26, 30). Wideman et al. (34) reported that women have higher serum GH concentrations at rest and during a single exercise intensity and attain their peak GH concentration sooner than men. Despite gender differences in the absolute values of GH release during rest and aerobic exercise, the relative response to a single exercise intensity was similar in men and in women (34).

The present investigation examines the joint effects of gender and exercise intensity on GH secretion by comparing data collected on women with our previously published data on men (20). We hypothesized that the GH secretory response pattern to varying exercise intensities would be similar in men and women. On the basis of previously reported gender differences in GH secretion, we further hypothesized that the magnitude of change in GH release with increasing exercise intensity would be greater in women than in men. Characterization of these gender-based responses during exercise should provide insight into potential mechanisms underlying gender differences in GH release during exercise.

METHODS

Subjects and preliminary screening procedures. Eight recreationally active women between the ages of 18 and 35 yr (mean age = 24.3 ± 1.3 yr, height = 171 ± 3.2 cm, weight = 63.6 ± 8.7 kg) participated after they provided voluntary written, informed consent, as approved by the Human Investigation Committee of the University of Virginia. Each subject underwent a detailed medical history and physical examination, and no subject had a history of hypothalamopituitary, renal, hepatic, hematalogical, or metabolic disease. The subjects were nonsmokers, did not abuse alcohol, and were not taking any systemic medications. Screening laboratory data revealed normal hematological, renal, hepatic, metabolic, and thyroid function. Subjects refrained from exercise for 24 h before each evaluation.

Body composition analysis. Body density was determined by hydrostatic weighing (14). Each subject was weighed in air on an Accu-weigh beam scale accurate to +0.1 kg and subsequently weighed underwater on a Chatillon autopsy scale accurate to +0.01 kg. Water temperature in the tank was maintained between 36 and 39°C. Residual lung volume was measured with the use of

an oxygen-dilution technique (36). The computational procedure of Brozek et al. (1) was used to determine percent body fat from body density measurements.

Peak O₂ uptake and lactate threshold test. Peak O_2 uptake ($\dot{V}_{O_2\,peak}$) and lactate threshold (LT) were evaluated via a continuous treadmill (Quinton Q65 treadmill) exercise protocol with increasing velocity until volitional fatigue. The initial velocity was set at 80 m/min, with increases in velocity of 10 m/min every 3 min. Open-circuit spirometry was used to collect metabolic data (SensorMedics model 2900Z metabolic measurement cart, Yorba Linda, CA). Heart rate was determined via a Marquette Max-1 electrocardiograph. An indwelling cannula was inserted into a forearm vein before subjects were tested, and blood samples were taken at rest and during the last 15 s of each stage for the measurement of blood lactate concentration (Yellow Springs Instruments 2700 Select Biochemistry Analyzer, Yellow Springs, OH). $\dot{V}_{O_2\,peak}$ was chosen as the highest O_2 consumption ($\dot{V}_{O_2}$) attained.

Determination of LT and the constant load treadmill velocities. The blood lactate-velocity relationship was determined by plotting blood lactate concentration against treadmill velocity. LT was chosen as the highest velocity obtained before the curvilinear increase in blood lactate concentration. An elevation in blood lactate concentration of at least 0.2 mM (the error associated with the lactate analyzer) above baseline was required for LT determination. $\dot{V}_{O_2}$ associated with velocity LT was then determined (31).

Exercise admissions consisted of 30 min of constant load exercise at a predetermined velocity. Treadmill velocity was set at 25 and 75% of the difference between the $\dot{V}_{O_2}$ at LT and $\dot{V}_{O_2}$ at rest (0.25LT and 0.75LT, respectively), at LT, and at 25 and 75% of the difference between the $\dot{V}_{O_2}$ at LT and $\dot{V}_{O_2\,peak}$ (1.25LT and 1.75LT, respectively), based on results obtained during the initial LT-$\dot{V}_{O_2\,peak}$ protocol.

General clinical research center admissions. After the initial exercise test, each subject was studied at the general clinical research center (GCRC) on a total of six separate occasions, five with exercise and one at rest. The order of study conditions was assigned in a randomized fashion. The admissions were scheduled in the early follicular phase of the menstrual cycle, with no more than two admissions over a 2-mo time frame allowed (to ensure that guidelines for blood withdrawal were not exceeded). Although a minimum of six menstrual cycles were required for each subject to complete the study, the randomly assigned GCRC admissions and the selection of habitually active subjects likely minimized any changes in aerobic fitness, LT, and/or body composition that might have confounded the data. Subjects were admitted to the GCRC on the evening before the exercise and control studies. Subjects were required to consume their evening meal at or before 1700 h and then received a standardized snack (500 kcal) at 2000 h. The nutrient composition of the snack was 55% carbohydrate, 15% protein, and 30% fat. Subjects were allowed to consume water ad libitum. To avoid the confounding effects of meals on GH secretion, subjects then fasted until the end of the study (8, 9). At 2100 h, an intravenous cannula was placed bilaterally in each forearm vein. Subjects remained at the GCRC after eating their snack and were asked to turn lights off by 2300 h (9, 11). Beginning at 0700 h, blood samples were withdrawn every 10 min until 1300 h for later measurement of serum GH concentrations.

Exercise admission. After 2 h of baseline blood sampling was conducted, subjects began their exercise bout at the predetermined velocity. The exercise bout began at 0900 h and continued until 0930 h. During the exercise bout, blood lactate was measured every 10 min and metabolic data were measured minute by minute. The respiratory exchange ratio was measured using open-circuit spirometry (SensorMedics 2900Z metabolic measurement cart) during exercise and during the 30 min immediately after exercise while the subject sat quietly in the exercise lab. Thereafter, subjects resumed bed rest until 1300 h when the test was terminated and vital signs were taken. Subjects were then fed and discharged.

Nonexercise admission. The above procedure was also followed on the nonexercise days. However, at 0900 h, subjects remained in their rooms and rested quietly until 1300 h. At this time, the cannulas were removed and vital signs were taken. Subjects were fed and discharged.

GH assay. GH concentrations were measured in duplicate by using the modified Nichols ultrasensitive chemiluminescence assay (13). The optimized assay consists of 200 µl of serum assayed in duplicate with 200 µl of GH antiserum, overnight shaking incubation, robotic pipetting, and automated washing of the antibody-coated polystyrene beads (Nichols Laboratories, San Juan Capistrano, CA). Assay sensitivity, defined as 3 SD above the zero-dose tube, was 0.005 µg/l, and that defined as 2 SD above the zero-dose tube was 0.002 µg/l (13). Recombinant human GH (22,000 Da) was used as the reference standard. All samples from a subject were assayed together to eliminate interassay variability.

Data reduction. Assay data were analyzed by a model-free dose-dependent extrapolation of triplicate standards (23). Mean and integrated serum GH concentrations over 6 and 4 h (0900–1300 h) [integrated GH concentration (IGHC)] were calculated as outlined by Veldhuis and Johnson (27) using Cluster version 6.01.

Deconvolution. A multiple-parameter deconvolution method was employed to estimate the attributes of GH secretory events from the measured serum GH concentrations for the entire 6-h time period (28). The subject-specific monoexponential half-life of apparent metabolic removal of endogenous GH was estimated concurrently (28). The procedure for deconvolution entails prefitting via an automated waveform-independent technique (PULSE2). This method identifies presumptive pulses, by their significant reduction of the total fitted variance by F ratio testing (29). Provisional peaks were used in further multiparameter deconvolution analysis, wherein pulse number, position, amplitude, and hormone half-life are evaluated concurrently (6, 29).

To avoid overdetermination of peaks (Nyquist concept), GH peaks that were closer than 20 min (2 sampling intervals apart) were eliminated, and the data were refit. In addition, any peaks that were outside the sampling window (0–360 min) by more than one sample interval (10 min) were eliminated. A secretory burst was approximated algebraically by a Gaussian distribution of secretory rates (28). Basal (nonpulsatile) secretion was estimated concurrently, from the preexercise baseline data, as previously described (29). GH secretory pulses were considered significant if the fitted amplitude (maximal value attained within the computed secretory event) could be distinguished from zero with 95% statistical confidence. The half-duration of the GH secretory pulse (defined as the duration in minutes of the calculated secretory burst at half-maximal amplitude), GH half-life, and GH distribution volume were assumed to be constant

throughout any one study period in an individual. The mass of GH secreted per pulse is the integral of the calculated secretory pulse (in µg/l distribution volume) (28). The pulsatile GH production rate was defined as the product of the number of GH secretory pulses and the mean mass of GH secreted per pulse. The 90-min GH burst mass was calculated as the summed secretion during and after exercise (0900–1030 h).

Statistical analysis. ANOVA with repeated measures over exercise intensity was used to examine mean differences in $\dot{V}o_2$ and blood lactate concentrations. Whenever mean differences were observed, mean comparisons (corrected for correlated data with the use of Huynh-Feldt epsilons) were examined. To examine the relationship between GH response and exercise intensity, separate regression models were estimated for each of the eight study subjects with the GH response regressed on exercise intensity. Separate models were estimated within subjects because of the intraindividual correlation that existed among the GH responses across levels of exercise intensity. Such methods, although likely to be conservative, were thought to be appropriate because of the limited sample size that was available for estimating intra-individual correlation structures. Simple linear regression was also used because, compared with more complex models that allow for curvature, departures from linearity were not apparent. To determine whether a GH response changed significantly with exercise intensity, the eight slopes associated with exercise intensity from the individual regression models were then subjected to a Wilcoxon signed-rank test (12). Similar methods were used to examine the association between each of the deconvolution parameters and exercise intensity. The relationship between exercise + recovery (0900–1300 h) serum IGHC values and exercise intensity was further assessed by adding each deconvolution parameter to the within-subject regression models. To determine whether the relationship between the GH response and exercise intensity was independent of a deconvolution parameter, the slopes associated with exercise intensity in the adjusted models were subjected to a Wilcoxon signed-rank test.

RESULTS

Subjects' $\dot{V}o_{2\,peak}$ was 45.6 ± 2.1 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} (2.87 ± 0.25 l/min), $\dot{V}o_2$ at LT was 29.9 ± 2.7 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} (1.90 ± 0.19 l/min), $\dot{V}o_2$ at the LT-to-$\dot{V}o_{2\,peak}$ ratio was 0.66 ± 0.9, and percent body fat was $23.4 \pm 2.6\%$. As previously reported in young men (20),$\dot{V}o_2$ at LT and$\dot{V}o_{2\,peak}$ were strongly correlated ($r = 0.79$). One-way ANOVA with repeated measures and post hoc analyses revealed that $\dot{V}o_2$and blood lactate concentrations increased ($P < 0.05$) across all exercise intensities. The mean$\dot{V}o_2$ value at each exercise intensity (0.25LT, 0.75LT, LT, 1.25LT, and 1.75LT) corresponded to ~33, 49, 62, 76, and 86% of $\dot{V}o_{2\,peak}$, respectively. Thus, whether data were examined relative to LT or relative to $\dot{V}o_{2\,peak}$, linear increments in exercise intensity were observed.

Figure 1 shows mean serum GH concentrations from blood sampled at 10-min intervals over 6 h at rest and during 0.25LT, 0.75LT, LT, 1.25LT, and 1.75LT exercise. No differences were observed among conditions for baseline IGHC (0700–0900 h; $P = 0.20$). Baseline IGHC values ranged from 1 µg $\cdot$ l^{-1} $\cdot$ min^{-1} at LT to 45 µg $\cdot$ l^{-1} $\cdot$ min^{-1} at 0.25LT. Mean $\pm$ SE IGHC values (in µg $\cdot$ l^{-1} $\cdot$ min^{-1}) during exercise + recovery were as follows: rest = 509 ± 126, 0.25LT = 799 ± 131, 0.75LT = $1,013 \pm 219$, LT = 764 ± 97, 1.25LT = 954 ± 186, and 1.75LT = $1,459 \pm 253$. The highest GH values occurred during the 1.75LT condition.
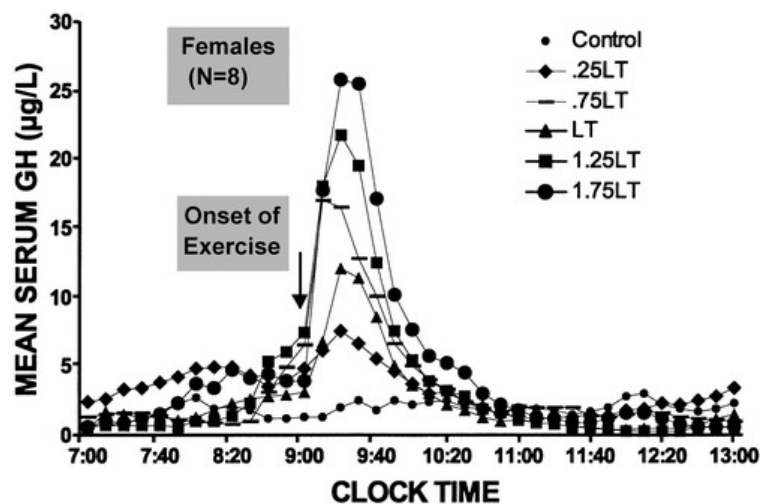
Fig. 1. Mean serum growth hormone (GH) concentrations during blood sampling at 10-min intervals over 6 h during C, 0.25LT, 0.75LT, LT, 1.25LT, and 1.75LT conditions. Values are means ± SE; $n = 8$ young women. C, control; 0.25LT and 0.75LT, 25% and 75% of the difference between O_2 consumption ($\dot{V}o_2$) achieved at lactate threshold (LT) and $\dot{V}o_2$ at rest; LT, at lactate threshold; 1.25LT and 1.75LT, 25% and 75% of the difference between the $\dot{V}o_2$ achieved at LT and peak$\dot{V}o_2$.

The individual relationships between exercise intensity and IGHC during exercise + recovery (0900–1300 h) are shown in Fig. 2. Within-subject regression revealed that IGHC increased significantly with each exercise intensity in a linear pattern ($P = 0.016$). This was the case when IGHC was plotted against either a percentage of LT (Fig. 2) or a percentage of $\dot{V}o_{2\,peak}$ (data not shown). There was no suggestion from the data that any of the individual GH responses increased differently across the ranges of exercise intensity.
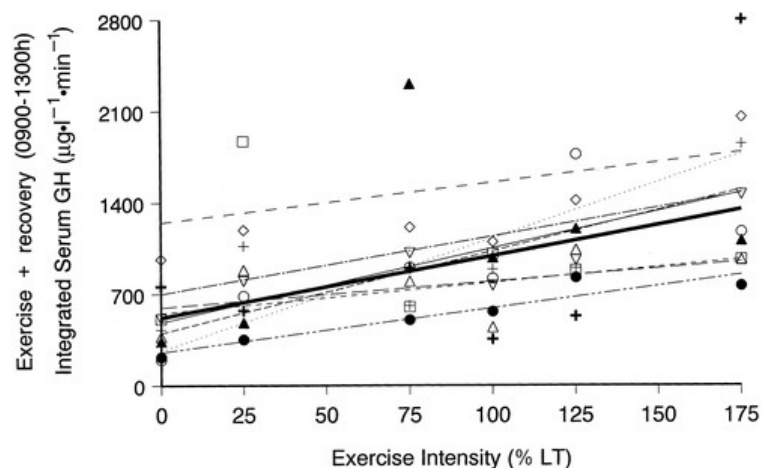

Fig. 2. Relationship between exercise intensity (expressed as a percentage of LT) and integrated serum GH concentration (exercise + recovery, 0900–1300 h). Symbols represent individual concentrations for 8 young women across 6 levels of exercise intensity. The thick solid line is derived from the average of the intercepts and slopes from the thinner within-subject regression lines. Integrated serum GH increases significantly with exercise intensity ($P = 0.016$).

Table 1 shows the results of the multiparameter deconvolution analysis of serum GH concentrations between 0700 and 1300 h. GH production rate, mass of GH secreted per pulse, and GH secretory pulse amplitude all increased significantly with increasing exercise intensity ($P = 0.032$, 0.016, and 0.016, respectively).

Table 1. Effects of increasing exercise intensity on specific measures of GH secretion and half-life during 6 h (0700–1300) in young women as determined by multiple-parameter deconvolution analysis and regression analyses

Variable	C	0.25LT	0.75LT	LT	1.25LT	1.75LT	X Slope	X Intercept
IGHC, $\mu g \cdot l^{-1} \cdot min^{-1}$	510 ± 126	799 ± 131	$1{,}014 \pm 219$	764 ± 97	955 ± 186	$1{,}459 \pm 253$	$449.98 \pm 79.6^*$	562.3 ± 112.2
GH basal secretion, $\mu g/l_v$	0.008 ± 0.002	0.005 ± 0.002	0.012 ± 0.003	0.008 ± 0.001	0.007 ± 0.002	0.006 ± 0.001	0.0024 ± 0.001	0.0077 ± 0.001
No. of GH secretory pulses	$8.4 \pm .6$	$6.5 \pm .7$	$6.8 \pm .6$	$5.9 \pm .6$	$5.6 \pm .4$	$6.3 \pm .7$	$-1.09 \pm .57$	$7.47 \pm .54$
GH mean interpulse interval, min	40.0 ± 2.2	50.9 ± 6.0	43.4 ± 4.1	54.3 ± 7.1	47.3 ± 5.9	47.2 ± 3.3	2.6 ± 3.5	45.05 ± 3.5
GH secretory pulse half-duration, min	18.0 ± 2.4	23.7 ± 2.5	17.6 ± 1.5	19.3 ± 1.8	17.4 ± 1.3	18.4 ± 1.9	$-1.41 \pm .84$	$20.2 \pm .94$
GH half-life, min	16.1 ± 1.3	16.8 ± 1.0	14.7 ± 1.1	$14.9 \pm .86$	$16.8 \pm .78$	15.7 ± 1.1	-0.52 ± 0.76	$16.1 \pm .75$
Mass of GH/pulse, $\mu g/l_v$	$3.3 \pm .5$	$8.2 \pm .91$	8.3 ± 2.4	7.1 ± 1.0	$8.3 \pm .82$	11.0 ± 2.4	$3.14 \pm 1.2^*$	$5.01 \pm .99$
GH secretory pulse amplitude, $\mu g/l_v$	$0.18 \pm .03$	$0.33 \pm .03$	$0.43 \pm .09$	$0.41 \pm .09$	$0.42 \pm .06$	$0.60 \pm .06$	$0.20 \pm .03^*$	$0.22 \pm .04$
GH production rate, $\mu g \cdot l_v^{-1} \cdot min^{-1}$	26.2 ± 3.5	51.0 ± 4.6	53.3 ± 14.3	39.6 ± 5.2	46.4 ± 5.8	77.2 ± 17.5	$16.8 \pm 7.7^*$	33.9 ± 5.5

Values are means ± SE; $n = 8$ subjects. C, control; 0.25LT and 0.75LT, 25 and 75% of the difference between the O₂ consumption (V̇o₂) achieved at lactate threshold (LT) and the V̇o₂ at rest; LT, at lactate threshold; 1.25LT and 1.75LT, 25 and 75% of the difference between the V̇o₂ achieved at LT and peak V̇o₂; GH, growth hormone; l_v, liter of distribution volume; X slope, mean of the slopes from the 8 individual regression lines; X intercept, mean of the intercepts from the 8 individual regression lines. GH basal (nonpulsatile) secretion = linear secretion term (usually set to zero for purely pulsatile secretion pattern); basal fit for preexercise baseline data and then applied to exercise conditions. GH secretory pulses = number of significant secretory peaks per sampling session. GH mean interpulse interval: mean time between secretory peaks per sampling session. GH secretory pulse half-duration = duration of the calculated secretory event as half-maximal amplitude. GH half-life = clearance time. Mass of GH/pulse = area of the calculated secretory pulses (amount of hormone secreted per unit distribution volume). GH secretory pulse amplitude = maximal value attained within the computed secretory event. GH production rate = product of mass/pulse and number of bursts (plus any basal secretion). *P < 0.05.

Because we have previously reported that the GH response to exercise was completed by 90 min in men (20), we examined the 90-min mean serum GH concentration after the stimulus (0900–1030 h), the absolute serum GH peak response, and the summed mass of GH secreted per pulse over the same time period in women (exercise + 1-h recovery) (Fig. 3). Data for women in the present study revealed significant increases with exercise intensity for all three parameters ($P = 0.008$).
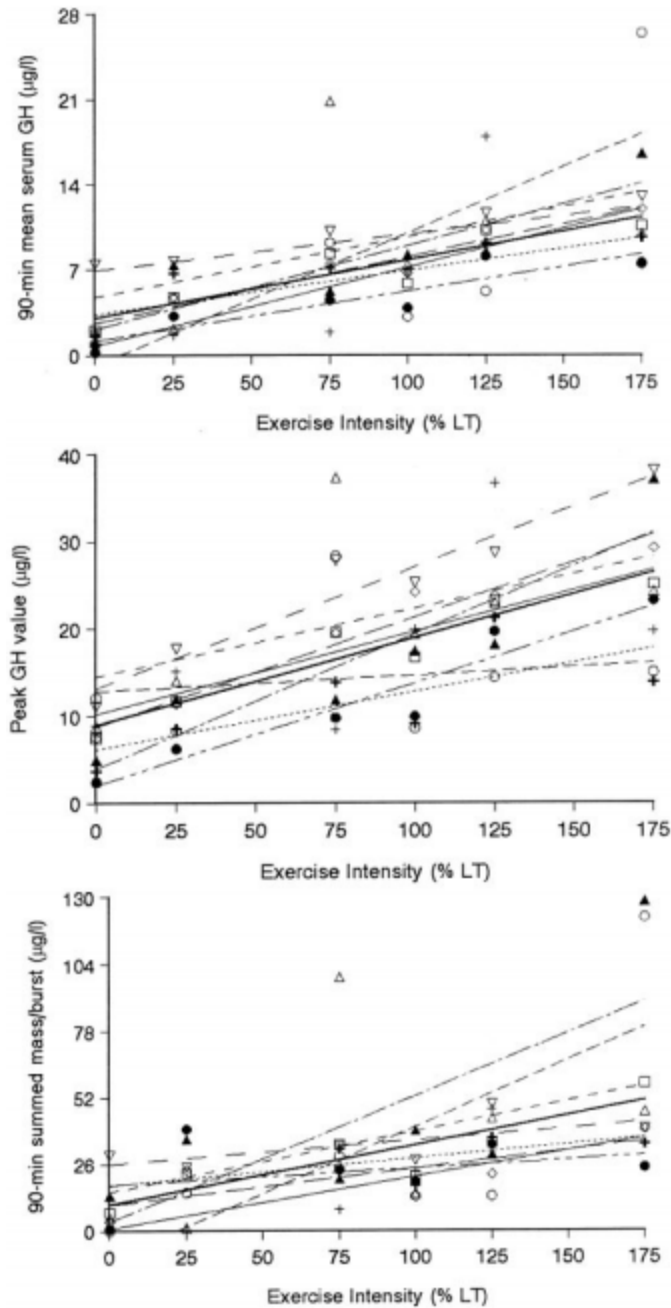
Fig. 3. Mean serum GH concentration (*top*), absolute maximal serum GH peak response (*middle*), and the summed GH mass secreted per pulse (*bottom*) over a 90-min interval (exercise + 1-h recovery, 0900–1030 h) according to exercise intensity in women. The thick solid line is derived from the average of the intercepts and slopes from the thinner within-subject regression lines. The 90-min mean serum GH, peak GH, and summed mass secreted per pulse increase significantly with exercise intensity ($P = 0.008$, $P = 0.008$, and $P = 0.008$, respectively).

DISCUSSION

The findings of the present study are similar to our previous observations in young men (20) in that *1*) exercise at all intensities stimulates greater GH release than that observed at rest, *2*) the

GH response to exercise is related to exercise intensity in a linear dose-response pattern, *3*) augmentation of GH production with increasing intensity of exercise is attributable mechanistically to an increase in the mass of GH secreted per pulse, and *4*) the number of GH secretory pulses and the GH half-life are not affected by exercise intensity.

Because the present data in young women were collected concurrently with our previously reported findings in young men (20), we felt that it was reasonable to examine gender differences. The reason that the analysis of the data collected in young women was delayed was because admission to the GCRC was menstrual cycle dependent (e.g., all admissions occurred during the early follicular phase). Students' *t*-tests were used to compare descriptive characteristics, whereas Wilcoxon ranked-sums two-tailed tests were used to analyze the slopes and intercepts from the regression models related to exercise intensity and GH release.

Men were significantly taller and heavier (20), and women had significantly more body fat. $\dot{V}_{O_{2\,peak}}$ expressed per kilogram of body weight was not significantly different in men and women, but absolute $\dot{V}_{O_{2\,peak}}$ was greater in men than in women ($P < 0.05$). There was no gender difference in treadmill velocity where LT occurred, in maximal heart rate, or in maximum blood lactate concentration. There was also no gender difference in $\dot{V}_{O_2}$ at LT expressed as a percentage of $\dot{V}_{O_{2\,peak}}$.

Basal (nonpulsatile) GH secretion at rest was twofold greater in women ($0.08 \pm 0.002\ \mu g \cdot l^{-1} \cdot min^{-1}$) than in men ($0.004 \pm 0.001\ \mu g \cdot l^{-1} \cdot min^{-1}$; Ref.20), but no significant within-gender differences were observed across the five exercise and one control condition. Gender differences in basal pulsatile GH secretion at rest are well recognized throughout the human lifespan (7). We recently reported that both basal and spontaneous GH secretion rates are greater in young women than in men. The gender difference in spontaneous GH secretion was accounted for solely by augmented GH secretory burst mass (35). In the present study in women as well as in our previous report in men (20), we observed stable basal GH secretion across the control and five exercise conditions. This allowed valid comparison of exercise-stimulated GH secretion between gender.

Women achieved higher serum GH concentrations at each exercise intensity compared with men (20) ($P < 0.05$). Statistical comparisons between gender revealed that women had greater mean slope (men = 277 ± 48, women = 449 ± 80) and intercept (men = $198 \pm 62\ \mu g \cdot l^{-1} \cdot min^{-1}$, women = $562 \pm 112\ \mu g \cdot l^{-1} \cdot min^{-1}$) values when the GH response was regressed on exercise intensity ($P = 0.08$ and $P = 0.02$, respectively) (Fig. 4). For each increase in exercise intensity corresponding to 0.25LT, the exercise + recovery IGHC (4 h) would be expected to increase by $\sim 70\ \mu g \cdot l^{-1} \cdot min^{-1}$ for men and by $\sim 121\ \mu g \cdot l^{-1} \cdot min^{-1}$ for women.
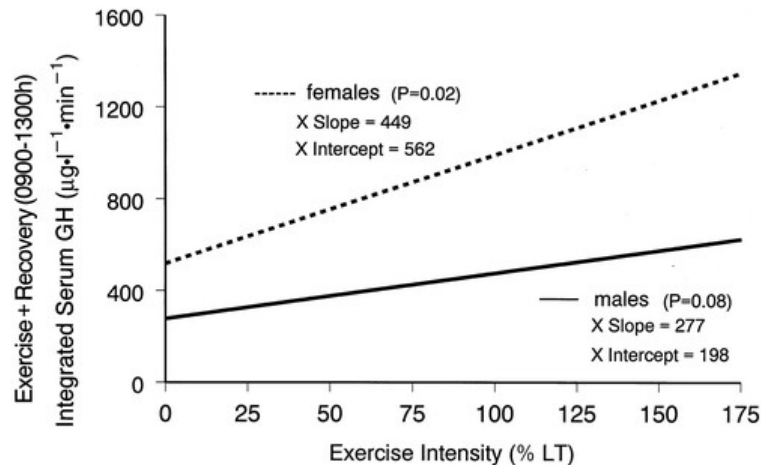
Fig. 4. Mean slope and intercept values when the GH response was regressed on exercise intensity in young men and women. The male data were taken from Ref. 20.

Gender comparisons further revealed that women had a greater GH production rate than men (20) at rest and at each exercise intensity ($P < 0.05$). The mean mass of GH secreted per burst increased significantly with increasing exercise intensity in both sexes, with a trend for greater mass of GH secreted per burst in women ($P = 0.09$). Gender differences in GH secretory pulse amplitude were observed as women had a higher mean amplitude (0.22 ± 0.04 µg · l^{-1} · min^{-1} vs. 0.08 ± 0.03 µg · l^{-1} · min^{-1}, respectively) ($P < 0.05$).

There were no significant differences in the mean interval between GH peaks or in GH half-life. The mean interval between GH peaks was ~45 min, regardless of gender or exercise intensity. Men (20) demonstrated a decrease in GH half-duration with increasing exercise intensity, which was significantly different from women ($P < 0.05$). Gender differences were observed in GH peak frequency ($P < 0.05$). The frequency of peaks was approximately eight for women and approximately six for men.

The regression models indicated that GH production rate during the 6-h period would be expected to increase by ~2.6 µg · l^{-1} · min^{-1} in men (20) and by ~5.26 µg · l^{-1} · min^{-1} in women for each increase in exercise intensity corresponding to 0.25LT. This was accounted for by an increase in the mass of GH secreted per pulse [~0.50 µg/l (men) and ~0.96 µg/l (women)] for each increase in exercise intensity corresponding to 0.25LT, with no change in the number of GH secretory pulses or the GH half-life of elimination. The amplitude (maximal secretory rate) of GH secretory pulses increased by ~0.04 µg · l^{-1} · min^{-1} (men) and ~0.05 µg · l^{-1} · min^{-1}(women) with each 0.25LT increase in exercise intensity, whereas the secretory pulse half-duration decreased by ~1.1 min (men) and ~0.28 min (women) with each increase in exercise intensity of 0.25LT. Thus, with increasing exercise intensities, GH secretory pulses were of shorter duration but greater amplitude. The positive relationship between exercise + recovery IGHC (0900–1300 h) and exercise intensity remained statistically significant after adjustment for each of the deconvolution parameters with the exception of a trend for GH secretory pulse amplitude ($P = 0.106$), suggesting that increased pulse amplitude is the primary statistical determinant of the increase in IGHC with increasing exercise intensity.

Data previously reported for men (20) and for the women in the present study revealed that the 90-min mean serum GH concentration, peak GH concentration, and the summed mass of GH secreted per pulse increased significantly with exercise intensity. Gender comparisons revealed that for this 90-min time frame women had greater slopes and intercepts for the relationship between exercise intensity and mean serum GH concentration ($P = 0.02$ and 0.102, respectively) and peak GH concentration ($P = 0.02$ and $P = 0.004$, respectively).

None of the limited studies that have compared GH release during exercise in men and women has explored the impact of exercise intensity (16, 35). In the present analysis, we establish that women have a greater GH response than men at all levels of exercise intensity. We observed that, similar to our findings in men (20), the GH secretory response to exercise was related to exercise intensity in a linear dose-response relationship in women. The GH secretory response to exercise rose with increasing exercise intensities below the LT and continued to rise above LT (Fig. 2). Notably, as we recognized recently in men (20), exercise intensities below the LT stimulated GH release in women, suggesting that no threshold relationship exists in either sex between exercise intensity and the GH response. The finding that the magnitude of change in GH release with increasing exercise intensity is greater in young women than in young men (Fig. 4) extends corroborative observations based on a single intensity of exercise (16, 35).

Maximal serum GH concentrations were reached within 20–40 min of onset of the (30-min) exercise bout in both men (20) and women. Other studies also observed that exercise-induced GH concentrations peak at or near the end of exercise (16,22). Likewise, as previously noted with exercise (5, 16,22, 24, 33) and other stimulation tests (8, 25), we observe considerable intersubject variability in peak serum GH values.

Women had significantly greater GH peak number, production rate, and pulse amplitude (Table 1) than men (Ref. 20 and see Table1). In addition, we confirm the prior inference at a single exercise intensity (35) that women attain a maximal serum GH concentration more rapidly (Fig. 1) than men (Ref. 20 and see Fig. 1) under exercise drive, independent of exercise intensity. This may be related to a greater anticipatory response in women compared with men (34). This could reflect more rapid onset of endogenous GH secretagogue release and/or somatostatin withdrawal in women (7). The results of gender differences in GH production rate mirrored the results for IGHC (we used IGHC as a complementary and model-free measure of GH release). Thus the gender difference is robust to the method of analysis.

Akin to previous reports (10, 26, 30), there was no gender difference in mean GH interpulse interval or GH half-life. There was also no significant interaction between gender and mean mass of GH secreted per burst, although there was a trend for a main effect of gender ($P < 0.10$). Van der Berg et al. (26) did report that a higher mass of GH was secreted per burst in women than in men. However, van den Berg et al. examined a full 24-h profile of resting data with intercurrent food intake. In the present study, gender differences may have been more pronounced if the data collection had lasted longer than 6 h. In addition, in the present study, subjects fasted from 2100 to 1300 overnight and during sampling. Whether gender and fasting control GH release in an interactive fashion is not known (9).

As a time-limited measure of the effects of exercise on GH secretion, we calculated the 90-min mean serum GH concentration, peak GH level, and summed mass of GH secreted per pulse (Fig. 3). Each parameter increased significantly with escalating exercise intensity. Women continued to maintain greater responsiveness to exercise than men (Ref.20 and see Fig. 3) with increasing exercise intensity (significant differences occurred for mean serum GH and peak GH concentrations). Analogously, exercise and l-arginine infusion stimulated GH release more in women than in men (35). If l-arginine decreases somatostatin outflow, exercise may stimulate GH release in part via withdrawal of somatostatin inputs, especially in men. Accordingly, the present gender distinction in exercise effects may reflect unequal somatostatin tone in men and women. The latter notion is consistent with early studies that suggest that GH release in response to arginine is greater in women than in men at rest (18, 35).

It should be realized that the findings of the present study are limited to young adults. Whether these findings remain consistent in middle-aged or older adults or in individuals with chronic disease cannot be addressed with the present data.

In summary, the present study delineates that young women maintain a linear relationship between the magnitude of GH release and increasing exercise intensity. The inferred dose-response relationship is robust to standardization against either LT or $\dot{V}o_{2\,peak}$. Moreover, gender comparisons establish that exercise-induced GH release is greater in women than in men. This sex contrast reflects an increased number and amplitude of GH secretory pulses during exercise in women, with no difference in estimation of GH half-life. In both genders, the augmentation of GH production rates with increasing intensity of exercise is attributable mechanistically to an increase in the mass of GH secreted per pulse. The latter response mode is consistent with somatostatin withdrawal and/or augmented release of endogenous GH secretagogues.

Notes

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