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# Assessment of a Treadmill Speed Incline Conversion Chart: A Validation Study

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***Purpose:*** To investigate the validity of a treadmill speed incline conversion chart using physiological and subjective measures. ***Methods:*** Two groups of experienced runners (SLOW and FAST: divided based on their easy run pace) ran 6 speed incline combinations for 5 minutes each. Stages were equivalent according to the HillRunner.com chart, and stage order was randomized. Due to limitations of the chart, SLOW ($n = 11$) ran at inclines up to 4%, while FAST ($n = 22$) ran at inclines up 10%. Oxygen consumption ($VO_2$), respiratory exchange ratio, heart rate, blood lactate, overall rating of perceived exertion (RPE), and leg RPE were measured for each stage. $VO_2$ was compared against the $VO_2$ predicted by the American College of Sports Medicine (ACSM) equation (ACSM $VO_2$). Repeated-measures analysis of variance was used to detect differences between stages and inclines, and Hedges *g* was used as a measure of effect size. ***Results:*** Pooled results (0%–4%, $N = 33$) showed no incline effect on $VO_2$, respiratory exchange ratio, heart rate, blood lactate, or RPE ($P > .05$; $\eta_p^2 = .198$), validating the chart at these inclines. At or above 6%, meaningful and significant increases occur in $VO_2$ ($g > 0.9$, $P < .05$), with increases in heart rate, blood lactate, and leg RPE at higher inclines. ACSM $VO_2$ underestimated oxygen consumption at all inclines up to 8% ($P < .05$) but not at 10% (45.9 [4.0] vs 46.7 [2.4] $mL \cdot kg^{-1} \cdot min^{-1}$; $P = .186$). ***Conclusion:*** The HillRunner.com chart is only valid at or below 4%. At higher inclines, supposedly equivalent stages result in increased exercise intensity. ACSM $VO_2$ underestimates $VO_2$ in trained runners at inclines up to 8%.

***Keywords****:* running, training, ACSM prediction equation

Motorized treadmills are a common training tool used to approximate the effects of overground running, particularly during unfavorable outdoor conditions. They also allow for additional control of speed and incline without relying on local topography. This may be advantageous to runners training for ultramarathons, which are often completed on trails.[1] As participation in ultramarathon running has been increasing rapidly over the last 20 years,[2,3] more individuals may be interested in training on inclined surfaces to provide a competitive advantage, particularly in mountainous events. Running at incline without decreased speed leads to increased heart rate (HR), oxygen consumption ($VO_2$), respiratory exchange ratio, and blood lactate concentrations (BL) when compared with level ground running.[4,5] Thus, to create a comparable physiological response between flat and inclined running, runners may reduce their speed.

An important aspect of endurance training is accurate prescription of exercise intensities. Determining equivalent intensity levels at various speeds and inclines on motorized treadmills may be useful for exercise prescription and endurance training. The American College of Sports Medicine (ACSM) has created an equation to predict $VO_2$ at various treadmill speeds and inclines, though the equation is limited to submaximal exercise.[6] Free online resources also provide supposedly equivalent combinations of speed and incline and conversion to minutes-per-mile paces, a more familiar and commonly used measure of speed in the United States.[7] One such chart, found at HillRunner.com, is widely used, with over 400,000 users visiting the page over 750,000 times in 2018 (see Supplementary Digital Material S5 [available online]). However, its purported basis is in unpublished research, so its validity and derivation remain unknown,[8] limiting its credibility and potential use, both in research and to the public. Without validation, online conversion charts may under or overestimate physiological demands. Underestimation of exercise intensity may lead to unintended plateaus in performance, while overestimations may lead to overtraining[9] or impaired recovery after exercise.[10] Therefore, the primary aim of this study was to validate the Hillrunner.com Treadmill Pace Conversion chart (“the HillRunner.com chart,” see Supplementary Digital Material S6 [available online] for complete copy) by comparing subjective and physiological measures of exertion across theoretically equivalent intensity combinations of speeds and inclines in a sample of trained runners. A secondary aim was to compare measured $VO_2$ with the predicted ACSM $VO_2$ in this group.

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## Methods

### Participants

Participants were recruited from the University of Minnesota-Twin Cities and surrounding communities. Inclusion criteria were as follows: an average of 3 runs per week over the previous year, one run of at least 60 minutes in the last month, a typical easy run pace between 2.68 $m \cdot s^{-1}$ (10:00 $min \cdot mile^{-1}$) and 4.47 $m \cdot s^{-1}$ (6:00 $min \cdot mile^{-1}$), and at least 18 years of age. Participants were excluded if they had sustained a major injury in the previous 3 months. Potential participants were screened for eligibility via a Qualtrics (Qualtrics, Provo, UT) survey prior to enrollment. This study was reviewed and approved by the institutional review board at the University of Minnesota (STUDY00006703) prior to participant enrollment, and all participants provided written informed consent. Thirty-four participants (9 females; 32.0 [10.3] y old) met inclusion criteria and were enrolled in the study.

## Study Design

A cross-over design was used with each participant completing 6 stages in a randomized order. Because the HillRunner.com chart did not provide equivalent speeds for the higher inclines for slower runners, participants were assigned into FAST and SLOW groups based on their easy run pace. There was an unequal allocation ratio between the groups, with the ultimate ratio of FAST:SLOW being approximately 2:1. Randomization was balanced across orders, with each individual running a unique order of inclines. The overall study design is outlined in Figure 1.

## Pretesting

Individuals interested in participating completed a screening and running history survey prior to enrollment in the study. Survey data were used to characterize participants. A complete list of survey questions is included (see Supplementary Digital Material S7 [available online]). To estimate each athlete's running ability, an estimation of maximal oxygen consumption over 1 minute (VDOT) was calculated using the Run Smart Project VDOT Running Calculator, based on work done by Jack Daniels.[7] The VDOT score provides a measure of aerobic fitness without requiring participants to undergo maximal $VO_2$ testing, though it may underestimate true maximal $VO_2$ in a trained population.[11] Additional details on VDOT calculation are included in the Supplementary Digital Material S1 [available online].

## Participant Preparation

Athletes came to the Human and Sport Performance Lab at the University of Minnesota-Twin Cities for a single visit. Standard previsit exercise testing measures were followed, as detailed in Supplementary Digital Material S1 (available online).

## Testing Protocol

Treadmill testing was completed on a Woodway Pro XL treadmill (Woodway, Waukesha, WI). Participants warmed-up with one minute of walking at 1.34 $m{\cdot}s^{-1}$ and 0% incline before beginning the incline testing. Participants ran for 5 minutes at each incline (FAST: 0%, 2%, 4%, 6%, 8%, and 10%; SLOW: 0%, 0%, 1%, 2%, 3%, and 4%). Inclines differed between groups because the HillRunner.com chart does not list pace and incline conversions for speeds lower than 3.35 $m{\cdot}s^{-1}$. For SLOW, the second 0% stage (0%_second) was included so the number of stages would be identical for each group. Speed was adjusted according to the HillRunner.com chart to create an equivalent exercise intensity in each stage. For each stage, the pace corresponded to the participant's self-reported easy run pace from the survey, assumed to be performed in level overground running. Additional details on selection of paces are included in the Supplementary Digital Material S1 (available online). For each participant, the order of inclines was randomized using an online list randomizer to mitigate any potential confounding effects of fatigue or cardiovascular drift.[12]

## Data Acquisition

Throughout testing, respiratory gases were measured, and standard calibration procedures were completed prior to measurement (Ultima CPX and BreezeSuite software; MGC Diagnostics, St. Paul, MN). Mid 5-of-7 averaging was used for all $VO_2$ measurements. HR was also recorded continuously using a Polar chest strap monitor and Polar RS800cx watch (Polar Electro Oy). The company description applies to both the HR monitor and the watch, as both were made by the same company. In the final 20 seconds of each stage, participants were asked to provide their overall rating of perceived exertion (RPE; 6–20) using the Borg RPE scale,[13] which was visually presented to them each time. Participants were also asked to provide an RPE for their legs (LRPE), to understand any differences between overall exertion and localized muscular fatigue associated with uphill running.[14–16] The treadmill display was covered during testing, so participants were blinded to the speed and incline of each stage. At the end of each stage, participants stepped to the side of the treadmill for a one-minute standing rest. At the beginning of each rest period, BL

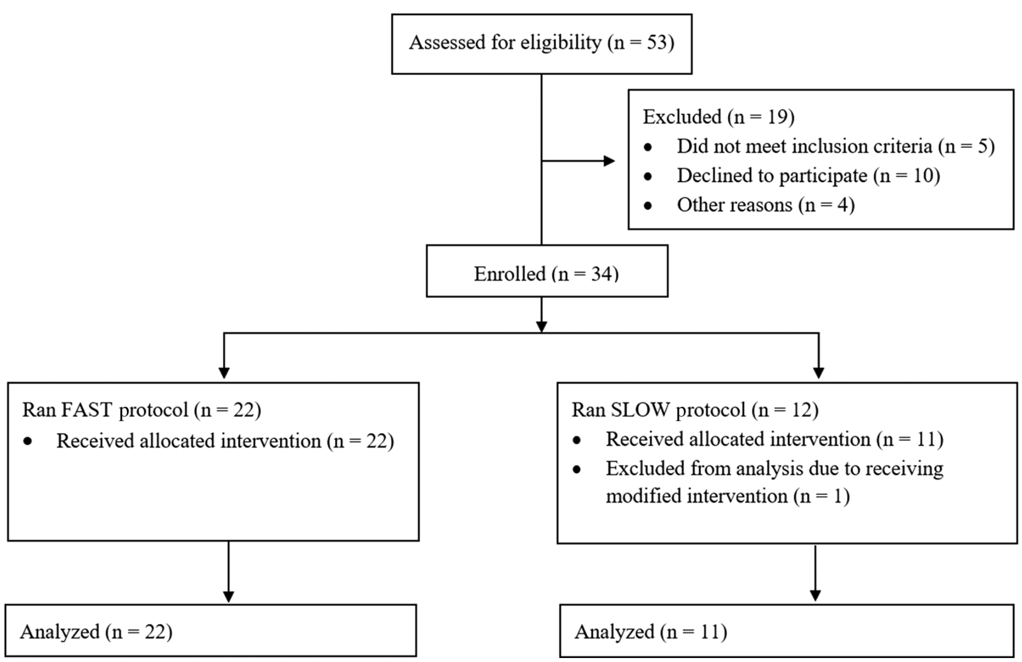


**Figure 1** — Overview of study design.

was assessed using a portable analyzer (Lactate Plus analyzer; Nova Biomedical, Waltham, MA), with blood samples obtained using a lancet on the participant's fingertip. A fan was placed perpendicular to the treadmill at the side of the participant in an attempt to limit cardiovascular drift throughout testing.

## Data Analysis

The $VO_2$ (in milliliter per kilogram per minute) and HR (in beats per minute) were measured continuously for each participant, and data from the last 2 minutes of each stage were averaged for both, based on work by Jones and Doust.[17] Plots of $VO_2$ were also examined visually to confirm attainment of a steady state. For these measures, data were organized, prepared, and averaged in Microsoft Excel (2013; Microsoft Corp). HR data were transferred to Polar ProTrainer software (Polar Electro Oy) and examined for artifact prior to selection of the final 2 minutes of each stage for averaging.

Statistical testing was completed using SPSS (version 25; IBM, Armonk, NY). An interim power analysis was completed after the first 10 participants completed testing. The analysis indicated that a sample size of 20 would be needed based on an alpha of .05 and a power of 0.80. After collection of all data, but prior to analysis, data were checked for normality and heteroskedasticity. Repeated-measures analysis of variance tests were used to compare $VO_2$, HR, BL, RPE, and LRPE between the 6 incline stages in FAST and SLOW. For data collected at inclines of 0%, 2%, and 4%, data from FAST and SLOW were pooled (ALL) and analyzed together for greater statistical power. Repeated-measures analysis of variance tests by stage number in FAST were used to determine the effect of stage number. Post hoc comparisons were done with Fisher least-squares difference tests due to our equivalency hypothesis, and thus, the priority to reduce type II error. Partial eta squared ($\eta_p^2$) was used as the measure of effect size for analysis of variance main effects. A corrected version of Hedges $g$, which adjusts for smaller sample sizes, was used for post hoc comparisons.[18] Paired-sample $t$ tests were used to compare RPE and LRPE and measured $VO_2$ to $VO_2$ predictions based on the ACSM equation.[6] Bland–Altman plots were prepared to further compare measured $VO_2$ and ACSM $VO_2$.[19] After a possible trend in the Bland–Altman plots was observed, linear models were fit to examine potential systematic bias in the plots. Assumptions were checked using R performance package (version 0.7.2).[20] An alpha level of $P \leq .05$ was set as the standard for significance.

**Table 1 Participant Characteristics**

| Variable | FAST (n = 22) | SLOW (n = 11) |
|---|---|---|
| Age, y | 31.0 (10.6) | 35.1 (9.7) |
| Mass, kg | 66.7 (7.3)* | 73.1 (10.2) |
| Height, cm | 175.6 (5.5) | 175.3 (10.3) |
| VDOT[a] | 59.17 (6.6)** | 39.26 (8.7) |
| Easy run pace, $m \cdot s^{-1}$ | 3.56 (0.15)** | 2.93 (0.16) |
| Km.Wk.Avg, $km \cdot wk^{-1}$ | 75.3 (29.0)** | 33.6 (13.8) |
| Km.Wk.Peak, $km \cdot wk^{-1}$ | 95.4 (31.3)** | 55.7 (29.6) |

Abbreviations: Km.Wk.Avg, average weekly training distance over the previous 6 months; Km.Wk.Peak, peak weekly training distance over the previous 6 months. Note: Values are presented as mean (SD).
[a]These values are analogous to 5000-m times of 17:15 and 24:27 for FAST and SLOW, respectively.
*Different from SLOW, $P < .05$. **Different from SLOW, $P < .01$.

# Results

Results are presented as mean (SD), and 95% confidence intervals are provided in square brackets where relevant. Thirty-four participants (9 females; 32.0 [10.3] y old) met the inclusion criteria and were enrolled into 2 groups: 22 in FAST for runners training at or above 3.35 $m \cdot s^{-1}$ (≤8:00 $min \cdot mile^{-1}$) for their easy runs and 11 in SLOW for runners training between 2.68 and 3.34 $m \cdot s^{-1}$ (<10:00 $min \cdot mile^{-1}$ and >8:00 $min \cdot mile^{-1}$) for their easy runs. Participant characteristics can be found in Table 1. Of the 27 participants who responded to the screening survey regarding their routine hill training, 70% reported encountering hills as a natural part of their training. Of the 27, 54% reported running hill repeats, which they reported completing an average of 2.5 times per month. Mean values in FAST and SLOW are presented in Tables 2 and 3, respectively. Information on pairwise comparisons in FAST and ALL are included in the Supplementary Digital Materials S2 and S3 (available online). Higher inclines lead to increases in exercise intensity; this was observed for most variables in FAST (Table 2 and see Supplementary Digital Material S4 [available online]). At lower inclines seen in SLOW, significant differences were limited to comparisons with the second 0% stage (Table 3). Differences in $VO_2$ by incline in FAST exceed the minimum detectable difference at 6% when compared with 0% (Figure 2). HR ($P < .03$; $g > 0.461$), BL ($P < .006$, $g > 0.596$), and LRPE ($P = .265$ for 8%, $P < .01$ for all others; $g > 0.318$) were significantly higher during the 10% stage compared with all other inclines in FAST. There were also

**Table 2 Measures of Exercise Intensity in FAST by Percentage Incline**

| | Incline | | | | | |
|---|---|---|---|---|---|---|
| | 0% | 2% | 4% | 6% | 8% | 10% |
| $VO_2$, $mL \cdot kg^{-1} \cdot min^{-1}$ | 42.18 (3.6)[c,d,e,f] | 42.56 (4.1)[c,d,e,f] | 43.22 (3.9)[a,b,e,f] | 43.91 (4.1)[a,b,e,f] | 44.66 (4.3)[a,b,c,f] | 45.86 (4)[a,b,c,d,e] |
| RER | 0.92 (0.07) | 0.92 (0.07) | 0.93 (0.09) | 0.92 (0.06) | 0.93 (0.08) | 0.93 (0.07) |
| BL, mM | 1.36 (0.87)[f] | 1.24 (0.85)[d,e,f] | 1.47 (1.17)[f] | 1.54 (1.15)[b,f] | 1.60 (1.15)[b,f] | 1.94 (1.2)[a,b,c,d,e] |
| Heart rate, $beats \cdot min^{-1}$ | 146.3 (11.8)[f] | 148.3 (10.7)[f] | 147.7 (11.7)[f] | 146.9 (12.3)[f] | 148.1 (13.4)[f] | 151.3 (12.5)[a,b,c,d,e] |
| RPE | 10.7 (1.8) | 10.6 (1.9) | 11.0 (2.0) | 10.5 (2.0) | 10.9 (2.1) | 11.4 (1.9) |
| LRPE | 10.1 (1.7)[f] | 10.2 (1.8)[f] | 10.7 (2.2)[f] | 10.4 (2.2)[f] | 10.9 (2.3)[f] | 11.9 (2.2) |

Abbreviations: BL, blood lactate concentration; LRPE, RPE for the legs; RER, respiratory exchange ratio; RPE, rating of perceived exertion; $VO_2$, oxygen consumption. Significantly different ($P < .05$) from [a]0%, [b]2%, [c]4%, [d]6%, [e]8%, [f]10%.

**Table 3 Measures of Exercise Intensity in SLOW by Percentage Incline**

| | Incline | | | | | |
|---|---|---|---|---|---|---|
| | 0% | 0%_Second | 1% | 2% | 3% | 4% |
| $VO_2$, mL·kg$^{-1}$·min$^{-1}$ | 37.29 (3.2) | 36.91 (4.2) | 37.1 (3.5) | 37.18 (3.7) | 36.97 (3.3) | 36.62 (2.9) |
| RER | 0.90 (0.04) | 0.89 (0.05) | 0.90 (0.04) | 0.91 (0.04) | 0.90 (0.04) | 0.9 (0.04) |
| BL, mM | 2.15 (1) | 1.82 (0.84) | 2.06 (1.26) | 2.31 (1.27) | 2.21 (1.37) | 1.9 (0.70) |
| Heart rate, beats·min$^{-1}$ | 153.3 (16.6)[a] | 160.8 (14.9) | 156.2 (14.9)[a] | 152.6 (16.3)[a] | 156.2 (14.8)[a] | 154.4 (14.9)[a] |
| RPE | 12.0 (1.9)[a] | 13.5 (1.0) | 12.0 (1.0)[a] | 11.8 (2.0)[a] | 12.1 (1.5)[a] | 12 (1.3)[a] |
| LRPE | 11.5 (2.5) | 12.6 (2.2) | 11.9 (1.6) | 11.8 (2.6) | 12.6 (2.1) | 12.8 (1.8) |

Abbreviations: BL, blood lactate concentration; LRPE, RPE for their legs; RER, respiratory exchange ratio; RPE, rating of perceived exertion; $VO_2$, oxygen consumption.
[a]Significantly different ($P < .05$) from 0%_second.

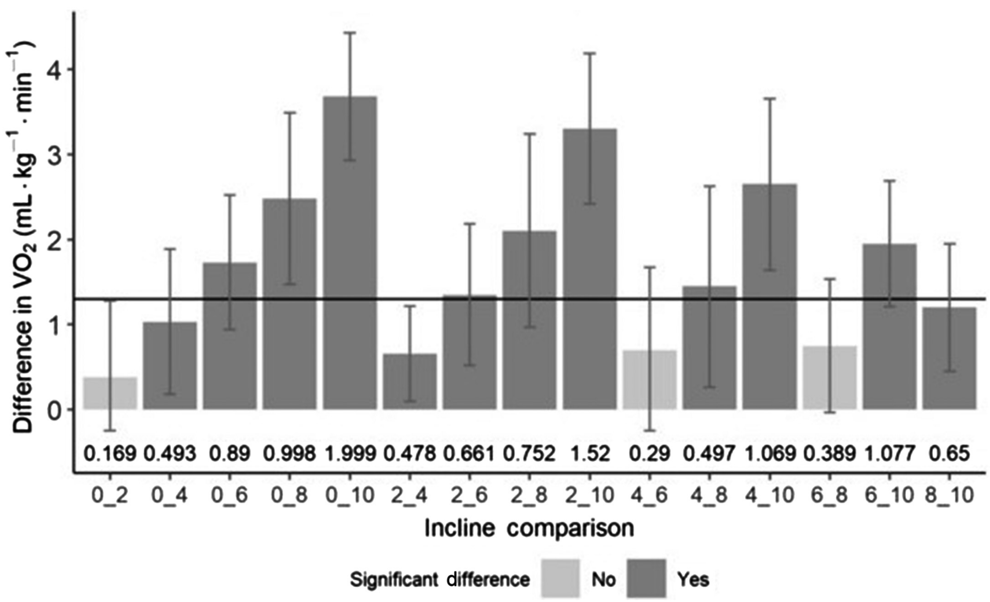


**Figure 2** — Difference in $VO_2$ by incline in FAST labeled with effect size. Corrected Hedges $g$ is used as the measure of effect size. Vertical bars indicate the 95% CIs for the difference in $VO_2$. The horizontal line across the figure approximates the minimum detectable difference by the metabolic cart used in this study. Dark bars indicate a significant difference (ANOVA, $P < .05$). ANOVA indicates analysis of variance; $VO_2$, oxygen consumption.

differences in BL between 0% and 8% ($g = 0.393$; $P = .06$) and between 2% and 6%, 8%, and 10% incline ($P < .02$; $g > 0.50$).

Data collected from SLOW and ALL further clarify changes seen at lower inclines. In ALL, there were significant differences in LRPE between 0% and 4% ([−1.35 to −0.18]; $P = .012$; $g = 0.433$) and between 2% and 4% ([−1.29 to −0.06]; $P = .031$; $g = 0.365$). Similar trends in LRPE were seen in the SLOW subgroup when comparing 0% with 3% ([−2.52 to −0.03]; $g = 0.563$) and 4% ([−2.19 to 0.01]; $g = 0.586$]). $P$ values and effect sizes for the main effect of each variable by study group are included in the supplemental materials (see Supplementary Digital Material S4 [available online]).

In ALL, FAST, and SLOW, measured $VO_2$ was lower than ACSM $VO_2$ at all inclines ($P < .05$) except 10% ($P = .186$). Linear models to assess for a relationship in the Bland–Altman data showed no significant relationship at 0% ($P = .173$), 2% ($P = .647$), or 4% ($P = .750$). There was a significant relationship at 6% ($P = .048$), but the homoscedasticity assumption was violated ($P = .004$). Significant relationships exist at 8% ($P < .001$, $R^2 = .49$) and 10% ($P = .004$, $R^2 = .32$). Therefore, regression lines were only included on the 8% (Figure 3E) and 10% plots (Figure 3F).

## Discussion

The present study aimed to determine whether the Hillrunner.com chart could be used to accurately adjust speeds to produce equivalent efforts at different inclines from 0% to 10%, and to evaluate the accuracy of the ACSM equation for predicting $VO_2$ across these inclines. While we found the Hillrunner.com chart to be accurate in producing equivalent efforts at inclines at or below 4%, it led to higher physiological and subjective efforts at higher inclines. The ACSM equation, on the other hand, overestimated $VO_2$ at 0% to 4% in ALL, 0% to 4% in SLOW, and 0% to 8% in FAST. A novel relationship was seen at higher inclines (8%–10%) such that $VO_2$ was no longer overestimated when $VO_2$ was high.

These findings mirror previous research by Minetti et al,[21] who showed increases in $VO_2$ and the energy cost of running at 10% incline compared with 0%, even with some decrease in treadmill

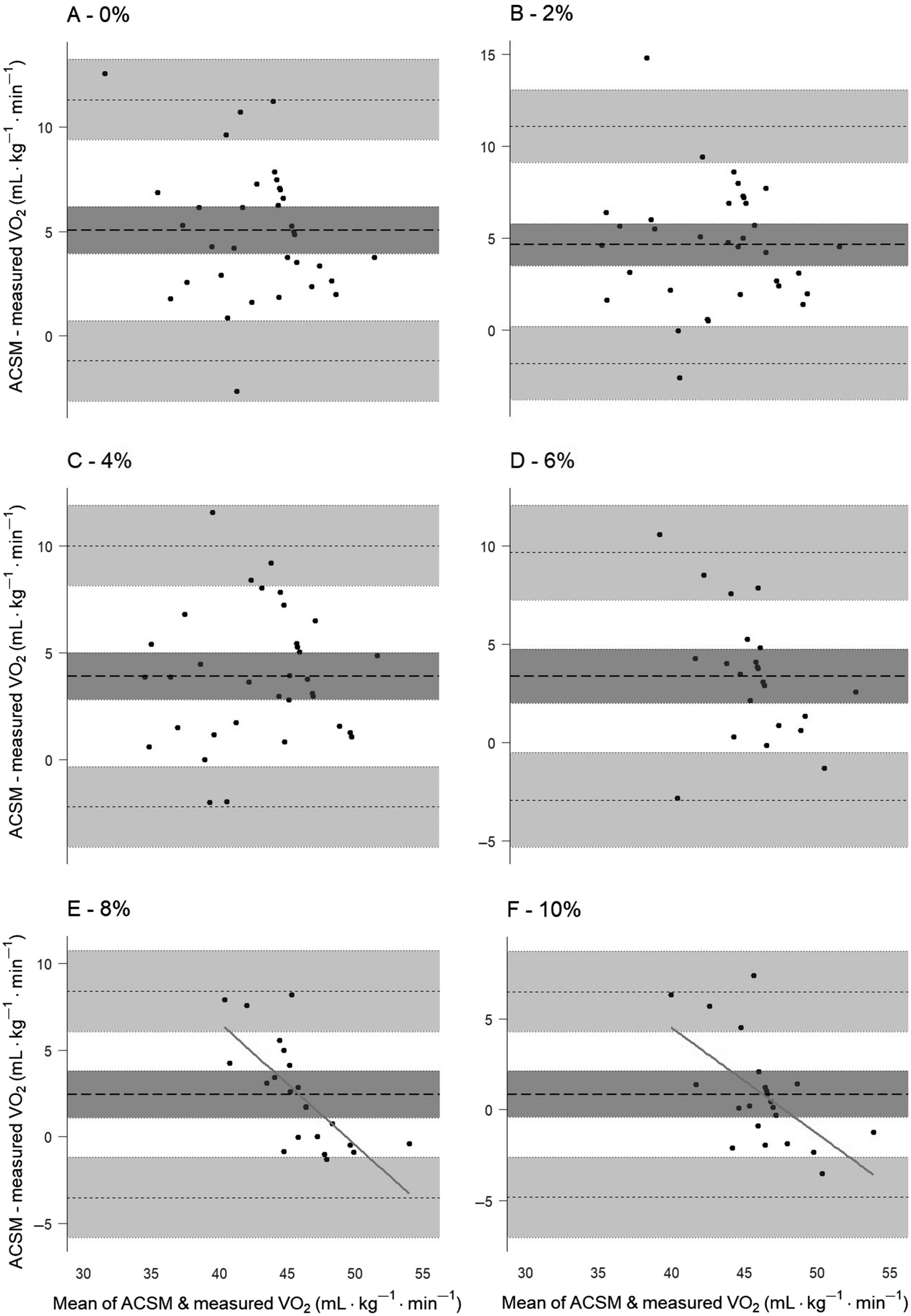


**Figure 3** — Bland–Altman plots of ACSM and measured $VO_2$. Plots include average difference (long dashes) and limits of agreement (dotted line), each with a 95% CI (shaded regions). All plots are scaled from 30 to 55 mL·kg$^{-1}$·min$^{-1}$ on the *x*-axis. Points greater than 0 on the *y*-axis indicate an overestimation by the ACSM equation. When significant, linear regression lines were added. (A) 0%, (B) 2%, (C) 4%, (D) 6%, (E) 8%, and (F) 10%. ACSM indicates American College of Sports Medicine; $VO_2$, oxygen consumption.

speed at 10%. Overestimation of $VO_2$ by the ACSM equation is also in agreement with previous research. These findings may be explained by previous literature showing a reduction in submaximal $VO_2$ (ie, improved running economy) at a given workload through chronic endurance training.[22,23] In each of the previous studies and in the present study, the submaximal $VO_2$ would likely be lower than that of the general population on which the ACSM equation is based.[23] In line with previous research,[24] the limits of agreement in the Bland–Altman plots are wide (~12 $mL \cdot kg^{-1} \cdot min^{-1}$), suggesting a high degree of individual variability when applying the ACSM equation (Figure 3). Plots of $VO_2$ at inclines below 8% show a consistent overestimation in ACSM $VO_2$. At inclines of 8% and 10%, a linear relationship exists between the differences in measured $VO_2$ versus ACSM $VO_2$; at a lower mean $VO_2$, the ACSM equation overestimates $VO_2$ and becomes more accurate as mean $VO_2$ increases. We are unable to determine the cause of the transition from overestimation to accurate prediction at high inclines as $VO_2$ increases. We caution against use of the ACSM equation in a trained population until the relationships between speed, incline, and magnitude of $VO_2$ are better understood.

Physiological measures provide specific insight into the differences at higher inclines and the implications for use of the HillRunner.com chart. Increases in $VO_2$ at 2% and 4% had 95% confidence intervals within the typical error of measurement for the metabolic system used[25] (Figure 2). At higher inclines, $VO_2$ continues to increase, with large effect sizes between low and high inclines (Figure 2), suggesting the chart is not valid beyond 4%. As incline increased from 0% to 8% in FAST, we observed no changes in HR, and corresponding effect sizes were low (see Supplementary Digital Material S3 [available online]). A difference of 3 to 5 beats per minute was observed when comparing HR at 10% to HR at lower inclines. Across inclines, the 95% confidence intervals for HR were quite wide (4–6 beats per minute, see Supplementary Digital Material S2 [available online]), indicating that individual HR responses may vary. For individuals whose training is guided by HR zones, these increases in HR may be enough to transition from a low-intensity zone to a moderate-intensity zone, which has been linked to reduced training adaptations and impaired race performance over a 5-month season.[26] We found BL in FAST began to increase by up to 0.5 mM at 6% when compared with both 0% and 2% (see Supplementary Digital Material S2 [available online]), and there were significant differences between 10% and all lower inclines. Depending on the intensity of exercise, these increases may also be enough to transition beyond a lactate steady state, leading to marked increases in BL, HR, and respiratory rate.[27] Increases in LRPE followed a comparable trend, with significant differences between inclines below 6% when compared with 10%. Based on data from FAST, the decreases in speed provided by the chart do not sufficiently correct for increased intensity above 4%.

Data from SLOW and ALL support the accuracy of the chart at lower inclines. Physiological measures of exercise intensity were not significantly different, and effect sizes were relatively small for both the main effect (all $\eta_p^2$ in ALL < .2) and for pairwise comparisons between inclines (all $g < 0.31$). While there was a significant increase in LRPE at these inclines, effect sizes were not notable in ALL ($g < 0.4$), and 95% confidence intervals suggest this difference is of little practical relevance (see Supplementary Digital Material S2 [available online]). Effect sizes were larger in SLOW than ALL ($g \approx 0.6$), but 95% confidence intervals were also wider (2 units in SLOW vs <1.2 in ALL). Given the greater power and tighter confidence intervals in ALL, the chart is likely accurate at all inclines up to 4%.

As this was a validation study, we felt it was most important to limit type II error; if inclines were reported as being equivalent, we wanted to ensure they were truly equivalent. As a result, we chose to use Fischer least significant difference instead of a Bonferroni correction. Had a Bonferroni correction been applied, the majority of notable findings would meet the threshold for significance ($P \leq .0083$).

## Evaluation of Testing Duration

We observed increases in HR, RPE, and LRPE over time. However, study design thoughtfully included randomization of inclines to mitigate any stage order effect. Therefore, these increases do not affect the validity of our overall results. Time-dependent elevations in HR, characteristic of cardiovascular drift, were observed. This is likely the cause of increased HR throughout testing in the present study.[28] A change in $VO_2$ over time was not observed, which is in agreement with previous literature showing the absence of a $VO_2$ slow component during low-intensity exercise or at incline.[29,30]

## Practical Applications

The HillRunner.com chart can be used by trained runners to create treadmill speed–incline combinations equivalent to overground speeds ranging from 2.68 to 3.62 $m \cdot s^{-1}$ (10:00–7:25 $min \cdot mile^{-1}$), provided the desired incline is <6%. Inclines greater than 4% are likely to induce increases in physiological and psychological measures of exercise intensity. We assessed only efforts that were submaximal in nature, and further studies are required to validate the HillRunner.com chart at higher speeds and maximal efforts. Our findings do not support use of the ACSM prediction equation to predict submaximal $VO_2$ at inclines under 10% in a trained population.

As noted in the study design, the HillRunner.com chart does not have any paces slower than 2.68 $m \cdot s^{-1}$ at a 10% incline, making the higher inclines impractical for some recreational athletes, walkers, or clinical populations. The present study used moderately trained runners to evaluate the validity of the HillRunner.com chart. As such, these findings cannot be applied to untrained or highly trained, elite runners. Furthermore, a limited number of female runners was included in the study, so it is unknown whether prescription using the HillRunner.com chart differs by sex. There is no previous indication or known physiological mechanism for a sex difference, but one still may exist.

# Conclusion

The HillRunner.com chart may be used for accurate prescription of submaximal exercise intensity in trained runners at speeds ranging from 2.68 to 4.47 $m \cdot s^{-1}$ (10:00–6:45 $min \cdot mile^{-1}$), and at inclines up to 4%. Across the same range of speeds, adjustments in speed, as recommended by the HillRunner.com chart, are not enough to maintain exercise intensity. Beyond a 4% incline, increases in $VO_2$, HR, and BL should be expected compared with speed adjustments recommended at lower inclines. Further decreases in speed beyond what the HillRunner.com chart currently recommends may be required for trained runners wishing to create equivalent efforts at these higher inclines. We show a novel relationship between magnitude of $VO_2$ and the degree of $VO_2$ overestimation by the

ACSM equation. Based on findings of the present study, the ACSM equation should not be relied upon to accurately predict submaximal $VO_2$ at inclines under 10% in a trained population.

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