EFFECT OF MIDSOLE THICKNESS ON RUNNING ECONOMY, COMFORT AND EFFORT IN WELL-TRAINED RUNNERS

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By the current rules, midsoles in running shoes cannot exceed 40 mm in thickness, but this limit seems arbitrary. We investigated the effect of midsole thicknesses beyond the current limits on running economy, perceived comfort and effort, and spatiotemporal variables. Sixteen well-trained runners completed twelve outdoor runs (1.2 km each) at 16 km·h^{-1} alternating between three different footwear (one entry-level shoe (EL) with 30mm thickness and two modern shoes with thickness of 40 mm and 50 mm). Both modern shoes showed lower O_2 uptake and effort compared with EL, but no differences between the 40-mm and 50-mm shoes were detected. Comfort was lowest for the EL and 50-mm shoes. Gait parameters did not differ between footwear conditions. As higher midsole thickness does not provide clear advantages, current rules could be re-evaluated to prevent stifling innovation.

KEYWORDS: athletics track, O_2 cost of running, stack height.

INTRODUCTION: Long-distance running performances have greatly improved by the introduction of modern running shoes, which reduce the O_2 required by athletes to run at a given speed, a concept known as running economy (Hoogkamer et al., 2018). In 2022, World Athletics imposed an upper limit of 40 mm for midsole thickness in shoes worn during competition, possibly to prevent shoes from having an overemphasized role in performance. However, this limit appears to be arbitrary, and further research is required to determine the effect of varying midsole thickness during distance running. Most research on the interplay between modern running shoes and cardiorespiratory responses has been limited to treadmill testing, and since indoor results cannot be directly translated to outdoor running (Mooses et al., 2015), more outdoor protocols are needed. Therefore, this study aimed to examine whether midsole thickness affects $\dot{V}O_2$, perceived comfort and effort, as well as spatiotemporal variables during track running.

METHODS: Following a familiarisation trial including an incremental test, 16 well-trained male runners (weight 70 ± 6 kg, age 28 ± 5 years, peak O_2 uptake ($\dot{V}O_{2peak}$) 64 ± 4 ml O_2·min^{-1}·kg^{-1}, peak running speed 20.0 ± 0.8 km·h^{-1}) participated in an outdoor running protocol on a 400 m athletic track. This protocol involved twelve 1.2 km runs at a speed of 16 km·h^{-1} with a 5-min break between the runs to change the shoes. To ensure that the runners maintained the correct pace, pacing feedback was provided every 200 m. Runners alternated their footwear conditions after each run, thus completing four replicates with each of the three shoes. The three different conditions were: an entry-level running shoe with midsole thickness of 30 mm (EL, On Cloud Runner), and two carbon-plated modern running shoes with midsole thicknesses of 40 mm (40-mm, On Cloud Boom Echo 3.0) and 50 mm (50-mm, On Cloud Boom Echo 3.0 Prototype). An additional 10 mm of PEBA foam, and the inherent increased mass, was the only distinction between the 40-mm and 50-mm shoes. The mechanical properties for the shoes were tested before and after the experiments. The order of the shoes was randomised and balanced within and across the four replicates. Perception of comfort and effort were assessed at the end of each replicate using a 10-centimeter Visual Analogue Scale (VAS). Spatiotemporal variables such as ground contact time, step frequency and step length were assessed using an accelerometer pod at the waist level (±16 g range, sampling at 1,024 Hz, Runeasi, Belgium). Throughout all twelve trials gas exchange (Metamax, Cortex, Germany), heart rate (Polar H10, Polar, Finland), and spatiotemporal variables were continuously assessed. A 2-

min steady-state window at the end of each replicate was selected for statistical analysis. A one-way ANOVA with repeated measures including the average of the 4 replicates for each footwear was used for the statistical analysis. In cases where a significant main effect for shoe was observed, Tukey's honest significant difference post hoc analysis was conducted to identify significant differences between shoes. Associations between different variables were tested using Pearson's correlation.

RESULTS: Running with 40-mm shoes reduced $\dot{V}O_2$ compared with EL shoes by 4.0 ± 1.2% ($P < 0.001$, ES = 0.72, Figure 1), while 50-mm shoes decreased $\dot{V}O_2$ compared with EL shoes by 4.6 ± 1.8% ($P < 0.001$, ES = 0.8). However, no differences were detected between the modern shoes (40-mm vs. 50-mm: +0.6 ± 1.4%, P = 0.189, ES = 0.11). Similarly, the heart rate was lower compared with the EL shoes in both 40-mm shoes (-2.0 ± 0.6%; $P < 0.001$, ES = 0.32) and 50-mm shoes (-2.3 ± 0.6%, both $P < 0.001$, ES = 0.38), but no differences were detected between modern shoes (40-mm vs. 50-mm: +0.4 ± 0.6%, P = 0.091, ES = 0.06). Interestingly $\dot{V}O_2$ decreased over time for the 50-mm shoes, reaching significance between replicates 1 and 4 (P = 0.017, ES = 0.37), which was not the case for the 40-mm shoes (P = 0.817, ES = 0.08). The $\dot{V}O_2$ ratio between the 50-mm and 40-mm shoes was 1.003 in replicate 1, and 0.987 in replicate 4 (P = 0.108 between replicates 1 and 4, ES = 0.63, two-tailed t-test). The use of 40-mm shoes compared with EL shoes decreased perceived effort by 0.7 ± 0.6 units ($P < 0.001$, ES = 0.74), while comfort was found to be higher (+1.3 ± 1.9 units, $P < 0.001$, ES = 0.76). Likewise, running with 50-mm shoes compared with EL shoes reduced perception of effort by 0.7 ± 0.8 units (P = 0.011, ES = 0.48), but no significant differences in comfort were detected between the two footwear (P = 0.951). Thus, while no differences could be detected for perceived effort between the 40-mm and 50-mm shoes ($P > 0.999$), the 40-mm shoes were perceived as more comfortable than the 50-mm shoes (-1.5 ± 1.6 units, P = 0.005, ES = 0.82). As perceived effort increased linearly for each shoe condition over the four replicates (Figure 2), an extrapolation was performed to estimate how many replicates could have been performed until exhaustion. This showed that the 50-mm shoes would theoretically allow over two additional replicates to be performed compared with the EL shoes and one additional replicate compared with the 40 mm shoes until a perceived effort of 10 would be reached. No correlation was detected for the absolute change in $\dot{V}O_2$ and perceived effort between the 40-mm and 50-mm (r = 0.295, P = 0.267). This lack of correlation persisted even when the analysis was conducted using the 40-mm and the EL data (r = 0.227, P = 0.397), which differed significantly both in $\dot{V}O_2$ and perceived effort. Furthermore, no correlations were detected between either the absolute change in $\dot{V}O_2$ and the absolute change in perceived comfort for the 40-mm and the 50-mm shoes (P = 0.520) or for the 40-mm and the EL shoes (P = 0.602). Lastly, no differences were detected between the three footwear conditions in any of the measured spatiotemporal variables, namely ground contact time (P = 0.682), step frequency (P = 0.8801) and step length (P = 0.7329). A correlation matrix between the absolute changes in $\dot{V}O_2$ between the different footwear and the spatiotemporal variables was not significant for any parameter (all $P > 0.682$).

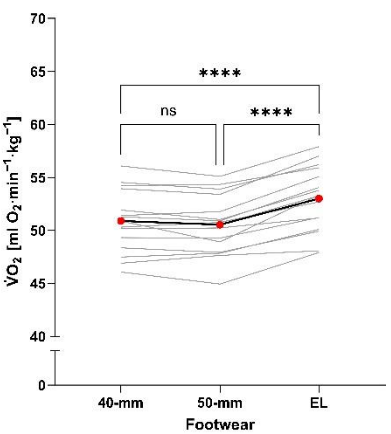

Figure 1: $\dot{V}O_2$ at 16 km·h^{-1} in each of three shoe conditions on the track. *40-mm,* Cloud Boom Echo 3.0 with 40 mm midsole thickness; *50-mm,* Cloud Boom Echo 3.0 with 50 mm midsole thickness; *EL,* Entry-level Cloud runner with 30 mm midsole thickness. Red dots depict the average, grey lines are the individual responses. **** $P < 0.0001$; *ns* not significant ($P > 0.05$).

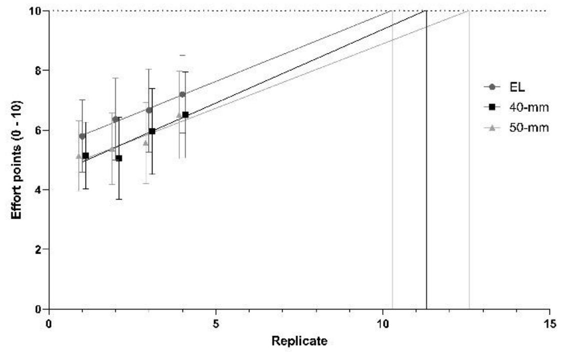

Figure 2: Simple linear regression of perceived effort (VAS) and extrapolation until maximal exertion is reached (VAS score of 10). *40-mm,* Cloud Boom Echo 3.0 with 40 mm midsole thickness; *50-mm,* Cloud Boom Echo 3.0 with 50 mm midsole thickness; *EL* Entry-level Cloud runner with 30 mm midsole thickness.

DISCUSSION: This study aimed to explore the influence of midsole thickness on cardiorespiratory responses, perception of comfort and effort, as well as on spatiotemporal variables during twelve 1.2 km runs on an outdoor 400 m track. Our main finding was that while modern running shoes improved running economy compared with entry-level running shoes, no clear further improvements were noticed by increasing midsole thickness beyond current regulations. Nonetheless, increasing midsole thickness appears to yield some marginal differences in O_2 uptake and perceived effort over longer time periods, which might have implications for performance. Runners experienced an average reduction of $\dot{V}O_2$ of 4.0% and 4.6% when wearing the 40-mm and 50-mm shoes, respectively, compared with the EL shoes, consistent with previous research on the impact of modern running shoes on $\dot{V}O_2$ (Hoogkamer et al., 2018). Although each single 50-mm shoe weighs 45 grams more than each 40-mm shoe, no difference between the two shoes could be detected. While this is in contrast to the expected deterioration of running economy stemming from the additional mass (Franz et al., 2012), in this case the additional mass comes in the form of an added layer of a highly responsive foam (polyether block amide, also known as PEBA), which is proven to be beneficial for running performance (Rodrigo-Carranza et al., 2023). Indeed, bench testing prior to and after the trials in this study showed that the forefoot of the 50-mm shoes have similar resilience compared with the 40-mm shoes (85.2% vs 85.5%) but show approximately 50% higher compliance.
Our data further suggests distinct $\dot{V}O_2$ responses over time between the 40-mm and 50-mm shoes, with the latter showing a downward pattern as exercise continues. Although significant attention is being paid in the literature to how modern midsoles influence running economy, few studies have taken into account how familiarisation with the footwear could be a factor that influences running economy. While it has been suggested that shoe familiarisation may not be necessary to obtain accurate readings of running economy (Nielsen et al., 2022), the present results indicate that there may indeed be a familiarisation or learning effect when running in shoes with a midsole thickness greater than 40 mm. Therefore, it appears that the number of replicates used in many studies published to date – typically two or three – might be insufficient to reveal a potential learning effect when runners are exposed to unfamiliar footwear. As no significant mean differences were observed in ground contact time, step frequency and step length between the different shoe conditions, our data lends further support to the notion that changes in $\dot{V}O_2$ are not closely related to spatiotemporal variables (Ferris et al., 1999). The possibility remains, however, that different shoe conditions might lead to similar gait patterns via different neurological pathways or muscle activation patterns, which in turn would help explaining the differences in $\dot{V}O_2$.
Surprisingly, both modern running shoes had similar $\dot{V}O_2$ in spite of large (1.5 ± 1.6 units) difference in perceived comfort. Research has shown that more comfortable shoes can reduce running economy by ~0.7% given a similar change in comfort (1.2 units on a 10-point range) (Luo et al., 2009). As the topic is largely unexplored, it remains unknown whether our data is in direct opposition to these or whether the differences in mechanical properties between the 40-mm and 50-mm shoes offset any losses in running economy triggered by the lower comfort in the 50-mm. Finally, the lack of correlation between absolute change in $\dot{V}O_2$ and perceived

comfort raises the question of the extent to which the personal experience of comfort is adequate to detect or explain differences in running economy.
Beyond affecting O_2 uptake per se, one's level of comfort might influence the willingness to perform and the amount of exertion dedicated to physical activity (Marcora et al., 2010). Interestingly, when effort levels were extrapolated towards maximal effort based on the theory that effort increases linearly over time (Marcora et al., 2010), we found that running with the 50-mm shoes would be predicted to last for longer than both with the 40-mm and EL shoes, even if comfort was lower for the 50-mm compared with the 40-mm shoes. Therefore, it might be that the added layer of foam not only provided superior mechanical properties, but also triggered desirable sensations that fell outside the scope of comfort. This raises questions about the practical implications of such a shoe in training sessions or during competitions. In training, when a session is prescribed and the efforts should be run at maximum exertion level, a runner wearing the 50-mm shoes could run longer, therefore increasing the total load on the body, which in turn could influence recovery, adaptation and even injury risk. During competition, given the lack of correlation between changes in $\dot{V}O_2$ and effort, athletes would be hard pressed to choose between a shoe that minimizes one or the other, as it is not immediately clear which of the two would be best indicators of improved endurance performance.

CONCLUSION: Running with shoes above the current guidelines imposed by World Athletics do not seem to result further improvements in O_2 uptake compared to what modern running shoes within regulations already offer, although longer trials are needed for drawing definitive answers. Furthermore, the current limitation in midsole thickness limit innovation specifically in competition footwear development, which could have negative consequences in the field as higher midsole thickness could play a role in allowing athletes to change training loads and possibly also modulate injury risk. However, designing a shoe with a thickness exceeding 40 mm may be beneficial for training purposes.

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