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Comparison of balance strategies in mountain climbers during real altitude exposure between 1.500m and 3.200m: effects of age and expertise.

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Introduction

Mountain sports result in a significant number of injuries [1]. The causes of injury can be categorized as intrinsic, such as fatigue, personal history and movement strategies; and extrinsic, such as high altitude, climate, backpack load and ground conditions. The frequency of injuries reported for mountaineers is 4.2/1000 hours of practice [2], with 48% of injuries caused by falls [3]. In many cases, falls occur as a result of posturo-dynamic instability, such that normal stability mechanisms are no longer sufficient to control body position [4].

Mountaineers are submitted to the same risk factors than other sporting individuals, with the addition of having to deal with large changes in terrain (ice, rocks, snow, ...) and exposure to altitude [1,5]. These factors must be considered when analysing posturo-dynamic strategies in climbers. Results of previous studies of the influence of hypoxia on postural control in both simulated altitude conditions [5-9] and real conditions [10,11] suggest hypoxia is a cause of postural instability. Instability occurs from an altitude of 1700m [11,12] after only a few minutes of altitude exposure [7].

Mountaineers in the Alps who have brief exposure times, difficult terrain to negotiate and use predominantly the visual system for equilibrium [12] seem particularly exposed to risks related to postural instability and consequently falls. However, the first studies in this domain were carried out in restricted groups of subjects and mostly under laboratory conditions. Furthermore, no study seems to have analyzed the impact of altitude exposure on postural strategies as a function of the age and expertise of climbers, despite the fact that it has been shown for other types of physical activity that both these factors influence postural stability [13]. Equally, shoe-wearing seems to be a determining factor in balance regulation, thus tests carried out with mountain shoes on are necessary to evaluate close-to-reality conditions [14]. A greater understanding of the impact of altitude on postural control in conditions close to reality (real altitude and mountain shoes on) would help to determine strategies to reduce the risk of injury.

The aim of this study was to compare, in real altitude conditions, balance strategies between 1500m and 3200m (on arrival in the cable car and following the ascent and return) as well as to estimate the influence of age and expertise on postural stability. Our hypothesis was that the rapid arrival in altitude would provoke disturbances in postural control and reveal the effect of age and expertise on these disturbances.

Material and methods

This study was conducted as part of "Grave Y Cimes" (La Grave village, France). This is an event organized by the FFME (French federation for mountain and climbing sports) to allow members to review safety in real conditions and test different types of alpine activities. Participants in this event were informed of the research project as well as test procedures. Eighty-nine volunteer mountain climbers were tested at 1500m ("low altitude - LA" - the village altitude they had reach by car), at 3200m immediately after descending from the cable car ("3200IM") and at 3200m at the end of the day following ascent and return ("3200ED"). All participants stayed on average for 6 hours above 3200m. All participants signed a consent agreement stating that at any moment they could leave the study.

All participants completed an initial questionnaire to obtain information regarding age, occupation, type of mountain sports practiced, number of mountain trips per year and medical history. This questionnaire made it possible to extract exclusion criteria (ie. medical history) and the data necessary to constitute the groups. Participants were categorized into two subgroups based on age and expertise: <40 years and >40 years (changes in balance capacity are known to occur from the age of 40 years [15]) and <20 days climbing/year and >20 days climbing/year).

Foot laterality was determined by applying a push from behind, which triggered a forward stepping movement with the dominant limb [16]. Ninety-three percent of subjects had right foot dominance.

Two balance conditions were tested for each altitude condition: 1) double-leg stance with eyes closed and 2) single leg stance with eyes open (dominant and non-dominant sides) [17]. In order to represent real conditions all tests were performed with mountain shoes on. Participants were asked to maintain the position for 12.8 seconds and every condition was tested twice [18]. A stabilometric force platform (Feetest6©, Technoconcept©) that measures the center of pressure (CoP) and limb loading at a frequency of 40Hz was used. Parameters were extracted separately for the left and right feet. For double-leg stance, participants were positioned on two force platforms 4cm apart. For single-leg stance, the participants stood on one foot with the knee unlocked. The knee of the "swing" foot was flexed and touched the supporting limb. For all tests, the upper limbs were crossed with hands on shoulders. Between each test, participants withdrew from the platforms and made a few steps before returning to the platforms.

Dependent variables associated with the CoP were measured as follows [18,19,20]: length of displacement (mm), surface of displacement (mm^2), length/surface ratio, speed (mm/s), and percentage of non-dominant/dominant limb loading (% body mass). CoP surface (corresponding to 90% of instantaneous CoP positions during balance) and length (total CoP displacement) are two direct measures of stability. The CoP ratio (length/surface) provides an indication of swaying strategy for balance control. When this ratio is greater than 1, it means that the CoP has covered a greater distance than the norm, implying greater energy expenditure to control swaying [19]. When the value is below 1, the subject is using an energy saving strategy. The CoP speed is calculated by dividing the total distance covered by the CoP by the duration of the sample period [19]. Limb loading (percentage) is the vertical force value (N) divided by the body mass (kg) multiplied by 100. All these balance parameters have been shown to have good intra- and inter-session reliability (ICC>0.76) [21].

Statistical analysis was performed using Statistica software (v.6, StatsoftTM). Means and standard deviations (SD) are reported for continuous variables. The normality of data dispersion was verified using a Shapiro–Wilk test for each parameter. Differences between altitude conditions were examined with repeated measures Anova and differences between groups were examined using two-way ANOVA. Interactions were analyzed a posteriori by performing a Newman–Keuls test to check the occurrence of specific effects. A threshold value of $p<0.05$ was adopted to rule out the non-significant difference.

Results

The mean age of participants was 40.06±14 years. The cohort was made up of 68% men and 32% women. The number of climbs per year was less than 10 for 14.17% of participants, 10-20 for 24.24%, 20-40 for 35.45% and > 40 climbs for 25.98%. Although the total number of climbs was similar between men and women, 33% of men carried out > 40 climbs/year compared with 19% of women.

Comparison of the three altitude conditions

There were no significant (NS) differences in CoP surface or length between LA, 3200IM and 3200ED (table 1).

Table 1.

The CoP ratio was significantly higher for 3200IM and 3200ED compared to LA for all balance tests (Figure 1). For double-leg stance, the ratio was significantly higher for 3200IM and 3200ED than LA (1.45±0.82 vs 3200IM: 1.83±1.15 vs. 3200ED: 2.21±1.55, $p<0.0364$). For single-leg stance, the ratio was significantly higher for both limbs for 3200IM and 3200ED than LA (non-dominant limb: 1.06±0.35 vs. 3200IM: 1.17±0.42 vs. 3200ED: 1.21±0.42, $p<0.05$, dominant limb: LA: 1.09±0.38 vs. 3200IM: 1.34±0.93 vs. 3200ED: 1.41±0.44, $p<0.006$). The only difference between 3200IM and 3200ED was for double leg stance ($p=0.0213$), although the ratio increased for all balance tests at 3200ED.

Figure 1.

There were NS differences in CoP speed between three altitude conditions for any of the balance tests.

There was NS difference in the percentage limb loading between the dominant and non-dominant sides at 1500m (dominant limb: 50.15±4.05%, non-dominant limb: 49.85±4.05%). At 3200IM, there was a significant difference between limbs (dominant limb: 48.98±3.28%, non-dominant limb: 51.02±3.28%, $p=0.043$). The result was similar for 3200ED (dominant limb: 48.05±4.25%, non-dominant limb: 51.95±4.25%, $p=0.0007$, *figure 2*).

Figure 2.

Influence of age on balance strategies in each altitude condition

The comparison between the two age groups showed NS difference at 1500m for CoP surface or length or for double-leg stance at 3200m (Table 1). However, for the non-dominant and dominant single leg tests, CoP surface ($p<0.0068$) and length ($p<0.0191$) were significantly greater at 3200IM for the > 40 years group compared to the < 40 years group. Significant differences were also found for 3200ED (CoP surface: $p<0.0163$, CoP length: $p<0.0166$, Table 1).

There were NS differences between the two age groups for CoP ratio and CoP speed parameters at any altitude.

Influence of expertise on balance strategies in each altitude condition

There were NS differences between groups for CoP surface or length at 1500m and 3200ED for any balance test. However, during double-leg stance at 3200IM, CoP surface was significantly greater for participants who made less than 20 climbs/year (p=0.00801), as was CoP length (p=0.0108), compared to participants who climbed more than 20 times / year. For non-dominant and dominant single-leg stance the only difference between groups was for CoP length, which was significantly greater in subjects who climbed less often (non-dominant side: p=0.0496 vs. dominant side: p=0.0454, *figure 3*).

Figure 3.

There were NS differences between groups for the CoP ratio or speed in any of the altitude conditions.

Discussion

The results of this study showed that altitude affected CoP ratio during double-leg stance with eyes closed and single-leg stance with eyes open. At 3200m, there was asymmetry of limb loading, that was accentuated after several hours of climbing. By contrast, there were no changes in CoP surface, length or speed. There was no effect of age or expertise at 1500m however at 3200m, greater age and lower expertise reduced postural stability immediately after exiting the cable car at 3200IM condition.

Previous studies have highlighted that postural instability appears to be primarily related to hypoxia and not to acute mountain sickness [4,6,10]. The alterations in stability on arrival at 3200m strengthen this hypothesis. Acute mountain sickness consists of nonspecific symptoms (nausea, dizziness, fatigue, loss of appetite,...) at altitudes above 2500m, normally occurring after 4-12h [22]. Stadelmann et al. [11] found a relationship between decreased oxygen saturation at 490m (97%), 1630m (95%) and 2590m (92%), and balance disturbances. Hypoxia affects the function of the somatosensory, visual and vestibular systems. The quality of information is altered first, then its integration [5]. Hypoxia inhibits certain reflexes [23,24] and is believed to increase the excitability of spinal α-mononeurons [5]. Immediate altitude exposure disturbs both day and night vision [25]. Thus in conditions of hypoxia, mountaineers must regulate postural stability in a highly modified context. Hypoxia seems to be greater immediately after the arrival from the altitude [11]. The hypothesis that hypoxia affects balance is strengthened by the fact that previous studies of arterial occlusion ("hypoxic anesthesia"), have shown that balance capacity is reduced during the hypoxia [26], which could explain why the parameters evaluated in our study were the most disturbed in the 3200IM condition.

In contrast with previous studies [7,12] that highlighted the influence of altitude on CoP parameters, there were few changes in CoP surface and length in the present study. These results are in agreement with Stadelmann et al. [11] at 2590m, compared to 1630m, for double-leg stance with eyes closed. Differences between the overall results of the present study and those of previous studies may relate to the participants. The originality of this work was the focus on mountaineers: other studies included healthy normal subjects with no mountain experience [11,12]. No studies have compared balance control between mountaineers and healthy subjects, although some have evaluated slacklining in the mountains that requires skilled balance [27]. Hoshikawa et al. [4] found also no significant increase in CoP length at a simulated altitude of 5000m in climbers. Although there were no differences in CoP surface and length between the 3 real altitude conditions, these parameters were the most relevant to reveal the influence of age and expertise at 3200m.

CoP ratio and limb loading were the most affected by altitude. CoP ratio increased at 3200m, with a trend to an increase in length and a decrease in surface. Thus, energy expenditure to control postural sway increased [19,20]. This might be associated with an increase in tonic activity of the soleus and gastrocnemius muscles previously observed at 5000m in unacclimated climbers [4]. It is therefore likely that the act of controlling balance causes premature fatigue particularly if the climber lacks expertise or is older. There was also an increase in asymmetry in double-leg stance at 3200m.

Increased asymmetry of limb loading has been associated with postural instability [28,29]. This reduces the efficiency of hip loading/unloading mechanisms during walking and increases compensatory ankle moments [28].

Similarly, to the findings of Degache et al. [12] at a simulated altitude of 3000m, the present study highlighted that the speed parameter was unaffected by the 3200m altitude compared to LA. This was also found in double-leg stance with eyes closed [7]. CoP speed constitutes a good index of the amount of activity required to maintain stability [19]. However, this parameter reflects the time needed to control the acceleration of the center of mass, and includes only CoP length, while the ratio also includes the surface area. Hence, its seems that 3200m altitude condition affects the surface parameter more than the CoP length parameter.

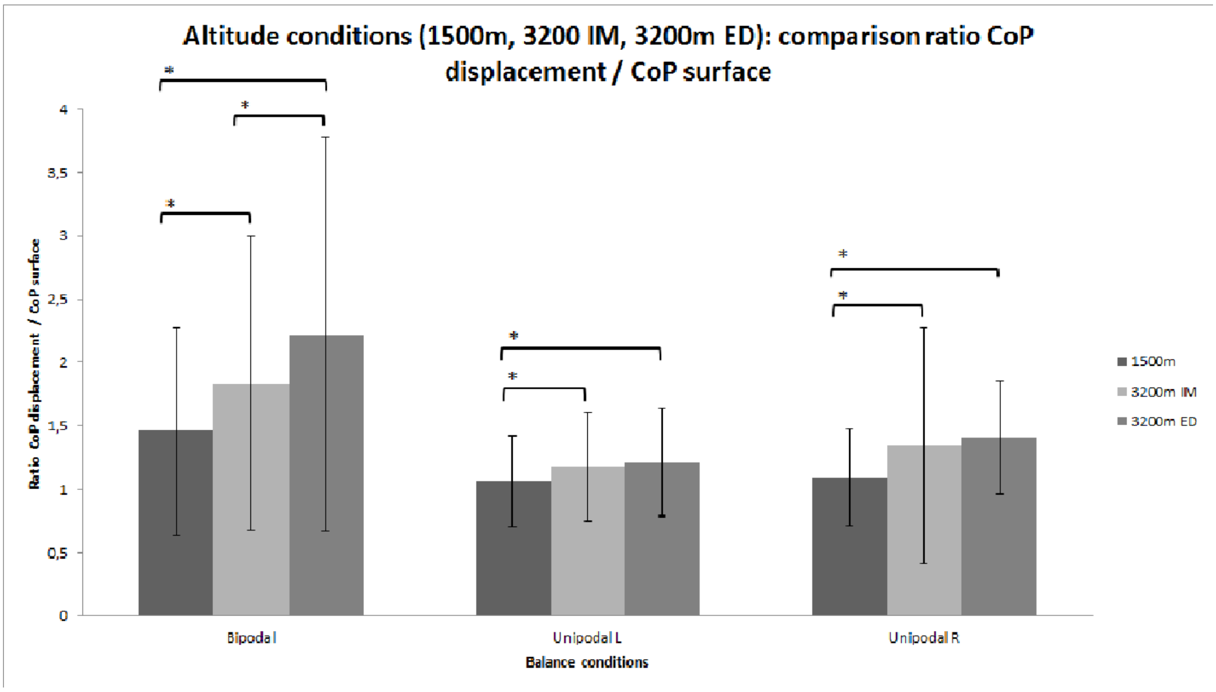
Disturbances in postural control occurred immediately on exposure to altitude, but were also present at the same altitude following return from the climb. The duration of the exposure seems crucial. Postural stability does not improve after 24h exposure at 4300m [6] or even 3 days at 4559m [10]. However, following 84 days at 5000m postural parameters improve [4]. Therefore, it is important to distinguish between mountaineering during an expedition of several weeks and shorter exposures, as is often the case in the Alps. We hypothesised that fatigue added to altitude following the climb would increase postural instability. However, other than for double leg stance, this was not the case. Therefore, instability-related risks are present from the onset of the activity, particularly if the climber is older and not expert. Greatest instability was found in the 3200IM condition in subjects of more than 40 years who made less than 20 climbs/year. In addition, non-experts particularly rely on vision for postural control [30], and the results showed postural instability was greater with eyes opened than eyes closed. This suggests a preferential effect of hypoxia on the visual system, as suggested in previous studies [7,12,25].

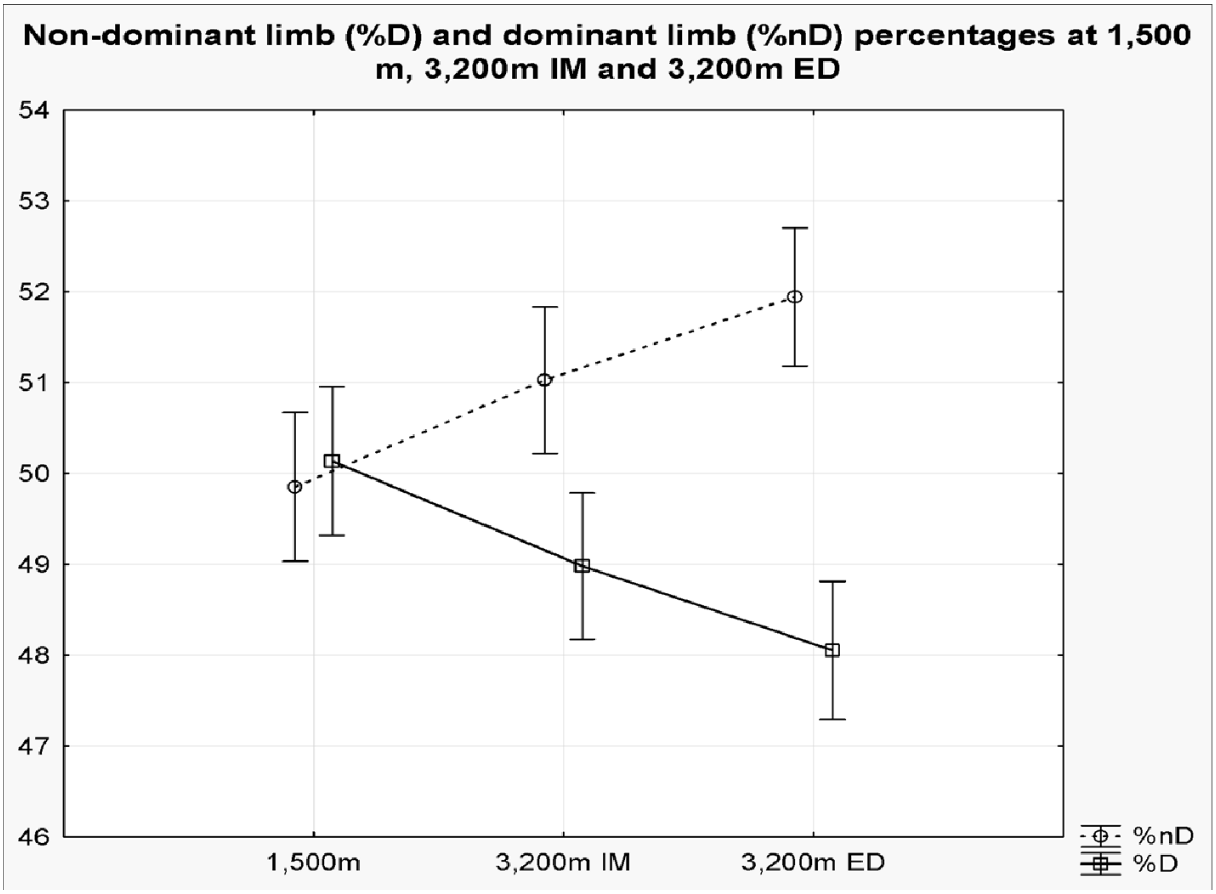
This study has some limitations. There were differences between parameters for each altitude condition, but also large standard deviations. In order to have sufficiently large groups to test the influence of age and expertise, the inclusion criteria were not restrictive. Eighty-nine participants were included, which is more than in previous studies [4,7,11,12]. To improve the quality of the evaluation, we chose the double-limb stance test with eyes closed. Test-retest reliability is higher (ICC>0.69) than with eyes open (ICC>0.48) [31]. The minimal detectable change for CoP surface is 55.99mm^2, it is 64.42mm for CoP displacement and 0.71mm/s for speed parameter [31,32,33]. Differences in these parameters were smaller than the respective thresholds and also than the results between 400m and 3000m [12]. However, values for the comparisons of the age and expertise groups were higher. Thus, despite large standard deviations, the significant differences were similar to the minimal detectable change and the results of previous studies. The balance tests were measured over 12.8s while 30s is often recommended [19]. We chose this duration because the altitude induces technical constraints and previous studies have already proposed 12.8s [18,34].

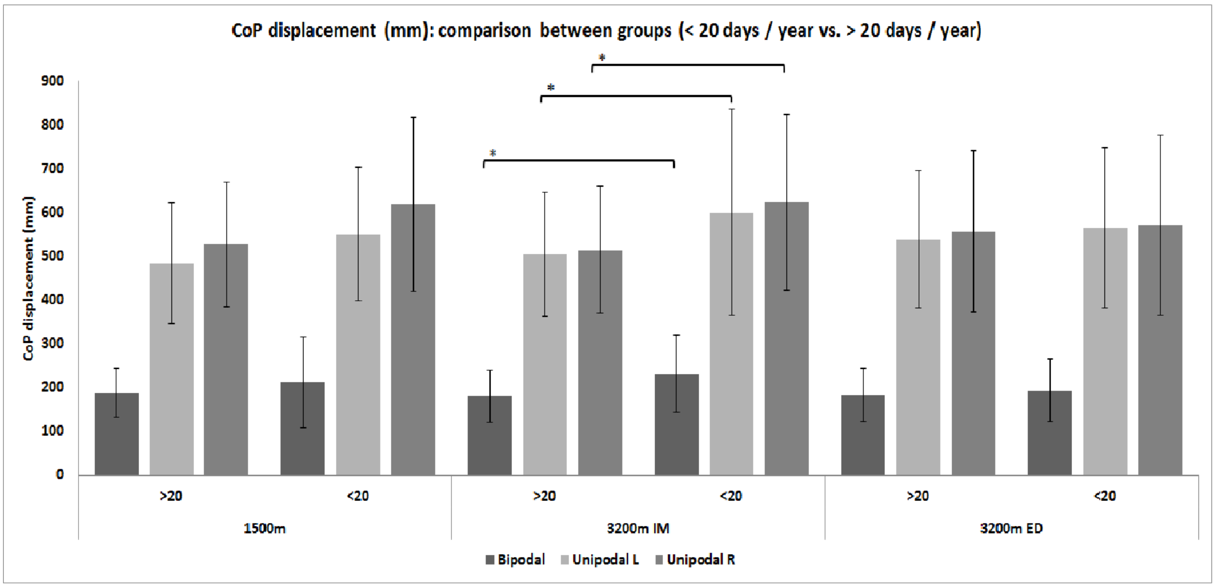
Regarding injury prevention, the results highlight the importance of considering climbers according to their expertise and age. Preventative measures should be put in place before the climbing season. Based on our results and the fact that postural control normalises on return to LA [7], it would be appropriate to carry out exercises to improve postural control at high altitude. Previous studies have shown the importance of carrying out balance tests with shoes on to mimic real conditions as much as possible [14]. Future studies should investigate hypoxia and fatigue to better understand balance strategies and develop effective prevention programs. Moreover, it would be interesting to compare immediate exposure to gradual exposure to identify the characteristics of two common conditions experienced by climbers: arrival by cable car versus arrival by foot.

Conclusion

This original study evaluated the effect of exposure to altitude on balance strategies. Results showed that there were alterations in postural control, particularly at 3200m. In addition, older and less experienced mountaineers were significantly less stable. Instability-related risks are present from arrival at altitude. The results suggest it may be pertinent to develop specific balance exercises to prevent fall-related injuries, particularly for non-expert and older mountaineers.







Figures legends:

Figure 1. *Comparison between 3 altitude conditions (LA vs. 3200IM vs. 3200 ED) for the CoP ratio in two balance conditions. A significant difference (p<0.05) is marked by the sign "*".*

Figure 2. *Asymmetry between limb loading for 3 altitude conditions (LA vs. 3200IM vs. 3200ED).*

Figure 3. *CoP lenght parameter (mm): comparison between groups (>20 days/year vs. <20 days/year) for balance conditions and altitude conditions (LA, 3200IM and 3200ED). A significant difference (p<0.05) is marked by the sign "*".*

Table 1. CoP surface and CoP displacement values for all subjects, *>40 years and <40 years groups for bipodal and unipodal conditions. A p value superior than p=0.05, is indicated with "NS". CoP: center of pressure; 1500m: LA; 3200IM: high altitude immediately after getting down the cable; 3200ED: high altitude at the end of the day.*

		Bipodal stance		**Unipodal non-dominant side**		**Unipodal dominant side**	
		CoP surface (mm2)	*CoP displacement (mm)*	*CoP surface (mm2)*	*CoP displacement (mm)*	*CoP surface (mm2)*	*CoP displacement (mm)*
1500m	**All**	**203.24±70.22**	**199.19±78.97**	**550.79±274.11**	**513.04±145.83**	**587.18±276.37**	**566.63±172.12**
	>40 years	222.65±82.94	209.86±90.17	579.74±283.37	526.77±158.84	635.57±307.41	595.81±187.23
	<40 years	178.35±53.55	185.52±61.47	513.68±264.43	495.44±129.26	525.15±223.61	529.23±147.07
	P value	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
3200m IM	**All**	**158.94±99.97**	**193.59±72.10**	**527.05±310.91**	**539±184.24**	**496.79±292.33**	**559.46±172.58**
	>40 years	199.55±112.11	206.21±79.31	663.28±374.80	614.97±208.21	597.27±369.29	621.05±194.24
	<40 years	120.76±86.57	181.49±63.19	411.45±172.29	467.80±124.04	409.68±155.58	505.63±131.60
	P value	***NS***	***NS***	***0.00073***	***0.00016***	***0.0068***	***0.0191***
3200m ED	**All**	**133.50±69.29**	**187.78±64.95**	**543.40±339.25**	**548.37±167.36**	**471.98±292.22**	**562.01±192.46**
	>40 years	147.39±79.74	189.61±68.71	648.78±398.04	594.40±186.92	557.07±327.73	615.25±209.82
	<40 years	119.33±58.83	185.88±60.81	435.90±219.06	501.41±128.73	385.17±219.11	507.70±155.18
	P value	***NS***	***NS***	***0.00345***	***0.01472***	***0.0163***	***0.0166***

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