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Abstract

The aims of this study were (*i*) to investigate the participation and performance trends at the Biel 100-km ultra-marathon in Switzerland from 1998 to 2010, and (*ii*) to compare the age-related changes in 100-km running performance between males and females. For both sexes, the percentage of finishers significantly ($P < 0.01$) decreased for 18-29 years and 30-39 years age groups, while it significantly ($P < 0.01$) increased for 40-49 years and 50-59 years age groups over the studied period. From 1998 to 2010, the mean age of the top 10 finishers increased by 0.4 years *per annum* for both females ($P = 0.02$) and males ($P = 0.003$). The running time for the top 10 finishers remained stable for females while it significantly ($P = 0.001$) increased by 2.4 min *per annum* for males. There was a significant ($P < 0.001$) age effect on running times for both sexes. The best 100-km running performance was observed for the age comprised between 30 and 49 years for males, and between 30 and 54 years for females, respectively. The age-related decline in running performance was similar until 60-64 years between males and females, but was greater for females compared to males after 65 years. Future studies should investigate the lifespan from 65 to 75 years to better understand the performance difference between male and female master ultra-marathoners.

Key words: ultra-endurance – long distance running – gender difference – aging – master athlete

Introduction

In recent years there has been an increased interest in investigating the effects of aging on endurance performance in runners (Jokl et al. 2004; Leyk et al. 2007; Leyk et al. 2009; Lepers and Cattagni 2011; Tanaka and Seals 2003; Tanaka and Seals 2008; Wright and Perricelli 2008). Over the last decade the participation of master athletes (> 40 years old) in these events has increased, especially in the longer running distances such as half-marathons (Leyk et al. 2007; Leyk et al. 2009), marathons (Burfoot 2007; Jokl et al. 2004; Lepers and Cattagni 2011; Leyk et al. 2007; Leyk et al. 2009), and ultra-marathons (Hoffman 2010; Hoffman and Wegelin 2009; Hoffman et al. 2010). A recent analysis of the participation trend at the 'New York City Marathon' from 1980 to 2009 showed that over the three decades, the percent of finishers at the 'New York City Marathon' younger than 40 years decreased, while the percent of master finishers increased for both males and females (Lepers and Cattagni 2011). Over the three decades 1980-1989, 1990-1999, and 2000-2009, male master athletes represented 36%, 45%, and 53% of total male finishers, respectively, while female master athletes represented 24%, 34%, and 40% of total female finishers, respectively.

Generally, the peak endurance performance is maintained until the age of 30 to 35 years, followed by a moderate decrease until the age of 50 to 60 years, and then a progressively steeper decline after the age of 70 to 75 years, independent of the distance and the sport's discipline (Baker et al. 2003; Balmer et al. 2008; Donato et al. 2003; Fleg and Lakatta 1988; Fuchi et al. 1989; Hunter et al. 2011; Leyk et al. 2007; Leyk et al. 2009; Tanaka and Seals 2003; Tanaka and Seals 2008; Wright and Perricelli 2008). Even if it is possible for a 70-year-old male athlete to finish a marathon in less than three hours (Trappe 2007), the gradient in declining performances increased notably after the age of 55 years for both sexes, and female performances tended to decline faster than those of males, especially in running (Ransdell et al. 2009).

Most studies examining endurance running performances in master athletes have focused on marathoners (Burfoot 2007; Jokl et al. 2004; Leyk et al. 2007; Leyk et al. 2009; Trappe 2007). Marathon running performance for males and females is generally fastest, as indicated by world record performances, when individuals are 25 to 35 years old. A significant age-related decrease in marathon performance begins at the age of 35 years (Leyk et al. 2007; Wright and Perricelli 2008). The time taken to complete a marathon gradually increases with age, with a substantial decrease in performance after the age of 70 years (Trappe 2007). In recreational marathoners there was no relevant time difference, in running, between the ages of 20 and 55 years, however, after the age of 55 years mean running times significantly increased (Leyk et al. 2009). The mean marathon performance of the age groups 35 to 44 years and 45 to 54 years tends to be better than the corresponding performance in the age groups 25 to 34 years (Leyk et al. 2007). Regarding the marathon running performance for master runners older than 50 years, an improvement in performance has even been observed in recent years. It has also been suggested that master runners of 50 years and older improved their performance at a significantly greater rate than younger runners (Jokl et al. 2004). An analysis of the performance trend at the 'New York City Marathon' from 1989 to 2009, showed that during that period, the running times of master runners significantly decreased for males older than 64 years and for females older than 44 years, respectively (Lepers and Cattagni 2011).

To date, the age-related decline in running performance has been investigated in half-marathoners (Leyk et al. 2007; Leyk et al. 2009), marathoners (Jokl et al. 2004; Lepers and

Cattagni 2011; Leyk et al. 2007; Leyk et al. 2009; Trappe 2007) and 161-km ultra-marathoners (Hoffman 2010; Hoffman and Wegelin 2009; Hoffman et al. 2010). However, no study has analyzed the age-related changes in 100-km road-running performance. Also, nowadays, elderly runners in ultra-marathons are able to finish within the time limit. Recently, it has been reported that an 81-year-old athlete was able to finish a 100-km ultra-marathon within 19h 44min (Knechtle et al. 2009). A 100-km ultra-marathon takes about three time longer than a 42 km conventional marathon for the best runners (World male record 6h 13min for 100 km *versus* 2h 04min for 42 km). The energetic demands and mechanical stresses are much greater during a 100-km ultra-marathon compared with a conventional 42 km run. For example, it has been demonstrated that long-distance running such as completing an ultra-marathon induced more impact-stress on the skeletal muscle than a marathon (Kim et al. 2009). Therefore, it may be interesting to analyse the age and gender interactions in 100-km road-running performance.

The aims of the present study were (*i*) to investigate the participation and performance trends in 100-km ultra-marathon from 1998 to 2010 and (*ii*) to compare the male versus female age-related change in 100-km running performance. Respecting existing literature regarding half-marathon, marathon and 161-km ultra-marathon, we hypothesized (*i*) an increase in participation and an improvement of performance for both male and female master athletes and (*ii*) a more pronounced age-related decline in the 100-km running performance for female compared with male runners.

Methods

This study was approved by the Institutional Review Board of St. Gallen, Switzerland, with a waiver for the requirement of an informed consent, given that the study involved the analysis of publicly available data. For each race the age of the athletes and the run performance times of both the male and female finishers at the Biel 100-km ultra-marathon (Switzerland) were analysed from 1998 to 2010. The data set from this study was obtained from the race website (www.100km.ch) and from the Race Director. No race results were available before 1998 as this was the year when electronic registration of race results started and paper results were not available from the races held before this date. The Biel 100-km ultra-marathon generally takes place on the first weekend in June. The runners start the race at 10:00 p.m. The Biel 100-km ultra-marathon involves a total altitude change of 645 m. Two thirds of the course is on asphalt, and one third is on unpaved roads. Throughout the 100 km there are 17 aid stations at intervals of ~5 to ~10 km supplying a variety of food and beverages. The organiser offers hypotonic sport drinks, tea, soup, caffeinated drinks, water, bananas, oranges, energy bars, cakes and bread. The athletes are allowed to be supported by a cyclist in order to have additional food and clothing, if necessary.

Data analysis

The age and the race time (converted to minutes) of all finishers were analysed from 1998 to 2010 for both male and female runners.

Age and performance of the winners and the top 10 overall

Firstly, the age and the race time of both male and female winners were analyzed during the 13-years period. Secondly, the age and race time data was averaged across the first ten male and female finishers for each of these years. The magnitudes of the gender difference were examined by calculating the percent difference for the race times of the male *versus* female winners and of the top ten male *versus* female finishers.

Age-related changes in performance

In order to analyse the age-related change in running performances, we pooled data from 1998 to 2010 and distinguished the age groups as follows: 18-24 years, 25-29 years, 30-34 years, 35-39 years, 40-44 years, 45-49 years, 50-54 years, 55-59 years, 60-64 years, 65-69 years, 70-74 years and 75 years and older. Because of the the small participation of athletes older than 65 years, especially for females, we therefore considered only the performances of the best 20 male and female runners per age group during the 13-years period. In addition, the 100-km running time performance of each runner finishing in the top 20 of each age group was normalized to the mean time performance of the top 20 of the best performing age group for both males and females. Thus, the age-related declines in performance were expressed using a ratio calculated between the individual and the mean time performances of the best performing age group.

Statistical analysis

Data is reported as means ± SD in the text. Linear regressions were used for estimating the changes of the selected variables in each year of the race. Pearson's correlation coefficients were used to assess the association between various variables (Statsoft, Version 6.1, Statistica, Tulsa, OK, USA). The ages of the female versus male winners were compared with an unpaired student's *t*-test. To determine if the age of the top ten male and female finishers differed over the years, a separate ANOVA with repeated measures for each year, with gender as the between-subject factor, was performed. One-way ANOVA was used to compare the race times between the different age groups for both male and female runners. A two way ANOVA (age x sex) was used to compare performance ratios between males versus females across age. Tukey's post hoc analyses were used to test differences within the ANOVA when appropriate. Statistical significance was accepted at $P < 0.05$.

Results

Participation trends

From 1998 to 2010, there was a total of 19,650 finishers (2,615 females and 17,035 males) at the Biel 100-km ultra-marathon. The number of finishers each year over the history of the event is shown in **Figure 1**. In these years, the average number of finishers per year was 1,312 ± 237 [range: 1,060-1,999] for male runners and 200 ± 47 [range: 167-349] for females. Females accounted on average for 13.3 ± 1.4% of the field over the 13-years period. The greatest participation, in 2008, corresponded with the 50th anniversary of the race.

Age of the 100-km ultra-marathoners

The mean age of the finishers during this period was 46.5 ± 10.8 years for males, and 46.8 ± 10.9 years for females. The age distribution of both male and female finishers during the 13-year period is shown in **Figure 2**. The 10 year age bracket with the largest participation was 40 to 49 for both sexes. Master runners older than 40 years represented ~73% of the total finishers. The change in the percentage of finishers per age group from 1998 to 2010 for both males and females are presented in **Figure 3**. Over this 13-year period, the percentage of finishers decreased for the age groups 18 to 29 years and 30 to 39 years, while it increased for the age groups 40 to 49 years and 50 to 59 years for both males and females. The percentage of finishers slightly increased for males in the age group 60 to 69 years and remained stable for females in the age group 60 to 69 years.

Winner and top 10 overall age trends

Figure 4 shows the historical age trends of the female and male winners (**Panel A**) and top ten male and female top ten overall finishers (**Panel B**) between 1998 and 2010. The female winners were significantly (P < 0.01) younger than the male winners with 33.2 ± 6.4 years *versus* 38.2 ± 4.5 years, respectively. In contrast, ANOVA revealed no difference in the mean age of the top ten males and females over the years (P = 0.19). The mean age of the top ten female and male runners was 39.4 ± 2.3 years and 40.4 ± 1.9 years, respectively. During the period studied, both female and male winners' age remained stable across the years. In contrast, the mean age of the top ten overall increased significantly by 0.36 year *per annum* for female and by 0.37 year *per annum* for male, respectively.

Winner and top ten overall performance trends

Figure 5 shows the historical performance trends of the female and male winners (**Panel A**) and top ten female and male overall (**Panel B**) during the 13-years period. The mean winner's running time was 430 ± 15 min [range: 409-451 min] for males and 502 ± 20 min [range: 471-523 min] for females. During this period, both female and male winner performances remained stable across the years. The average time difference between the male and female winners was equal to 17 ± 6 % [range: 6-28%]. The mean top ten running time was 459 ± 11 min [range: 438-474 min] for males and 558 ± 9 min [range: 554-578 min] for females. During this period, the top ten running time remained stable for females while it significantly increased by 2.4 min *per annum* for males.The average time difference between the top ten males and females was equal to 22 ± 3 % [range: 18-27%].

Age-related changes in performance

The mean age-related changes in both male and female race times throughout 1998-2010 are shown in **Figure 6**. The race time increased in a curvilinear manner with advancing age. There was a significant (P < 0.0001) age effect for both male and female race times. No significant difference in time was observed for the four age groups between 30 to 34 years and 45 to 49 years for males, and for the five age groups between 30 to 34 years and 50 to 54 years for females. In males, the race time was significantly ($P < 0.01$) longer for the age groups 50 to 54 years and older, 18 to 24 years and 25 to 29 years compared with the age groups between 30 to 34 years and 45 to 49 years. For females, the running times were significantly ($P < 0.01$) longer for the age groups 55 to 59 years and older, 18 to 24 years and 25 to 29 years compared with the age groups between 30 to 34 years and 50 to 54 years.

For both males and females, the performance ratios for the 100-km running decreased in a curvilinear manner with advancing age (see **Figure 7**). There was a significant interaction between age and sex for performance ratio ($F = 18.2$, $P < 0.01$). For the males, the performance ratio for age groups 45 to 49 years and above was significantly different from the best age group (i.e. 35 to 39 years). For the females, the performance ratio for age groups 50 to 54 years and above was significantly different from the best age group (i.e. 35 to 39 years). The performance ratio was significantly different ($P < 0.01$) between males and females for the age groups 18 to 24 years, 65 to 69 years, and 70 to 74 years.

Discussion

The first aim of the study was to investigate the participation and performance trends at the Biel 100-km ultra-marathon from 1998 to 2010. Regarding the participation trend over the studied period, the percentage of both male and female finishers decreased for the age groups comprised between 18 and 39 years, while it increased for the age groups comprised between 40 and 59 years. For the age group 60-69 years, the percentage of finishers slightly increased for male while it remained stable for female.

The age group with the largest participation in these 100-km ultra-marathoners was 40-49 years for both males (~36%) and females (~42%). By comparison, Leyk et al. (2007) described that in marathoners, the age groups from 35 to 54 years had the greatest percent of finishers with ~36%, surpassing the age segments of 25 to 34 years with ~13% and 55 to 64 years with ~12% by more than a factor of two, irrespective of the gender. Hoffman (2010) analysed the participation and performance trends in 161-km ultra-marathoners from 1977 to 2008 in the USA. The annual finish rates increased initially and then remained unchanged to the early 1990s. The age group of 40 to 49 years showed the largest participation for both males and females (Hoffman and Wegelin 2009). It appears therefore that the age group with the largest participation in 100-km ultra-marathoners was quite similar from marathoners and 161-km ultra-marathoners. A possible explanation for the relative decrease in 100-km finishers of the younger age groups might be that younger athletes are more and more attracted by other sport’s disciplines with more technical abilities and higher intensities (Bernard et al. 2010; Baker and Tang 2010). In contrast, the relative increase in 100-km finishers of the older age groups might be explained by the rapid increase in the older population in Switzerland (Robine and Paccaud 2005), as well as the considerable increase in life expectancy over the last 20 years in Switzerland (Savidan et al. 2010; Wanner 1998). Factors such as enjoyment, health and fitness benefits, social and competition appear the main drivers for involvement of master athletes (Shaw and Ostrow 2005).

Regarding the performance trend of elite (i.e. top ten) 100-km runners during the 1998-2010 period, the results showed that both the male and the female winner times remained unchanged during the period studied. From 1998 to 2010, the fastest winner time was 409 min for males (110% of the male world record set in 1998 by Takahiro Sunada from Japan with 373 min) and 471 min (119% of the female world record set in 2000 by Tomoe Abe from Japan with 393 min) for females, respectively. The 100-km run at Biel involves a total altitude change of 645 m that may significantly increase the running times compared with a flat course. Surprisingly, the top ten female running times remained unchanged while the top ten male running times significantly increased during the 13-years period. The decrease in elite male running performance while elite female performance stabilized is difficult to explain; lower competitive elite male field across the years could be a possible explanation. The average gender difference in 100-km running performance between the top ten males and females over the 1998-2010 period was ~22%. This was consistent with previous studies. In marathoners and half-marathoners, the running times of the best female athletes were ~20% for marathons and ~22.5% for half-marathons, greater compared with males (Leyk et al. 2007). Similarly, in 161-km ultra-marathoners, the fastest females were ~20% slower than the fastest males (Hoffman 2010).

The second of the study aim was to compare the age-related change in 100-km ultra-marathoners between males and females. We hypothesized a more pronounced age-related decline in 100-km running performance for female compared with male runners. The first interesting finding was that both male and female 100-km ultra-marathoners younger than 30 years were slower compared with male runners between 30 and 49 years, and female runners between 30 and 54 years. These findings were different from reports on marathoners. Finish time data for the top 50 finishers in the 'New York City Marathon' has demonstrated that, regardless of gender, the marathon times were either comparable in the age groups 20 to 29 years and 30 to 39 years, or were slightly slower in the younger age group; followed by a curvilinear increase in times for each advancing 10-year age group (Jokl et al. 2004). It has been previously suggested that the age of the peak performance increased with the length of the race (Schulz et al. 1987). The present data confirms this assumption since it appears that high-level performances in a 100-km ultra-marathon can be achieved at a higher age compared with a 42-km marathon. Our results suggest that 100-km ultra-marathoners can succeed until 50 years of age for males and until 54 years of age for females. Regarding endurance performance, a cumulative number of training years is required for peak performance but in contrast age-related changes in physiological (and psychological) factors lead to the decline in performance. For 100-km ultra-marathoners, increasing training experience and age-related declines in physical function may balance each other between the age of 30 and 50 to 54 years. Hoffman (2010) showed, in 161-km ultra-marathoners, that beyond the age of 30-39 years the average finish times increased linearly with age. The female age group 40-49 years and the male age group 30-39 years had the fastest race times, where runners in younger and older age groups were slower. In females, the age group 40-49 years was ~5.5 % faster than the 30-39 years one; among the males, the age group 40-49 years was ~4.0 % slower than the 30-39 years one (Hoffman 2010). In Hoffman and Wegelin's study relating to 161-km ultra-marathoners, the best times among females were observed for ultra-runners aged between 30 and 39 years. The examination of the best times among the males revealed that the performance of the 40-49 years age group was no different from age-groups 20-29 and 30-39 years (Hoffman and Wegelin 2009). Both the moderate decline in running performance and the large number of successful master athletes suggest that master runners are able to maintain a high degree of physiological performance late into life (Young & Starkes 2005).

It has been previously observed a greater rate of decline in endurance performance (e.g. swimming, running and triathlon) in females compared to males (Donato et al. 2003; Lepers & Maffiuletti 2011; Ransdell et al. 2009). For example, Wright and Pericelli (2008) investigated 1,351 male and 1,248 female finishers in the 2001 National Senior Olympic Games. Between 30 and 50 years old, there were minimal changes in performance *per annum*. Over the next 25 years, from 50 to 75 years, the percentage change in performance *per annum* was three times the rate seen from 30 to 50 years (males, 1.46% *per annum*; females, 2.52% *per annum*, respectively). After the age of 75 years, the rate of performance decline *per annum* increased dramatically, with 10.29% for females and 4.1% for males, respectively. In the present study, the age-related decline in performance was similar between males and females until the age of 64 years but was significantly greater after for females compared with males. A first reason for this gender difference may partly be explained by selection bias. Indeed, there were a smaller number of female 100-km runners in the older age groups with females accounted for ~13% of all finishers from 1998 to 2010 ; which was lower than the female participation of ~20% in the 161-km ultra-marathons in the USA (Hoffman et al. 2010). Social and psychological factors that leading to an improved performance in master runners should also be considered. It is possible that males are gaining more competitive opportunities as they age, or that they are seeking out competition later in life or later in their career (Ransdell et al. 2009). In addition, as age increases master athletes do not have the same intrinsic drive to train as hard as they did when younger (Korhonen et al. 2009; Reaburn and Dascombe 2008; Spirduso et al. 2005). Reaburn and Dascombe (2008) reported gender-based differences in motivation with increasing age. Initially, males were more motivated by achievement and females by health, social interaction, and enjoyment. Over time, both male and female athletes ranked social interaction as the most important motivator for participation in master athletic events. Greater decrease in training volume and intensities in elderly female runners compared with their male counterpart may be the result of a change in intrinsic drive to train hard between male and female (Korhonen et al. 2009; Okonek 1996; Reaburn and Dascombe 2008; Spirduso et al. 2005). Apart from these socio-psychological reasons, physiological factors may also explain the gender difference in 100-km running performance with advancing age.

According to Reaburn and Dascombe (2008), the physiological factors affecting endurance performance with increasing age are maximum oxygen consumption (VO_2max), maximal heart rate, stroke volume, lactate threshold, economy of movement, muscle fiber type, activity of aerobic enzymes, blood volume and skeletal muscle mass. We should first address the finding that the females were able to achieve the same 100-km running performance time until the age of 54 years. At approximately 50 years old, females are generally peri- or postmenopausal (Bernis and Reher 2007; Dratva et al. 2009). In recent years, the age at menopause has shifted higher (Dratva et al. 2009). This might be a reason why the female peak performance has been maintained in the older age groups. Increased physical activity may also have increased the menopausal-related changes in bone mass. Physically active postmenopausal females show an increase in bone mineral density (Hagberg et al. 2001) which may lead to a shift of the postmenopausal osteoporosis to higher ages (Gibson et al. 2000), thus related to a reduced physical activity with increased morbidity and mortality (Compston 2009). At the age of ~50 years, body weight and waist circumference increase in females. In addition, lean body mass and skeletal muscle mass decrease and fat mass increases (Ho et al. 2010; Showers et al. 2007; Sternfeld et al. 2004). As the time after the menopause increases, the increases in fat mass and body weight become greater (Guo et al.

1999). It has been shown that maintaining or increasing participation in regular physical activity contributes to prevention or attenuation of those gains (Sternfeld et al. 2004).

Other factors leading to an improved performance in female master runners until the age of 54 years should also be considered. Ransdell et al. (2009) described the smallest gender differences for running over 100 m, 800 m, 1,500 m, 5,000m, 10,000 m and the marathon in the age group 45 to 49 years. It is possible that females are gaining more competitive opportunities as they age, or that they are seeking out competition later in life, after childbirth, or later in their career (Ransdell et al. 2009). Further reasons for the maintenance of running performance with age in 100 km female ultra-marathoners might be improved nutrition with an increased use of ergogenic supplements (Striegel et al. 2006), less over-use injuries despite increased age (Knobloch et al. 2008), and less age-related diseases with increased morbidity and mortality (Chevalier et al. 2009). However, Taunton et al. (2002) reported that females accounted for significantly more over-use injuries of the lower limbs, depending upon age and training history.

The age-related decline in 100-km running performance was greater for females compared with males after the age of 64 years. The decrease in running performance after the age of ~50 years can be explained in part by a decrease in skeletal muscle mass. A decreased muscle mass plays a role in the age-related decrease in VO_2max in master endurance athletes (Proctor and Joyner 1997) thus leading to an impaired performance with increasing age. The decline in endurance performance appears primarily due to an age-related decrease in VO_2max (Reaburn and Dascombe 2008) where gender differences in the rate of the age-related decline in VO_2max are common (Weiss et al. 2006). Between 20 and 80 years old, the muscle area decreases by ~40% (Lemmer et al. 2003). Muscle tissue analyses showed that both slow- and fast-twitch fibres decline with increasing age, although the loss of fast-twitch fibres is greater

(Korhonen et al. 2009). This is probably because of fibre atrophy as opposed to loss of inherent force production of the myofibrils (Lemmer et al. 2003). Because muscle cross-section is related to overall muscular force production, strength declines with age. Females have a lower skeletal muscle mass compared to males, independent of the age and aging causes a similar decline in aerobic capacity in both genders, when expressed per kilogram of appendicular muscle mass (Proctor and Joyner 1997). With advancing age, females tend to lose skeletal muscle mass more rapidly than males (Spirduso et al. 2005). This may explain partly the greater age-related decline in 100-km running performance for females compared with males after the age of 64 years.

Conclusion

Although this study lacks some data about factors of endurance performance such as physiological and anthropometric parameters, training characteristics, previous experience (Knechtle et al. 2010a; Knechtle et al. 2010b; Knechtle et al., 2010c; Knechtle et al., 2011) and environmental conditions of the race (Ely et al. 2007; Wegelin and Hoffman 2011; Vihma 2010), it provides valuable data because master runners present a unique model to study the effects of high levels of physical training into older age (Tanaka and Seals 2003). The percentage of both male and female 100-km finishers for the age groups comprised between 40 and 59 years increased during the 1998-2010 period. According to the top ten elite performances, the best age for a 100-km ultra-marathon performance is about 39-40 years, for both males and females. The age-related decline in performance was similar between males and females until the age of 64 years, but after 64 years it was significantly greater for females compared to males. The reasons for such a greater age-related decline in performance of female master runners compared with male master runners in the higher age groups are not clear. Differences in training volume and motivation, aerobic capacity, orthopaedic, nutrition, bone density, hormonal status, muscle mass, body composition, muscle typology for elderly female compared with male counterpart require further investigations.

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Figure legends

Figure 1

Number of finishers in the Biel 100-km ultra-marathon, by gender, from 1998 to 2010. Female finishers represented 13.3 ± 1.4 % of all finishers over the period. The greatest participation, in 2008, corresponded with the 50^{th} anniversary of the race.

Figure 2

Percentage of male and female finishers per age group in the period 1998 - 2010. Values are means ± SD.

Figure 3

Changes in the percentage of finishers per age group from 1998 to 2010, males (upper panel) and females (lower panel). In both males and females, the percentage of finishers decreased over this 13 year period for the age groups 18 to 29 (males: r = -0.69, P = 0.009; females: r = -0.71, P = 0.007) and 30 to 39 (males: r = -0.98, P = 0.0001; females: r = -0.83, P = 0.0005), while it increased in the age groups 40 to 49 (males: r = 0.79, P = 0.0013; females: r = 0.83, P = 0.0004) and 50 to 59 (males: r = 0.82, P = 0.0006; females: r = 0.78, P = 0.0018). The percentage of male finishers in the age groups 60-69 slightly increased (r = 0.56, P = 0.047), but remained stable in females (r = -0.28, P = 0.35).

Figure 4

Age of the overall male and female winners (Panel A) and mean (± SE) age of the overall top ten male and female finishers (Panel B) in the Biel 100-km ultra-marathon from 1998 to 2010. The dotted line and solid line represent the linear regressions for the females and the males, respectively.

Figure 5

Performance times of the overall male and female winners in Biel 100-km ultra-marathon from 1998 to 2010 (see Panel A). Mean (± SD) performance times of the top ten overall male and female finishers over the same period (see Panel B). The dotted line and solid line represent the linear regressions for the females and the males, respectively.

Figure 6

Age-related changes in running performance in the Biel 100-km ultra-marathon. Data was pooled from 1998 to 2010. Values are means ± SD. For males (n=240), race time was significantly ($P<0.01$) longer for the age groups 50-54 and older, 18 to 24 and 25-29, compared with the age groups between 30-34 and 45-49. For females (n=220), race time was significantly ($P < 0.01$) longer for the age groups 55-59 and older, 18-24 and 25-29, compared with age groups between 30-34 and 50-54. NS : Non significant difference between age groups from 30-34 and 45-49 for males, and from 30-34 and 50-54 for females.

Figure 7

Age-related declines in 100-km running performances for male (n=240) and female (n=220) runners expressed using a ratio calculated between the individual and the mean time performances of the best performing age group (mean ± SD). For male, the performance ratio for age groups 45-49 years (full arrow) and above was significantly different from the best age group (i.e. 35-39 years). For female, the performance ratio for age groups 50-54 years (dotted arrow) and above was significantly different from the best age group (i.e. 35-39 years).

*: $P < 0.01$: Significantly different from female for the same age group.

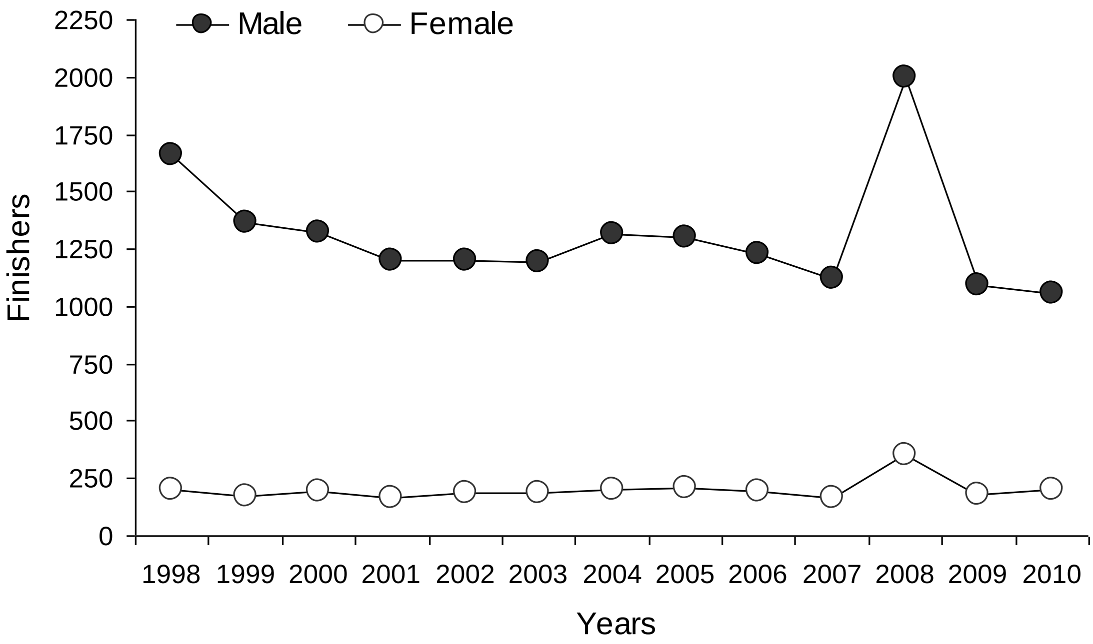

Male
Female
Finishers
2250
2000
1750
1500
1250
1000
750
500
250
0
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Years

Figure 1

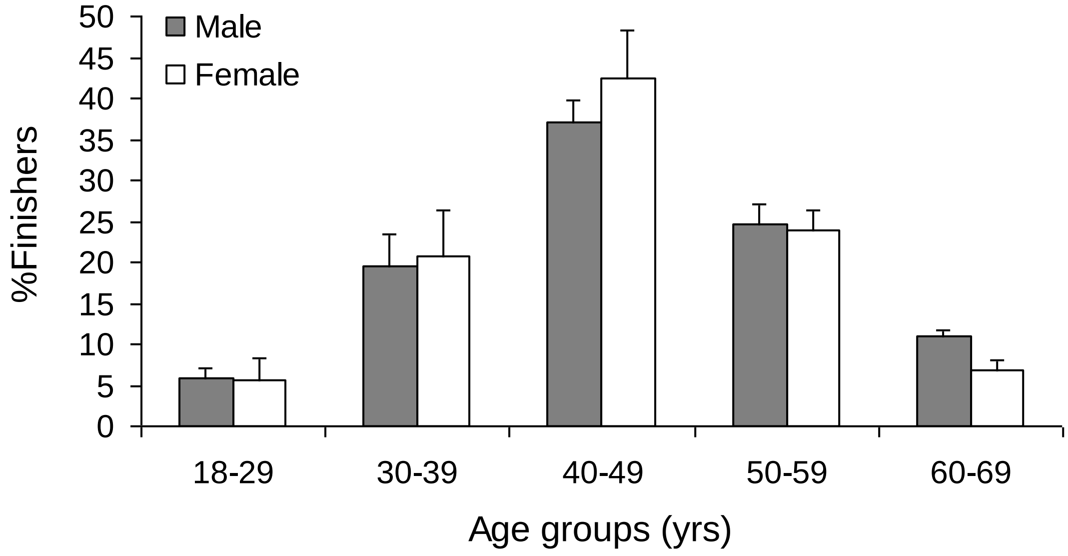
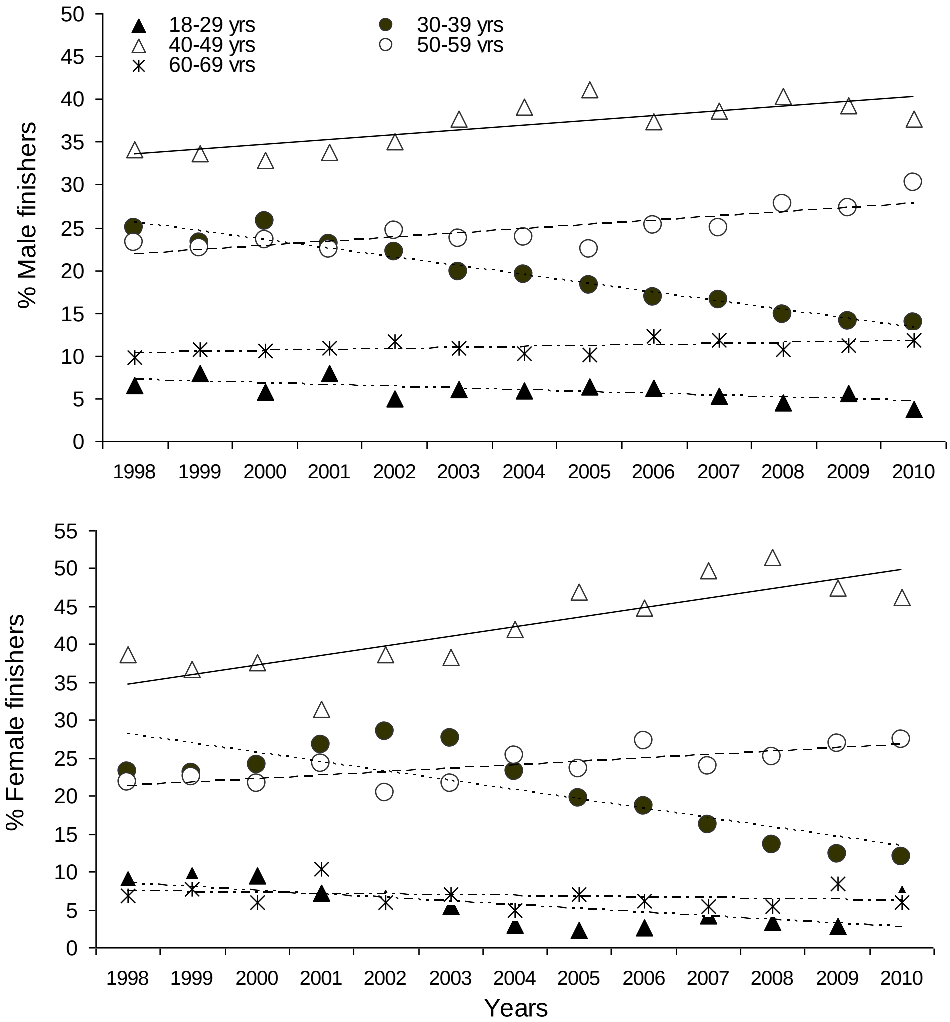

50
45
40
35
30
25
20
15
10
5
0
Male
Female
%Finishers
18-29
30-39
40-49
50-59
60-69
Age groups (yrs)

Figure 2



18-29 yrs
30-39 yrs
40-49 yrs
50-59 yrs
60-69 yrs
% Male finishers
% Female finishers
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Years

Figure 3

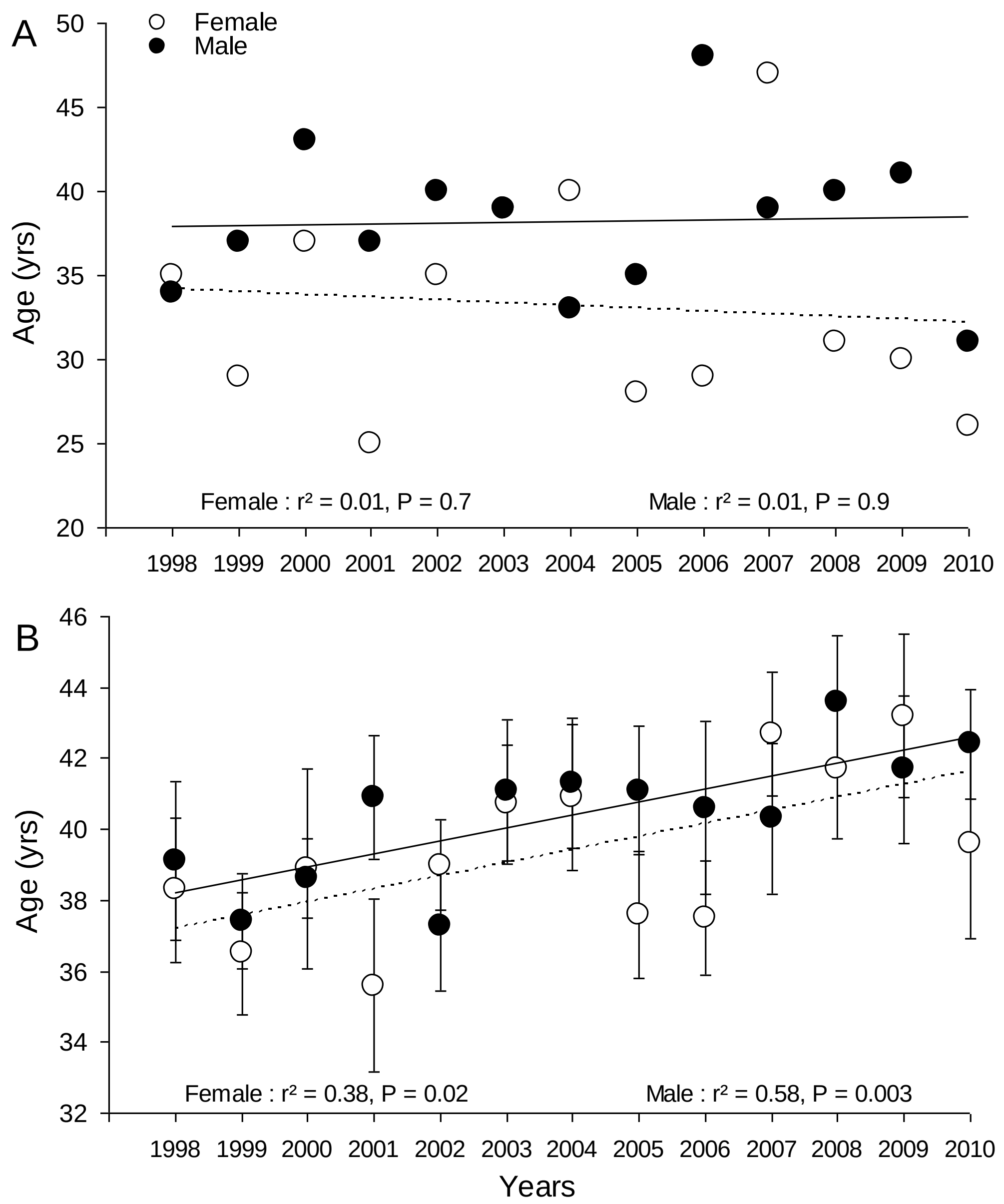

A
Female
Male
Age (yrs)
50
45
40
35
30
25
20
Female : r² = 0.01, P = 0.7
Male : r² = 0.01, P = 0.9
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
B
Age (yrs)
46
44
42
40
38
36
34
32
Female : r² = 0.38, P = 0.02
Male : r² = 0.58, P = 0.003
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Years

Figure 4

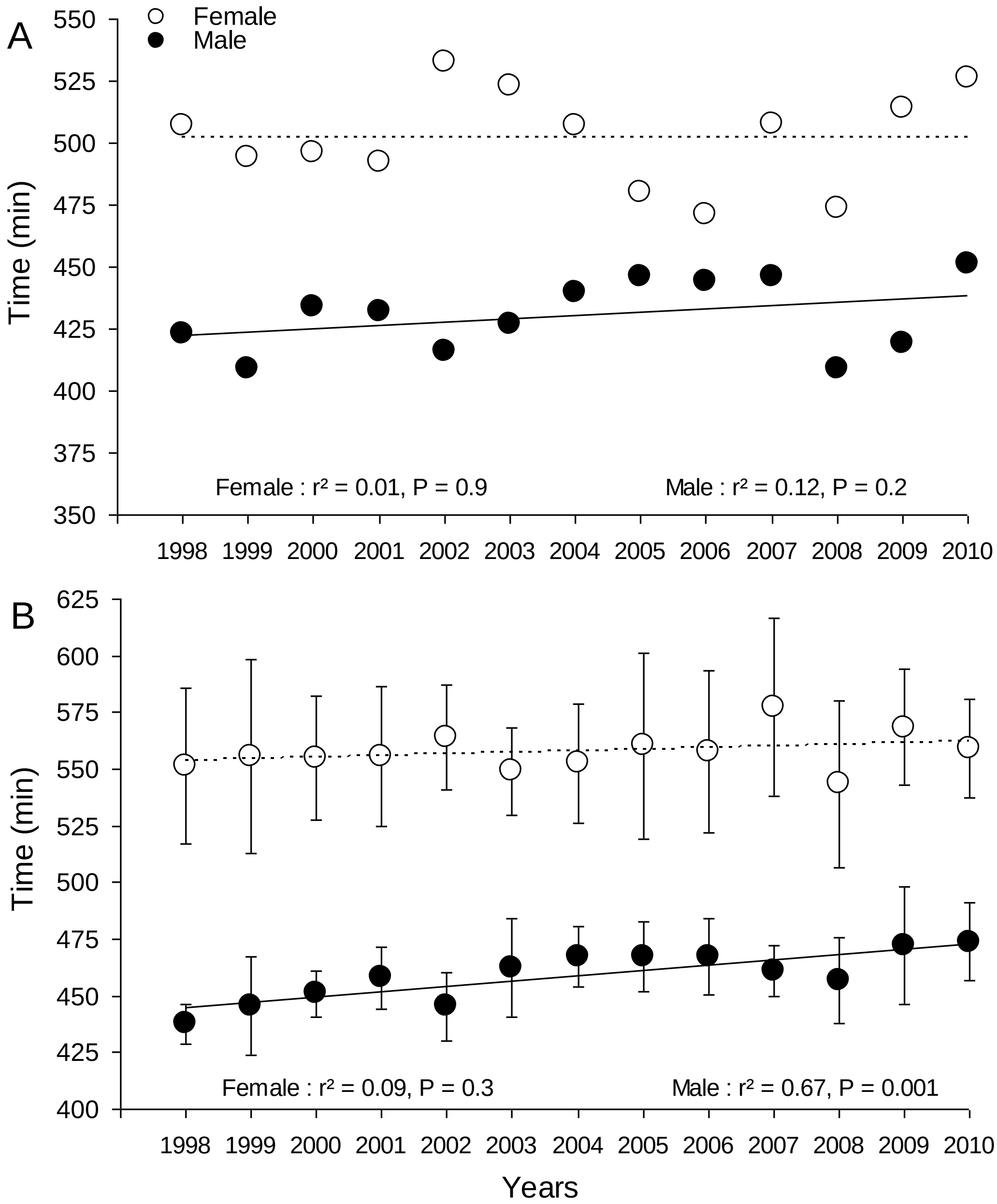

A
B
Female
Male
Time (min)
Time (min)
550
525
500
475
450
425
400
375
350
625
600
575
550
525
500
475
450
425
400
Female : r² = 0.01, P = 0.9
Male : r² = 0.12, P = 0.2
Female : r² = 0.09, P = 0.3
Male : r² = 0.67, P = 0.001
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Years

Figure 5

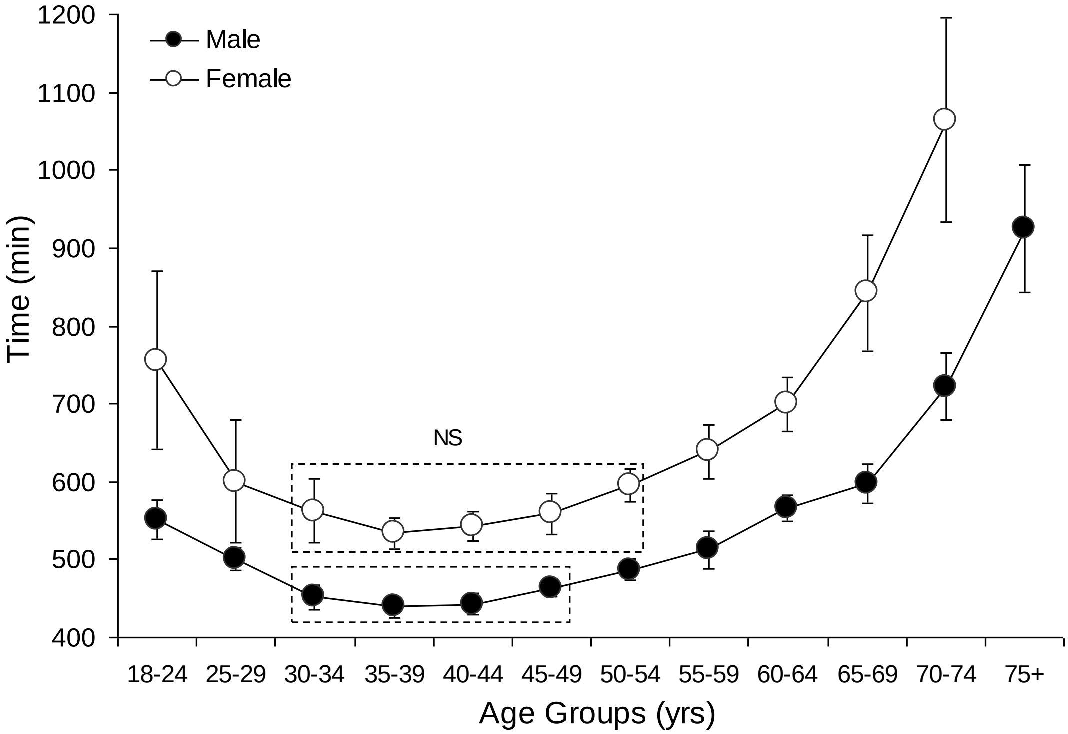
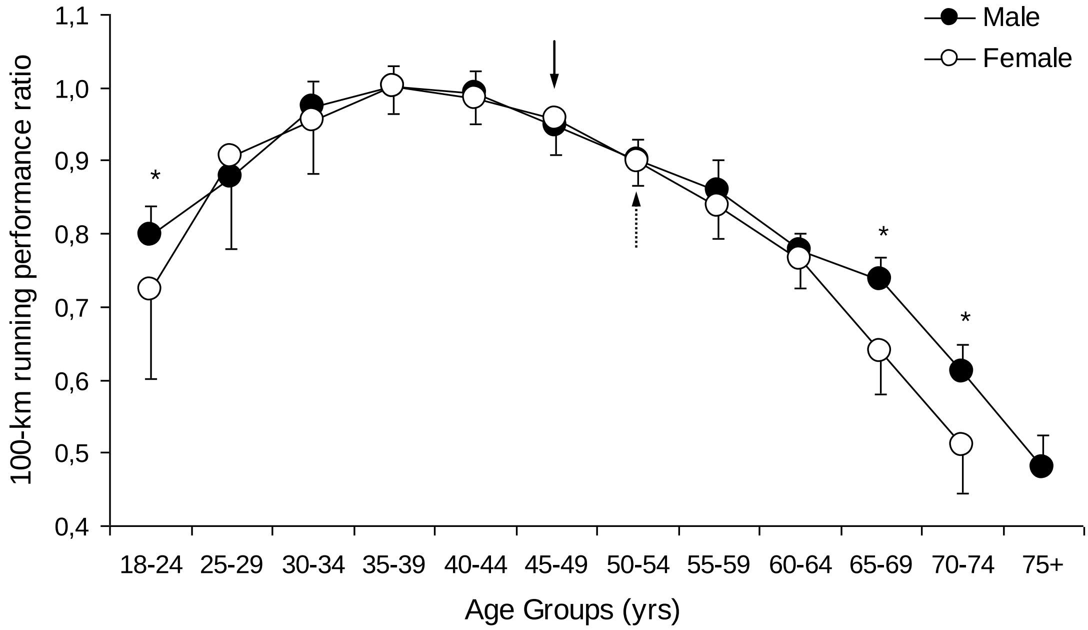

1200
1100
1000
900
800
700
600
500
400
Time (min)
Male
Female
NS
18-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75+
Age Groups (yrs)

Figure 6



1,1
1,0
0,9
0,8
0,7
0,6
0,5
0,4
100-km running performance ratio
Male
Female
*
*
*
18-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75+
Age Groups (yrs)

Figure 7