Doctoral theses at NTNU, 2023:357

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Variations and insights from alpine skiing

Doctoral thesis

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Thesis for the Degree of
Doctor Philosophiae
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Abstract

This thesis tries to explore and explain variations in relative age effects in competitive environments by using alpine skiing as an example. The *relative age* describes the differences in chronological age that exist among participants in a competitive group and are often associated with certain cut-off dates for that group. The *relative age effects* describe the potential differences that occur due to a such organization. This effect has been shown to be prevalent in competitive situations, in conditions where selection takes place, or in other situations where a group are being compared or assessed in terms of certain skills. This organization is often advantageous for participants who are relatively older than the rest of the group. To study the effects, it is relevant to find conditions where the effects can be detected. Sport is a context where the competition is a key element and where different aspects of the relative age effects are studied. In order to study the variations of relative age effects, alpine skiing contains several variables that may explain the variations and consistency of relative age effects, e.g., gender, physical variations, and cultural aspects. Alpine skiing is an individual sport, and the performances are independent of the coaches' eyes, at least in races, because the results are dependent on timing. The range of events are limited, but there are two main events (technique and speed) that favor different characteristics of the skiers, which may contribute to understanding of the relative age effects.

In this thesis the RAE is examined in two different studies. In the first study, a cohort consisting of the 50 best World Cup skiers each year, over 21 years of age, were analyzed. This study resulted in two papers. The first paper showed the existence of a RAE in World Cup skiers among males, but only in speed events. In the second paper, analyzing the performance of the absolute best skiers in this cohort, a reverse of the RAE was found among males, meaning that the best male skiers were born late in the annual cohort. The second study consisted of a cohort of skiers from the Junior World Championship, consisting of skiers in a multiple age group between 17-21 years of age. The first paper from this study (paper III in this thesis) showed a constituent year effect in this group, meaning that the older the skiers in the cohort were, the more likely they were to participate in the Junior World Championship in speed events. A similar effect was found for female skiers, but the difference in participation was two years ahead of that of the males, suggesting that the RAE is a proxy for relative development. The second paper from this study (paper IV) showed that the performances reflected the participation, though were even stronger than the participation.

As the research field of RAE has been criticized for being atheoretical, the results in this thesis are discussed from the theoretical framework of constraint (constraint-based framework). This theory discusses the complexity in performance due to three different categories: the task, the environment, and the individual (organism).

Abstract (Norwegian)

Denne avhandlingen har undersøkt relativ alderseffekt i konkurransemiljø, hvor det er brukt alpint som eksempel. Med relativ alder menes forskjellen i alder som finnes mellom deltakere i et utvalg som konkurrerer sammen. Den relative alders*effekt*en beskriver hva slags forskjeller som oppstår innad i en gruppe bestående av ulike relativ alder. Denne forskjellen er ofte fordelaktig for de eldste i kohorten. For å studere denne effekten er det best å finne situasjoner hvor effekten kommer tydelig frem og hvor flere variabler kan bli kontrollert for, og det er gjerne hvor det er hard konkurranse eller hvor en gruppe blir sammenlignet med hverandre. Et slikt konkurransemiljø finner man i sportens verden, og der har relative alderseffekter blitt studert i en rekke idretter og sammenhenger. I alpint finner man flere variabler som kan undersøkes og som kan forklare noen av variablene, f.eks kjønn, fysikk hos utøverne og kulturelle aspekter. Alpin skisport er en individuell idrett der utøverne konkurrerer på tid, og resultatene i en konkurranse er uavhengig av trenernes skjønn på prestasjonen. Variasjonen i ulike grener er begrenset, men det finnes to hovedgrener (teknikk og fart) som favoriserer ulike karakteristikker av utøverne, noe som kan gi innsikt i forståelsen av relative alderseffekt.

Denne avhandlingen har studert relative alderseffekt i to ulike studier, bestående av to ulike kohorter. I den første kohorten så ble de 50 beste alpinistene fra hvert år i World Cup over 21 år analysert. I den første artikkelen viste det seg at også blant de beste alpinistene finnes det en relativ alderseffekt blant menn, men bare i fartsdisiplinene. I artikkel to, ble de aller beste prestasjonene over disse 21 årene analysert, og sett opp mot når de var født på året. Det viste seg at de alpinistene som hadde samlet flest World Cup poeng i løpet av perioden var født seint på året, altså en reversering av den relative alderseffekten.

Den andre kohorten besto av alpinister fra verdensmesterskapet blant juniorer, som er i alderen 17-21 år. Dette er personer som befinner seg i brytningen mellom ungdom og voksen. Den første artikkelen fra denne studien (artikkel 3 i avhandlingen) viste en constituent alders effekt, som betyr at det var flere alpinister på 21 år som deltok sammenlignet med de yngre. Denne fordelingen gjaldt hovedsakelig menn, men også delvis kvinner. For kvinnene så flatet fordelingen av alder seg ut, noe som var 2 år før menn. Denne fordelingen var tydeligst i fartsdisiplinene. I artikkel 4 fra denne studien viser at det ikke bare er deltakelse hvor

fordelingen følger alder, men den finnes også resultatene. Det viste seg at fordelingen er sterkest i fartsdisiplinene og at den også gjaldt kvinner.

Siden forskning på relative alderseffekter har vært kritisert for manglende teoretisk forankring har denne avhandlingen forsøkt å forstå resultatene i lys av en rammefaktor basert tilnærming (constraint-based framework). Ut fra denne teorien kan relativ alderseffekt forstås som et resultat av individuelle rammefaktorer, miljømessige rammefaktorer og rammefaktorer knyttet til oppgaven.

Acknowledgments

This has been a long and winding road towards my dissertation. The journey started as a discussion with friends and colleagues about talent and talent identification in general, and within alpine skiing in particular. As a former skier and trainer in alpine skiing, I discussed with them what kind of mechanisms contribute to development as a top-level skier. Simultaneously, I have been concerned about learning and assessment in my profession as a teacher in sports and physical education. I have both experienced and noticed the comparison that exists in school settings.

Together, the interests of skiing and learning comprised an urge to find out more about the mechanisms that work in skill development. At that time (2015), existing scientific work on variations in the effect of birth month on technical and individual sports was scarce, and I was intrigued by the mechanisms of time of birth on sports participants. I have noticed that the same mechanisms work in education settings and other areas where competitions and evaluations take place.

The discussions with my colleagues led to data collection from the FIS website, and together with my colleagues we discussed methodological considerations. The research field of relative age effects in groups concerned, as it would also with the top level of skiers, the impact of equipment, differences between skiers in technical events and speed events, and so forth. The first paper attempted to answer these questions. The answers from the first paper led to new questions needing to be answered, which were the origin of paper II, and then leading again to papers III and IV. The fun and interesting part of this work was that the answers led to new questions with new insights and answers. There was no fixed frame where the hypothesis and research questions were determined in advance. Rather, genuine interest and curiosity led to new questions, answers, and new designs to study the phenomenon.

The curiosity behind this work was paralleled with teaching and other projects. Throughout my academic career I have been involved in many other projects as well, both scientifically and in developing new teaching methods. The idea for the thesis came from an interest in learning and what kinds of constraints impact the learning history of students and athletes. The fact that time of birth has a huge impact on our lives is fascinating. The logic is easy to grasp, but the mechanisms of time of birth are not always as straightforward as they seem.

Therefore, this research can be regarded as one piece in the puzzle to understand the mechanisms surrounding the relative age effects.

This has been a long project, and I am grateful to NTNU for giving me time to finish this work. I would like primarily to thank Arve Vorland Pedersen and Håvard Wuttudal Lorås for their discussions and competence in relation to the academic work. This thesis would not have been accomplished without the high standard of academic work that they command, and from the initial discussions I had with them about talent development, skiing, and competitive environments. I would also wish to thank Professor Ellen Beate Hansen Sandseter for her valuable thoughts and input into this thesis.

Finally, I would like to thank my wife Gunn for her support and for being the most important supporter and discussion partner in my life, and Trygve and Gustav, who contribute to real life perspectives and making it all meaningful.

Trondheim 18/4 - 2023

List of papers in the thesis

Paper I:

Bjerke, Ø., Lorås, H., & Pedersen, A. V. (2016). Variations of the relative age effect within and across groups in elite alpine skiing. *Comprehensive Psychology, 5*, 1-6. doi:10.1177/2165222816648077

Paper II:

Bjerke, Ø., Pedersen, A. V., Aune, T. K., & Lorås, H. (2017). An inverse relative age effect in male alpine skiers at the absolute top level. *Frontiers in Psychology, 8*(1210). doi:10.3389/fpsyg.2017.01210

Paper III:

Bjerke, Ø., Lorås, H., & Pedersen, A.V. (2020). Variations in the constituent year effect in Junior World Championships in alpine skiing: A window into relative development effects? *PloS one, 15*(4), e0231384. doi:10.1371/journal.pone.0231384

Paper IV:

Bjerke, Ø., Lorås, H. & Pedersen, A.V. (2023). The association between constituent year effects and performance in alpine skiing Junior World Championships. Submitted.

List of abbreviations

RAE – Relative age effect

RDE – Relative development effect

CYE – Constituent year effect

CLA – Constraint Led Approach

WC – World Cup

SL – Slalom

GS – Giant slalom

SG – Super giant slalom

DH – Downhill

YoB – Year of birth

Q1-Q4 – quartal 1 (January-March), quartal 2 (April-June), quartal 3 (July-September), quartal 4 (October-December)

List of figures and tables

Background and rationale

A society of competitions and assessment

Growing up in a modern society will expose humans to competitions and assessment in a wide range of situations and in different environments. Children are exposed to some sort of competition or assessment as soon as they are born. Parents discuss and compare their own child with others in a variety of contexts and aspects. The discussion often encompasses how far their own child has come on the developmental path, like reaching crucial milestones such as crawling, walking, and talking. Throughout childhood, children are striving to show their knowledge and skills in a wide range of daily situations. They compete to attract attention from their parents and other adults, and later their peers, whether it is throwing a stone as far as possible, climbing fences in the playground, or learning to ride a bike. Further, whether in school or at work, people are exposed to a plethora of contexts and situations where comparisons and competitions take place, from grading in school, application to higher education, or being ranked in job applications. One nature of competition is that several people are striving towards the same goal, and it involves some kind of ranking, assessment, or selection. Selection involves that someone is chosen, and other are not, while assessment is some kind of evaluation in terms of a norm, ranking the order or standing within a group (Dictionary, 2023). This ranking usually occurs with peers born in the same annual year as each other, but also within larger age groups. In this thesis, a closer look at competition environments will be discussed, and light will be shed on some of the consequences of competitive environments and of organizing children into cohorts.

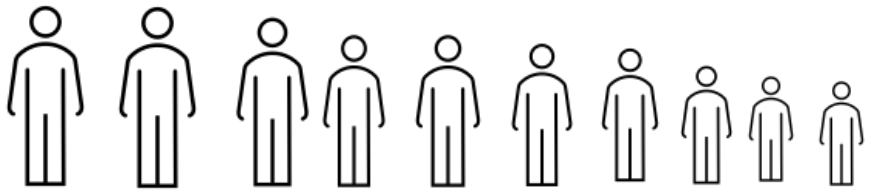
For a teacher educator in physical education and sports, exposure to competition and ranking is pervasive in the daily work. There is a ranking process in assessing students in terms of their academic achievements, and in practical teaching situations the use of competition seems to be common in physical education, using games, play, and relays as practical examples. Competition or assessment is a part of life and a part of daily work, and learning more about the potential consequences of competition can easily be transferred to other contexts as well.

The consequences of grouping people in cohorts

Grouping people together is a common way to organize people in western society, whether when it be starting at school or attending sport clubs. Children are typically divided into groups based on their year of birth, and the intention is to assemble children at the same cognitive and physical development (Schorer, Cobley, et al., 2009). Usually, the grouping of children follows the annual year, which means that children born from January 1st to December 31th are placed in the same group. Grouping the people together based on chronological age relies on an assumption that these children are similar in terms of development in physical and cognitive skills and to maintain these general developmental similarities in a competitive situation (Baker et al., 2010). However, being born early in an annual year compared to those born late leads to a potential 364 day difference. In Figure 1, the potential differences of one annual year are displayed, symbolized by the relatively older as being bigger than the younger ones organized in the same annual year.

Figure 1

Children born in the same annual year symbolized regarding developmental differences due to age.



The grouping of children in the same annual year has some consequences when it comes to competitions and assessment (Musch & Grondin, 2001). Observing and analyzing the differences where the relatively younger children in their age group perform at a different level than their older peers is called *the relative age effect* (RAE) (Barnsley et al., 1985), or *the birth date effect* (Bell et al., 2009). The effect was discovered in the early 1960s, where children born early in a scholastic year received better grades than those born late in the same

annual year (Freyman, 1965; Jinks, 1964). Dividing children into groups based on annual birth date has shown several consequences in many school parameters, and usually academic advantage is conferred on children born early in their cohort. Children born early in an annual year have better reading skills in terms of being faster readers at the age of 9 years (Lawlor et al., 2006); they have better numeracy skills scored in the Norwegian national numeracy test for children in grades 5, 8 and 9 (Aune et al., 2018), and they also tend to receive better grades in physical education in 10th grade (15-16 years) and the last year of upper secondary school (18-19 years) (Aune et al., 2016), amongst others.

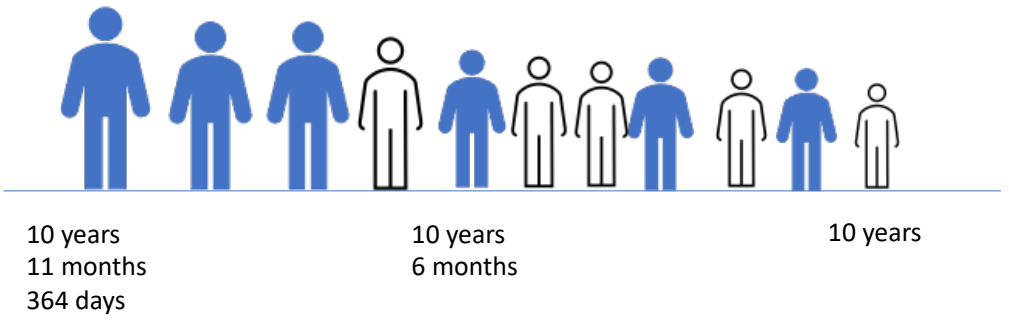
The advantage of being born earlier seems well documented in education and in other situations. An advantage for some means a disadvantage for others. Conversely, this relative age effect, in terms of being born late in an annual year, has been associated with psychiatric risks and health problems (Goodman et al., 2003), and even youth suicide (Thompson et al., 1999). The effect is most pronounced in childhood or in the early years, and many researchers claim that the advantage of the RAE disappears as children become adults (McCarthy & Collins, 2014). However, there is research showing that the effects of being born earlier than your peers are evident also into adulthood, for instance among students undertaking higher education (Bell et al., 2009). The grouping of people into cohorts has therefore a large impact on everyone´s life and seems to be a consequence of how society is organized. Therefore, it is important to understand the mechanisms behind this phenomenon, and a research field where the effects of different birth dates are systematically studied, is in sports. Hence, most of the examples in this thesis are collected from sports, but the results could easily be related to other competitive contexts as well.

In sport, RAE was discovered in ice-hockey, where players born early in the annual grouping were over-represented in the team (Barnsley et al., 1985). Since then, a vast number of studies have studied the prevalence of relative age effects, with many of these studies being performed on *team sports* like ice hockey (Barnsley et al., 1988), soccer (Helsen et al., 2005) and basketball (Delorme & Raspaud, 2009), especially at a level where there is a high selection pressure. A high selection pressure means that children regarded as the best of that group are placed in a situation where only a few are chosen to play or participate in a team or in a situation. These persons are regarded as having greater potential than their peers, and the selection is made by coaches or significant others. Sometimes, being relatively older has been interpreted as being more talented (Helsen et al., 2000). In *individual sports*, RAE is studied

to a lesser degree (Baker et al., 2014). However, there are studies that demonstrate that physically demanding sports are related to the RAE, such as swimming (Cobley et al., 2018), tennis (Edgar & O'Donoghue, 2005), and track and field. The argument is that being stronger and bigger in those events are advantageous due to the physical demands of the sport, e.g., in throwing objects, running faster, or using more muscular force. In individual sports, where weight and size are a disadvantage, the RAE is absent or even reversed, as documented in sports like gymnastics (Baxter-Jones et al., 1995) or in ski jumping (Hammer, 2020). In these sports, the disadvantage of being heavier and having a larger size means that gravity and biomechanical forces work against the athlete. In individual technical sports where success is largely dependent on technical (motor) skills, researchers claim there should be no expectation of finding a relative age effect in sports (van Rossum, 2006). This is because the advantage of being stronger and heavier than your peers are less favorable, as technique can be independent of size. The selection of a typical RAE can be symbolized in Figure 2 displaying those athletes who are selected in an annual year (blue persons), with an overrepresentation of athletes born early in the cohort.

Figure 2

Selection of athletes (blue) in a cohort in a physically demanding activity.



Relevance for this thesis

Despite the large number of studies on relative age effects carried out, most have investigated whether the RAE exists in another sport, or across sport contexts, and discussing the potential consequences for that particular sport. Additionally, many studies on RAE have been carried out within the context of selection and participation, and to a lesser extent connected to performance. There seems to be a consensus in the research field that the relative age effects give unequal opportunities for children within the same cohort. There are surprisingly few studies that discuss what the relative age *effects* actually express, or more precisely, what the potential proxies of the RAE are. Studying the *variations* of RAE offers an opportunity to ascertain why the effect is present. Studying individual sports is more suitable when investigating the varied effects of RAE (Baker et al., 2014), and one explanation for that is because other extraneous inter-athlete factors are not decisive, e.g., team cooperation. To understand these mechanisms, one sport that may increase understanding of the mechanisms is the study of RAE in alpine skiing.

Alpine skiing is an individual sport which is characterized by having a substantial selection pressure to represent your club, region, or country in larger competitions (Müller, Müller, Kornexl, et al., 2015). The competition is intense, and the sport is complex because it requires strength, power, and endurance, together with a high level of technique and motor skills (Gilgien et al., 2018; Supej & Holmberg, 2019). Alpine skiing consists of both technical events (slalom and giant-slalom) and the more powerful speed events (super-G and downhill). There is an advanced FIS ranking system based on various factors such as e.g., results in previous competitions, time difference from the winner, ranking of the winners, and length of the race. The system is well-known and has been working for several years. The ranking system applies from the age of 16, which is the lowest age possible to enter the FIS system. Before entering the FIS ranking system there is selection for skiers entering ski schools or boarding schools, which is an education system for skiers in high school. Together with the fact that alpine skiing, especially in certain countries in the Alps, is regarded as culturally important (Müller et al., 2012), this sport illuminates a wide range of potential variations in RAE. Given the paucity of research on RAE in individual sports (Baker et al., 2014), alpine skiing is therefore one way to investigate several aspects in RAE. Even if the RAE is found among young skiers, the mechanisms as to how this effect works over a longer age span has not been studied. Studying alpine skiing over a larger time range would presumably make it easier to discover variables that can explain the RAE. Based on the results in alpine skiing,

the application of a constraint-led approach will also illuminate the implications for other competition situations. In the next section the aims of the thesis will be specified.

Aim of the thesis

The aim of the thesis is to understand the mechanisms of relative age effect in competitive environments, using alpine skiing as an example. By studying alpine skiing and its variations it should be possible to reveal how RAE works and how it affects participation and performance. In the alpine events (slalom, giant slalom, super-G, and downhill) different somatotypes are discovered due to the technical or speed characteristics of the event, and most skiers specialize in either technical or speed events (Gilgien et al., 2018). Since the RAE among adolescents is well established in alpine skiing, the research questions of this thesis can therefore be summarized as follows:

1. Will there be a RAE at the absolute top-level in alpine skiing, and in what ways does the effect vary across events?
2. How can the effects of relative age vary across a larger age span?
3. How can the use of a constraint-based framework explain the variations in RAE in alpine skiing in top level skiers?

Structure of the thesis

In this thesis, a further elaboration of the concept of RAE and related concepts will be given. This will provide the reader with a historical understanding of the concept and research where the effects are studied. Presenting research in RAE field will contribute to understanding the variations of RAE. Besides the description of topics and concepts, some of the shortcomings of the research on RAE will be discussed. Since much of the research in RAE has been criticized for being rather atheoretical and more descriptive in its orientation (Cobley, Abraham, et al., 2008), a theoretical framework in which the RAE can be understood will be introduced and elaborated. Next, an introduction to the methodological choices to answer the main aims of this thesis will be given, followed by a summary of the results. The discussion aims to discuss the results in an overarching perspective, and will include limitations of the study and implications for teacher education. At the end of the thesis a copy of the included papers can be found.

Relative age effect

What is RAE?

Organizing people into groups based on their chronological age is a common way to organize learners or competitors in society, both in education and in sports. Although well intentioned in meeting the learners' physiological and psychological developmental stage, discrepancies occur between those born immediately after a cutoff date, and those immediately before a cutoff date (i.e., relative age). The differences based on this division are collectively known as the relative age effects (RAE) (Wattie et al., 2015). The RAE is a mechanism that works universally, meaning that its presence can be found everywhere whenever selection processes take place. The higher the selection pressure, the more pronounced the RAE will be (Musch & Grondin, 2001). The fact that selection exists implies directly that there must be some kind of competition or assessment, and the competition leads to significant differences in social evaluations (Wattie et al., 2015). The RAE phenomenon usually appears as a skewed birthday distribution of people in the same cohort or age group (Musch & Grondin, 2001).

The discovery of RAE

Historically, the phenomenon of RAE is not unknown, and how age may reflect maturity in a group has been well known. In education settings, Dickinson and Larson (1963) found that the age on entering school in first grade had a profound effect on later school achievements. They measured the children´s basic skills entering school at 6 years of age and found that the youngest children (born in the last quartile of the year) had a lower score in basic skills than their classmates. This study also showed that the differences still existed in 4th grade indicating that late matured children did not manage to compensate for the difference that were established at early ages. In sport, a discovery of RAE was made in the distribution of birth months in ice hockey by Barnsley et al. (1985), and this study has perhaps become one of the most well-known studies since it attracted public interest through the book "Outliers" by Malcolm Gladwell (2008). Barnsley and his wife first become aware of this while watching a hockey match for juniors, and they studied the match program where the players' birthdays were printed. Based on this discovery, they investigated the birth dates of hockey players in three major hockey leagues in Canada. They discovered a highly skewed distribution of birthdays among hockey players with 71.7% of the players born in the first 6 months. They followed up this study by investigating minor hockey and found similar results in hockey players aged between 11 and 19 years. A similar age distribution was also made

very clear in a study by Helsen et al. (2000) who studied soccer players in the national youth league in Belgium, where a change in cut-off dates was made in the selection years in the mid 90's. In 1996-1997, the cut-off date was August 1st (month 1) and ended on July 31st (month 12), whereas in 1997-1998 the cut-off date changed to January 1st. The change of date had a great impact on the distribution of birth month of the players in the selected teams at all ages, from those children who were 10-12 years old, up to 16-18 year old soccer players. In the first cohort, players born early in their cohort (August-October) were more likely to be selected in all age groups. After the change in cut-off date in 1997, there was a dramatic shift, where players born in January-March (Quartile 1 - Q1) were more likely to be selected for the team. From then, the birth date has been extensively studied and unveiled within several team sports like soccer (Cobley, Schorer, et al., 2008), where the RAE has been persistent over time for professional male players in the German Bundesliga. Also in ice hockey the existence of RAE in elite male and female ice hockey has been studied (Wattie et al., 2007), in both regional and national levels of male and female handball (Schorer, Baker, et al., 2009). In French basketball, the effect of RAE has been proved to exist in the elite national level, but has also shown asymmetry in height among all licensed youth players from 8 to 18 years old, favoring players born early in the annual year (Delorme & Raspaud, 2009). The effect has also been found among Brazilian elite volleyball players, where players born in Q1 are more likely to play at elite level than those born in Q4 (Parma & Penna, 2018). In a recent bibliometric analysis there has been a growing number of publications on RAE in sports, with most research performed on soccer, followed by ice hockey (Bilgiç & Işın, 2022). In total, 26 sports were listed where research on RAE has been performed.

Explanations of RAE

One of the explanations for RAE is how the physical precocity differs and how it is reinforced within a one-year cohort. This reinforcement is due to having an opportunity to receive better coaching, having better training facilities, and a possibility to compete with better opponents (Baker et al., 2012). One of the first reviews on RAE was performed by Musch and Grondin (2001), who found that physiological maturity can differ by approximately two years depending on whether the children are late or early to mature. Further, these researchers point out that children earlier to mature have psychological advantages in terms of perceived competence, based on Harter´s theory of competence motivation (Harter, 1982). This means that when having a higher perceived level of competence, the children will show higher

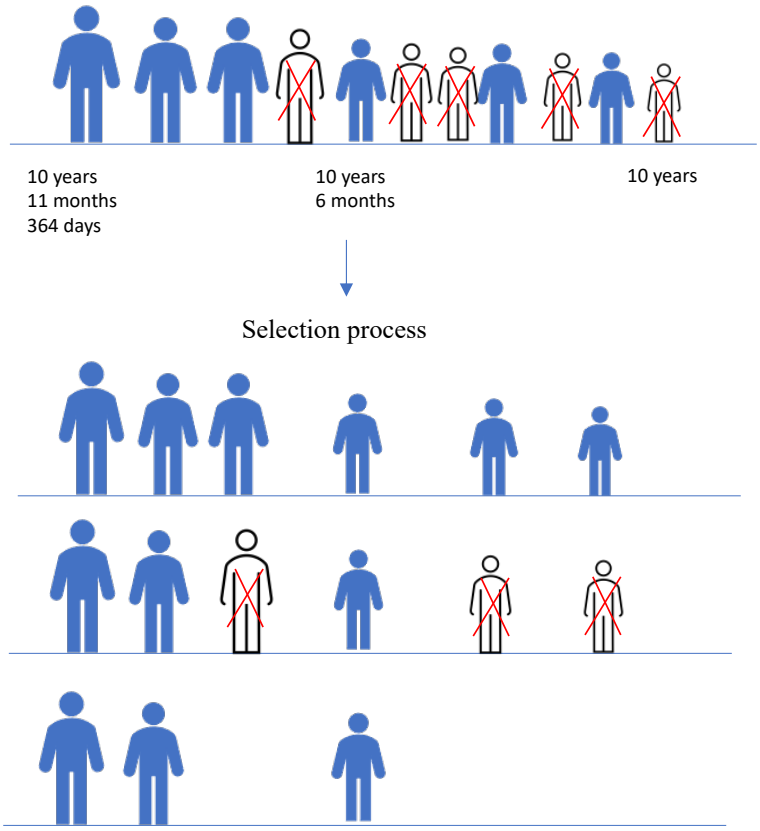
intrinsic motivation and report higher enjoyment than those who have low perceived competence. In other words, children born early are more intrinsically motivated and like to participate more than those born late. Moreover, the fact is that being born 11 months before for a 10-year-old child represents almost 10% more experience at this age.

RAE in team sports

RAE in *team sports* is often explained in terms of the selection process, where coaches often pay attention to players who are bigger, stronger, and faster than the others. These players will be more involved in the game, and they will receive more attention and feedback from the trainers and audience (Musch & Grondin, 2001). When the selection has taken place to create one group of athletes regarded as most talented, the group becomes more homogenous. In this new group of selected players, the same selection procedure will take place again. When this process is repeated again and again, a comparatively smaller percentage of athletes reach the next developmental stage within the system (see Figure 3). As a result, the selected athletes will survive in that system over time and the situation will continue in a vicious cycle for the relatively younger players. In this process the number of participants and the number of players selected for a higher level of competition will influence the existence of RAE (Schorer, Cobley, et al., 2009).

Figure 3

The selection process visualized. The selected athletes (blue) are grouped. In the new group of selected athletes, the same selection process is repeated again and again. (Inspired by https://ussa-my.com/publications/articles.php?artnum=82)



RAE in individual sports

There seem to be great variations in how the RAE exists in *individual sports*. Sports that are less dependent on physical characteristics and more dependent on technical skills are less likely to be related to RAE (Baker et al., 2014; Cobley et al., 2019). This is explained by the lesser advantage of being stronger and heavier than your peers. In individual sports the RAE is found among elite players in tennis, both in male and female players (Edgar & O'Donoghue, 2005). In swimming the effect is evident among both male and females,

regardless of types of swimming strokes in youth swimmers (Cobley et al., 2018). In alpine skiing, a review on RAE has shown the advantage of being born early in an annual year among youth skiers, adolescents, and adult skiers (Steidl-Müller, Hildebrandt, et al., 2019). Also in certain events in track and field the advantage of being born early is present (Allen & Hopkins, 2015). In combat sports, the RAE depends on the nature of the combat sport, where grappling combat sports (e.g., wrestling and judo) are more exposed to RAE due to higher physical requirements like higher anaerobic energy demands, body weight, and height than in striking combat sports (e.g., boxing and taekwondo) (Albuquerque et al., 2016). Many combat sports usually separate the athletes by weight to ensure as equal competition as possible and to prevent RAE, but in the meta-analysis by Albuquerque et al. (2016) the authors refute this notion as RAE still is observed in many combat sports. In taekwondo and boxing, technical and tactical skills play a key role, and therefore the RAE is more diverse, for instance it is not found among Olympic taekwondo athletes (Albuquerque et al., 2012). In heavier weight classes in, for example, judo, the RAE is found because there is no upper limit, resulting in an advantage for bigger, stronger, and earlier matured athletes among adolescents (Albuquerque et al., 2015).

In sports where increased length and weight of the athlete can be a disadvantage, e.g. in figure skating and gymnastics, where the aesthetic components are combined with a high degree of technical skills, a reverse effect is found (Baxter-Jones et al., 1995). This means that it is an advantage being born late in a cohort. However, some scholars in the field of RAE claim that the study of individual sports is valuable to investigate the mechanisms and limits of RAE since it is easier to discover and investigate the variables that may explain the effect (Baker et al., 2014, p. 188).

RAE and sex

RAE has historically found to be different between sexes. The effect is more dominant in *male* athlete sports than in *female* athlete sports (Cobley et al., 2009), and it is argued that sex appears to be the most important moderator for RAE (Baker et al., 2010). One reason for that may be that there is less competition and smaller groups in women's sport than in men's, and therefore there is no evidence for RAE in elite sports for women in handball, basket, and soccer (Goldschmied, 2011). Many studies which have included both male and female athletes have not found RAE among females, even if it is present among male athletes. That

said, in a review by (Cobley et al., 2009), only 2 % of the work done on RAE had investigated women´s sports, and some scholars suggest that the lack of research addressing RAE in women´s sports may be related to the lower interest and value placed on female sports as compared to male sports (Weir et al., 2010). Some scholars conclude that the effect is not there in female sports, or that the effects show differently among females. However, in a review by Smith et al. (2018), including 44 studies containing 308 samples, it was concluded that a small RAE is prevalent across female sport, more pronounced in pre-adolescents, and with higher competition levels, and more within sports associated with higher physiological demands. In this review it was found that female athletes born in Q1 are 25% more likely to be selected than females born in Q4. This means that most likely the same mechanisms of RAE will work among females, the prevalence depending on competition level and physiological demands, which is basically the same as in male sports. The higher the level of competition, the more likely will be the presence of RAE. Also, if the physical demands increase, and it is more advantageous to be stronger and heavier than your female peers, the presence of RAE will exist.

RAE and culture

Another aspect that influences the prevalence of RAE in a sport is its *cultural importance*. If it is regarded as culturally important to succeed in a particular sport, it is more likely that a RAE will exist in that country or region (Baker & Horton, 2004). In Canada, it is regarded as important to learn to skate at a young age, while long-distance running is important in Kenya, hence it is more important to succeed in that particular sport. If the country or region finds it important to succeed in a particular sport, it is more likely that there will be more sports facilities for that kind of sport, more political interest in the sport, and more attention from the media and from families. In Austria, where alpine skiing is a cornerstone of the sporting culture, interest in that country is very high (DeCouto et al., 2021). To enter ski boarding schools in this country will therefore be more difficult than in other cultures due to higher selection pressure, hence a selection bias will occur (Müller, Müller, Kornexl, et al., 2015). The existence of RAE has also been linked to city size, where the city needs to be large enough to provide competition among available members. If the city is too large, the participants will have a plurality of activities to participate in, and there will not be enough competition in that city (Cote et al., 2006). Suggested possible benefits for smaller towns and cities are increased access to sport facilities, a more integrated approach to participation that

involves families, schools, and the community, and also enhanced social support (Turnnidge et al., 2014). Large cities often offer a wide range of activities; consequently adolescents can choose another club or activity if they are not selected for the team. Research has found that if an athlete is born in a city that has between 50 000-100 000 residents, the chances of becoming an elite athlete increases substantially, with an optimal community size for development of between 1000 and 500 000. This is called the *birth place effect* (Baker et al., 2009).

Other considerations about RAE

A meta-analytical review performed on 38 studies, containing 253 independent samples from 14 sports in 16 different countries, showed that the RAE is lower at an elite level than in the early stages of skill development (Cobley et al., 2009). In many sports the advantages of being born early are found to be greater among children and youth sports, and then at around 15-16 years the advantage of being born early will slightly disappear as the late born children catch up with the maturating difference (Cobley et al., 2018). This means that the advantage of being born early seems to disappear or fades out at the elite level. One explanation for this is that the physiological advantages disappear at the senior level as all participants reach their final stage of physical development, especially in sports less dependent on physiological characteristics (Cobley et al., 2018). The disappearance of the effects is also explained by athletes' withdrawal from competitive level due to injury, overtraining, burnout, and boredom (Cobley et al., 2009). Some scholars argue that a "rocky road to success" is an advantage in becoming an established senior athlete since the athletes experience how to overcome small traumas on their talented pathway (Collins & MacNamara, 2012). In this way, the athletes have experience of not succeeding, hence overcoming this obstacle by finding a solution, and by developing a mental resilience to stay in the system (McCarthy & Collins, 2014). In one study by DeCouto et al. (2021), it was found that the relatively younger athletes compensate for this by attending training centers more frequently than their relatively older peers.

It is not always a disadvantage to be born late in a cohort. In some sports it is an advantage to be smaller and lighter than one's peers, like in gymnastics, where an *inverse of RAE* is found (Baker et al., 2014; Hancock et al., 2015). In sports that are artistic and aesthetic, it can be advantageous to be small due to the biomechanical advantages in performing some of the movements in, for example, gymnastic performances. Therefore, being less mature and

physically developed is superior in that activity. This means that athletes born late in an annual year are most likely to be selected for a team.

There can also be psychological reasons why it is advantageous to be born later than your peers. Ford and Williams (2011) found that the most award-winning athletes and the most valuable players in team sport (e.g., soccer, ice hockey, and baseball players) were more likely to be born late in the selection year. Gibbs et al. (2012) found that the RAE reversed at the elite level in ice hockey, and that relatively younger players endured a nearly one year longer career than their older peers did. In rugby and cricket data show that the relatively younger player were less likely to be selected into their national academy system, but they were more likely to go on to national senior level, indicating a reversal of the RAE advantage (McCarthy et al., 2016). Yet another study has shown that late born entrants into hockey were playing relatively more games and scoring more goals in NHL than those born early in a cohort (Deaner et al., 2013). In the German soccer Bundesliga, relatively younger players earned significantly higher wages compared with relatively older ones (Ashworth & Heyndels, 2007), underpinning the fact that those players are more valuable for the Bundesliga than the relatively older players. This reversed effect has been explained by the psychological consequence of the 'underdog-effect' where athletes develop resilience in the sport and a mindset such as mental toughness to overcome the disadvantage of being born relatively later (McCarthy & Collins, 2014). Another possible explanation for the inverse RAE is that the relatively younger athletes develop superior motor skills and tactical skills, which help them to persist in an unfavorable system (Baker et al., 2010).

Constituent year effect

There have been different terminologies in the field of relative age research. One of them stems from Masters sport, and is called the *constituent year effect* (CYE). Masters' sport consists of older athletes who systematically train to compete in organized sports and events that are only available to older athletes, like Masters' tournaments (Medic et al., 2007). In particular, Medic et al. (2007) have explained how the effects work in Masters' sport, where athletes are often grouped in multiple age bands (e.g. 40-44, 45-49 years). Even though there are a large number of studies on RAE, relatively few studies have focused on the impact of age groupings that differ from the annual system. Medic and colleagues (2007) examined the National/World records in Masters' competitions for each constituent and successive year of

various 5-year age bands. They found that athletes who were relatively younger performed at a better level than relatively older athletes in the same cohort, which means that those who were 40 years old performed at a better level than those who were 44 years old. Medic and colleagues referred to this as the *constituent year effect,* which is an extension of the RAE concept. While the RAE concept typically refers to a within-one year effect, the constituent year effect refers to multiyear age bands, typically in a 5-year age band.

In a multi-year age band, the effects of age will be more visible because the age works over a larger time span. The focus is not on the differences in a cohort for each month, but rather is the effect of being born in different years that make up categories studied. Schorer et al. (2013) distinguish between the within-1-year and within-2-year effects of the relative age, where the selection typically spans over 12 months or 24 months respectively.

This switch, from having the advantage of being relatively older than your peers, which is the most typical RAE, to gaining an advantage from being relatively younger than your peers, is interesting. This change to the reversal of the effect among adults and Masters´ sport has been associated with a decline in peak performance since it is connected to decline at a certain age. The decline in peak performance varies with the sport, as sports which depend largely on physiological characteristics have a peak age of around 30 years, while for those who depend on cognitive skills the peak age increases to at least 60 years since experience, tactics, and cognitive evaluations are less likely to disappear (Allen & Hopkins, 2015). The use of RAE has been widely used in youth sport and in investigating the short-term effects, and in competitions where physical characteristics are dominant, it can lead to biases in age distribution. The long-term effects have been less studied, but knowledge from Masters' sports and insight into elite sports may reveal some of the effects over time.

Another concept of group categorization is the *constant year effect*, where the multiyear groupings are fixed (constant) across the youth sport development (Schorer et al., 2013). In the latter, the relatively younger athletes never benefit from being relatively older than their peers. This is different from the constituent year effect because in a CYE system the persons who are the youngest through the age development alternate, while in a constant year effect the youngest athletes always remain the youngest, which is disadvantageous for the youngest athletes (see Schorer et al., 2013).

Growth and development

When discussing development among children, there are three distinct processes that are different to each other: growth, maturation, and development (Malina, 2014). The internal cellular process is not so easy to detect, but some of these processes can be observed directly as a consequence of the internal processes that occur. Height and sexual maturity are two of these. In most studies dealing with growth development, girls are physically mature earlier than boys. On average, girls reach the peak height velocity (PHV) two years earlier than boys, and pre-pubertal children at the same chronological age may have a difference of 4 years in their skeletal age (Malina, 2014). There are several studies that have investigated the anthropometrics of different athletes in order to understand performance in sports. A study by Wong et al. (2009) investigated the relationship between anthropometric and physiological characteristics in youth soccer players, and they found a relationship between the shooting speed of the ball with body mass and physiological tests with body mass, favoring those who are earlier mature. Also among youth ice hockey players it has been found to be advantageous to be biologically mature as it increases the chances of being selected at ice hockey selection camps (Lauren B. Sherar et al., 2007). In figure skating, different anthropometry and somatotype at different performance levels in female skaters has been investigated (Monsma et al., 2005). This study found that figure skaters are lighter, leaner, and of a different somatotype than free skaters and pair skaters, and that this is associated with the characteristics of the sport. In sports where late maturation is advantageous, like dance, there is no RAE (van Rossum, 2006). Many of the studies where RAEs are found to be strong have been performed on adolescents and young children. In the longer term, studies propose that maturation inequalities will disappear or be transient in an athlete's development (Cobley, Abbott et al., 2018).

Relevance for this thesis

This thesis will take a closer look at the variations of relative age effect in order to understand the mechanisms of RAE. As has been shown, there are great variations in how the effect is visible. In modern society people are grouped together in cohorts, and this grouping leads to skewedness in the distribution of participants. In activities where people are assessed with each other, where they compete against each other, or where there is a selection process, research shows that there is an advantage to being born early in a cohort. The advantage is

moderated by the nature of the activity, and by other moderators such as type of activity, sex, and level of performance. In activities where there is an advantage by being stronger, heavier, or taller, it is advantageous to be born early in a cohort. The same applies with cognitive skills. Conversely, in situations and competitions where the advantage is to be smaller and lighter than your peers, there is an inverse RAE with more people born late in the cohort. The RAE varies between male and female athletes in sports having elements of technical skills, or in sports where several age bands compete together, or even in what kind of cultural framework the activity exists within. At some point, the advantage of being older and stronger seems to switch to being a disadvantage. In this plethora of activities there are variations in RAE, and to understand these variations there is a need for a theoretical framework that can contribute to understanding the variations and the complexity. This will be elaborated in the next section.

Theoretical perspective

Maturation selection hypothesis

Research on relative age effects is being criticized for the lack of a theoretical framework (Cobley, Abraham, et al., 2008). There have been several attempts to explain why RAE exists, the most common being *the maturation selection hypothesis* (Cobley et al., 2009; Helsen et al., 2000). This explanation suggests that there is a greater likelihood of being selected in competitions for those with stronger physical characteristics (e.g., body mass index, aerobic and anaerobic power, muscular strength) amongst athletes with higher chronological age (Baker et al., 2003; Musch & Grondin, 2001). According to this theory chronological age reflects greater maturation at any given time, and this explains the developmental advantages (Baker et al., 2010). Being relatively older than the other participants in the same group might contribute to higher individual performances, especially in sports or situations requiring power, speed, and endurance (Schorer, Cobley, et al., 2009).

A complementary explanation to the maturation hypothesis describes the process further, and has been referred to as *the social agent model* (Dixon et al., 2020). This process involves the relatively older participants being selected by coaches (partly) due to their physical advantages, which in turn influences the training volume and the possibility to compete against opponents who match their skills and competition level (Musch & Grondin, 2001). The relatively younger athletes, and perhaps their non-selected peers, will not get this opportunity. This can lead to self-fulfilling prophecy theories like *the Rosenthal effect* (Rosenthal & Jacobson, 1968). The Rosenthal effect is a psychological effect that was first discovered in education and describes how expectations may alter the view of those being observed. Their experiment consisted of teachers being misinformed before teaching. Before the teachers met a new class, they were told that some of the students were extra gifted and intelligent, while others were not, even if the class was quite homogeneous. As a result of this information, the teachers acted differently towards their students, and the teachers paid extra attention to those students who were more `talented` and treated them as if they were more gifted, resulting in a better outcome. The students who were ´less intelligent´ received less attention with an inferior outcome. This Rosenthal effect therefore became an example of how self-fulfilling prophecies work. Another term related to the Rosenthal-effect is the *Pygmalion effect*. The Pygmalion effect refers to the perception that the more an individual has great expectations placed upon them, the better the result will be (Hancock et al., 2013).

Conversely, if there are low expectations, the outcome will decrease accordingly. For instance, in an education setting, if one student is told that there is an expectation of high grades and good results, the student will act according to that expectation. The same mechanisms occur in other competition settings, and these self-fulfilling prophecies have become one of the explanations for RAE, because athletes who are stronger, bigger, and more mature than others receive more attention from coaches, parents and the surroundings. The Pygmalion effect is generated in many power relationships, such as teacher-student, boss-employee and coach-athlete (Hancock et al., 2013).

Another form of self-fulfilling prophecy is the *Galethea effect* proposed by Merton (Hancock et al., 2013). While the Pygmalion effect describes the teachers' expectations of the students, the Galetea effects refers to the students' expectations of themselves. Thus, if a student falsely believes that they are more gifted than their peers, they start to act as if they are more gifted. This will maybe change their behavior to attend more training sessions and have higher self-confidence than their peers, and eventually becoming more skilled than them.

Yet another explanation can also be described as *the Matthew effect*. The Matthew effect is found in many reward and competitive systems like education, economics, and in the allocation of scientific resources (Merton, 1968). The Matthew effect describes a phenomenon where rich people get richer, poor people get poorer, and so forth (see Hancock Adler, Côté, 2013 for review). For example, students with good reading skills tend to read more frequently, thereby increasing their reading skills exponentially. Their self-expectations will increase, encouraging more practice and further self-expectations. The advantage that one student or athlete gains in the beginning therefore tends to persist over time. The same mechanisms are believed to occur in other competitive contexts: the better skilled person will be encouraged by performing that particular skill over and over again, thereby receiving extra training and practice.

Collectively, these concepts and theories are related to social agents and propose an integrated theoretical model for explaining how RAE works. According to these concepts and theories, athletes in a sport would attempt to perform according to the expectations of social agents (coaches, parents, peers), hence increasing the effort to perform in line with these expectations.

Relevance for this thesis

The nature of RAE research is to compare birth dates in a certain cohort. Therefore, investigating how age is distributed in a group consisting of the absolute best athletes in the world in specific skills may explain some of the differences in participation and in performance. Much of the research has investigated biological maturity, shown by differences in anthropometric variables, like leg length, weight, and strength. The literature shows that biological maturity reflects chronological age and that there are great variations. However, the research is not cohesive in that maturation is the most important variable and moderator for RAE, as some claim that sex is the most important moderator. Psychological factors have not been studied in this thesis, but the aspects of self-fulfilling prophesies can easily be linked to competitions and assessment situations and may explain some of the variations in RAE. The variations need to be further elaborated and discussed and will be explained by a theoretical perspective in the next section.

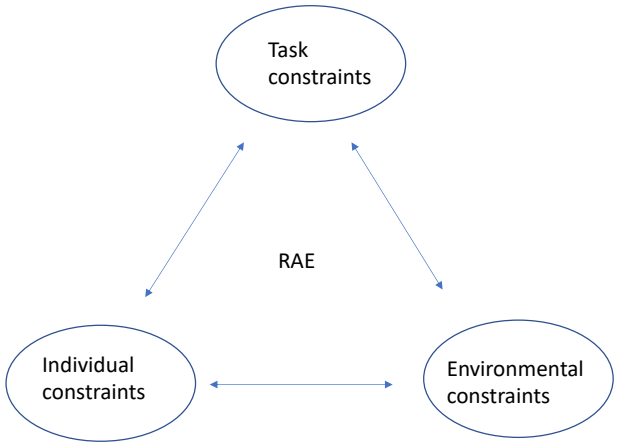
The constraint-based framework.

The relative age effect could be said to be a complex phenomenon as it varies in magnitude and in expression in different situations, and the research has mainly centered around discovering new sports and contexts where the RAE occurs with its potential consequences. One theory to understand complex theories is the ***constraint-based framework,*** which is rooted in the dynamical systems theory, a theory which originates from the Russian physiologist Nicholai A. Bernstein (Bernstein, 1967). The dynamical system theory has traditionally been applied in explaining motor behavior and the coordination of complex movements (Kelso, 1995; Kugler et al., 1980), but has also been used to attempt to explain other complex systems in education (Koopmans & Stamovlasis, 2016) and sports (Davids, Hristovski, et al., 2013). The principles in dynamical systems theories are the same as how other complex systems are organized, irrespective of whether the system is molecules, cells, words, people, or human organizations (Koopmans & Stamovlasis, 2016). The dynamical systems theory has moved in different directions, but all the directions are based on the same tenets.

The constraint-based framework underpins many of the same key elements as the dynamical systems theory, and has tried to translate a theoretical approach to a coaching practice, making the theory more comprehensible (Davids et al., 2005). Hence, it is also known as the constraint-led approach (CLA) as it describes how teachers and coaches use the constraint framework as a tool to enhance learning in a practical setting. Further in this thesis the constraint-based framework and constraint-led approach will be used interchangeably since they are built upon the same tenets. The constraint-based framework takes its departure point in the model of Karl M. Newell's (1986) dynamical model of constraints. According to Newell, "constraints may be viewed as boundaries or features that limit limb motion of the entity under consideration" (Newell, 1986, p. 347). Essential in this theory is the view that in complex systems, like the human body, behavior or movements arise as a consequence of three different constraints that work on the body in a non-linear way (see Figure 4). The movement results from the interacting network of three categories of constraints: the individual (organism), the task, and the environment. Therefore, a more contemporary view of the constraints can be explained as "information to shape or guide the (re)organization of a complex adaptive system" (Renshaw et al., 2019, p. 14). These constraints includes emotions, cognitive processes, morphology, intentions, physiology, and cultural and social factors (Renshaw & Chow, 2019). The CLA was introduced in 1994 and is founded on the dynamics and integration between theory, science, and knowledge from applied practices in sport (Renshaw et al., 2019). In Figure 4, it displays how the RAE can be understood in the same way, emerging as a consequence from the three different constraints, the individual constraint, the environmental constraints and the task constraints. Both the content in each category and the dynamics between the constraints will be further elaborated in the next section.

Figure 4

The relative age effect (RAE) emerges as a result of three categories of constraints.



The dynamics of constraints

An important principle in the constraint-based framework is that a person can be viewed as a movement system that contains nonlinear properties, and that the changing of one factor will subsequently affect another. This nonlinearity is based on the key principle of self-organization which is inspired from the principles in stable and unstable patterns in thermodynamic equilibrium (Kugler et al., 1980). Understood in terms of movement, it means that different subsystems (e.g., joints, muscles, limbs) of the learner organize themselves in a way which is most energy efficient for that person.

Another key element in this theory is how stable patterns emerge and how new patterns arise, a characteristic known as multi-stability (Davids, Hristovski, et al., 2013). A stable pattern is achieved as a consequence of the three interacting constraints, and a new movement pattern arises as a consequence. The new pattern is established because the moving system will, e.g., save energy consumption. One example of this could be a walking pattern and energy consumption, which is based on the research by Hoyt and Taylor (1981), which, explains that everyone has an individual and preferred walking pattern and walking speed. If the speed increases, a shift in movement pattern from walking to running will take place at a particular speed (around 2.4 ms^{-1}). The rate of speed depends on the constraints of action, which are leg length, fatigue (individual constraints), the surface and obstacles where you are running

(environmental constraints), and the task constraints (rules, regulations, and types of shoes, for instance). The shift in movement pattern is a result of the system moving in a more energy efficient way, and this shift in pattern occurs as a result of the interacting constraints, and the shift is self-organized due to these constraints on action.

In order to reorganize from one stable pattern to another, there is a need to perturb the system in such a way that the system reorganizes into a new stable pattern (Kelso, 1995). This means that new performance levels can emerge out of the fluctuations which exist in the system's instability, as increased speed will be in a walking pattern as exemplified in the previous section. Similarly, a small change in one organismic constraint can lead to a dramatic effect on the total performance or the movement pattern (Renshaw et al., 2010). One example of a change in a structural constraint is an injury in one foot, which will have a great impact on the walking pattern, but the person still finds their own solution in how to walk based on the other constraints. If a person who succeeds and increases their self-confidence, a change in the performer's functional constraint could lead to transitions to a new stable state. Conversely, mistakes, injuries, or traumatic experiences can move the performer's system to a less stable state. This multi-stability could manifest itself for athletes in several ways, and a change in task constraints may influence the stability of the performance. These changes were shown in equipment changes (e.g. the change from a bamboo to fiberglass pole in pole vaults), a change in playing surface (e.g. artificial grass instead of grass in soccer), and change of rules (e.g. the back pass rule in soccer) that produce a huge change in the performance (Davids, Hristovski, et al., 2013). Also, within a sport, the presence of spectators influencing the performer can be a perturbation that highly affects the performance by destabilizing an existing pattern. According to the constraint-based approach to expertise development, the task is to become an expert at exploiting the informational constraint and to stabilize the intended performance (Davids, Araújo, et al., 2013).

Even if the CLA was originally launched as a practical tool for coaches and educators to teach athletes in a non-linear approach, it has been applied to understand complexity in both education (Koopmans & Stamovlasis, 2016) and in different sport competitions, both in dyadic (one-to-one, e.g., squash) and team competitions (Davids, Hristovski, et al., 2013; McGarry et al., 2002). In fact, in 2016 the constraint-based framework was launched as an idea of a grand unified theory (GUT) of sports performance (Glazier, 2017). A central tenet of this GUT theory is that all levels of analysis of performance outcomes (intra- and inter-

individual levels) emerge from the interacting organismic, environmental, and task constraints which were launched by Newell (1986), hence promoting a more holistic approach to sport performance across different levels of analysis. The description of the constraints will be given in the next section.

Organismic constraints

Organismic constraints refer to a person's individual characteristics, and hence these constraints are also termed *individual constraints* (see Haywood & Getchell, 2019) or *performer constraints* (Davids et al., 2005), and they are used interchangeably. Organismic constraints can be viewed as relatively time dependent or time independent, often called structural or functional, respectively (Newell, 1986). *Structural factors* are those factors which develop at a slower rate, like change of body weight, height, and shape. On the other hand, time dependent factors are faster and functional, like synaptic connections in the nervous system. Structural factors (i.e. height, weight, genetic) will therefore include biological age, since the onset of puberty varies among genders and between persons (Baker & Horton, 2004). The timing of maturation can be very different within a specific age group. The increase of height and weight will influence movement due to the biomechanical changes in the individual. For example, in alpine skiing an increasing height will influence the center of gravity, the leg length will increase, the body weight will be affected, thus increasing the potential energy of the skiers, which again influences the forces in a slalom turn at high speed. Another structural factor is gender. Usually the RAE is not consistently shown among female athletes, but in a recent review the prevalence of RAE among females is shown to exist, though less expressed than among males (Smith et al., 2018).

The *functional factor* also includes cognitive elements like motivation, fear, attentional focus, and those factors that can change over a shorter period of time (Haywood & Getchell, 2019). While growth and maturation are biological processes that take time, development is mainly a behavioral process that is underpinned by sociological processes specific to the culture (Malina, 2014). The individual constraints embrace everything linked to the performer, which also include the amount of training and previous experience (Davids et al., 2005).

These individual constraints provide affordances (or opportunities) for movements and illustrate how different person-related factors can be used to solve a movement problem, e.g.,

how to ski as fast as possible. The constraints can also be seen as resources in how individuals channel their way of solving the same movement problem, for instance using the missing strength by compensating with higher agility.

Task constraints

Task constraints are the rules, the goals, and the demands from the sport. According to (Newell, 1986), task constraints can comprise three categories. The first category includes constraints related to the *goal of the task*, the second *the rules* specifying or constraining the response dynamics, and the third category *implements or machines* specifying or constraining response dynamics. This can be exemplified in alpine skiing where the rules from FIS regulate the distance between gates, the minimum vertical drop of the hill (called homologation), rules of the ski length, etc. The rules constrain the action, as different skis require different techniques. The implements or machines can be exemplified by the equipment used, which highly shapes the behavior, such as ski length, boot support, and so on. In a sport like alpine skiing the skiers spend much time adapting and attuning the skis and boots before each season, which is called the preparation period (Gilgien et al., 2018). The success in a particular sport is underpinned by the qualities of strength, agility, flexibility, as well as rules or goals of a particular sport (Wattie et al., 2015). Succeeding in sport depends on how performers exploit the rules, and this ability to exploit the constraints may even create new sports, e.g., the ski skating technique in cross country invented in the late 80´s by Bill Koch, or the V-style technique in ski jumping by Jan Boklöv, or even the clap skate in speed skating (Stefani, 2000). The invention of carving skis is also an example of how alterations in equipment constrain the movement action (task constraint). To give an example from a team sport, there was a change of rules for goal keepers in soccer, namely the back-pass rule in 1992, where the keeper was not allowed to pick up the ball from a back-pass from players on their own team, which in turn affected the tactical elements in the game. Other task constraints are the size of the court, or the amount of players which is used to increase the intensity of the play and the number of ball contacts in soccer (Clemente et al., 2012).

Environmental constraints

Environmental constraints refer to those constraints that are external to the performer. Newell (1986) distinguished between those environmental constraints that are general and those that are task-specific. General environmental constraints are global, physical variables in nature

such as temperature, altitude, and light. Task-specific environmental constraints are the terrain, the slope style and snow conditions. However, the "[e]nvironmental constraints and the task constraints are not mutually exclusive as their definition depends on the nature of the task" (Newell, 1986, p. 350). This means that any change in the constraints affects a change in a specific movement outcome, and that there are sliding changes between the different constraints. Another characteristic of environmental constraints is that they are either physical or social, which means that environmental constraints also includes social constraints such peer groups, social attitudes, and culture (Davids et al., 2005). Especially among younger learners, involvement in an activity is strongly dependent on how society views the involvement. This could either be attitudes from the surroundings, or if there is a culture for that type of activity. This is exemplified in an activity where the whole of society is involved, like the example from Austria, where alpine skiing is a major interest in the country as it is directly or indirectly involved in alpine tourism and culture. Similarly, American football has a great impact in the USA, where the sport is given much time and coverage in media and advertisements, e.g., the Super Bowl.

The environmental constraint also works within a country or region, where some sports are regarded as important in that area. Moreover within a city or club, or even a certain age group, environmental constraints play an important role in influencing a certain cohort. For instance, in football the environment of the age group of Erling Braut Haaland has been the scope for particular case study, aiming to understand how a club can foster players to perform at an international level (Erikstad et al., 2021).

The application of a constraint-based framework.

The constraint-based framework has proved itself also to be suitable to explain conditions other than motor learning. Previously it has described ways to expertise (Araújo et al., 2010), where the interacting constraints have been elaborated. In this paper, the environmental constraints are in particular elaborated in discussing the interaction of internal and external constraints to performance. This is analyzed using Bronfenbrenner´s bio-ecological model. The framework of constraints has also described learning in educational settings (Ennis, 1992), where especially the learning process of each student is analyzed using concepts from

dynamical theories. This model has also been applied to understand skill acquisition and game play (Renshaw et al., 2010), where the CLA is a practical tool for physical education teachers to understand how learning takes place. It is especially as a practical tool that the CLA has been used before, either to help physical education teachers to design appropriate learning tasks (Davids et al., 2005) or in aiding teachers designing a learning landscape in physical education (Roberts et al., 2019). Additionally, the CLA has also been applied to understand talent development in sports, where the interacting constraints have been analyzed in terms of performance and the effect of relative age (Araújo et al., 2010; Baker et al., 2012; Phillips et al., 2010). The constraint-based framework has also been used to explain the relative age effect, but merely as a theoretical approach, not supplied by data (Wattie et al., 2015).

In the next section the different constraint categories in this constraint-based framework will be further explained in order to understand RAE. By using the framework of constraints, this can help in understanding the dynamics of the complexity in RAE.

Relevance for this thesis

The constraint-based framework is a model where a complex system can be distributed into three different constraints. This model can be helpful in order to gain insight into how different variables influence the complex system. The present thesis argues that the RAE can emerge as a consequence of the different interacting constraints. The individual (organismic) constraints are those factors related to different maturation of the individual, both structural (genes) and functional (motivation). The environmental constraints are those factors that describe the performance environment and culture impact on the RAE. Task constraints are both the rules that a skier works within in terms of gate distance and ranking rules. It could also be the skiers' skis and boots. These will be further elaborated on in the next section.

The complexity of relative age effects – applications of a constraint-based framework in alpine skiing

Many studies on RAE have recommended that future research should be grounded on theoretical foundations (Cobley et al., 2009). Wattie et al. (2015) proposed the constraint-based model, based on the dynamical systems theory approach to the research on relative age studies. In the following section, an overview is presented on how the relative age effect can be understood in terms of a constraint-based framework. Using the theory may help to understand how the RAE in competitions can emerge from the interactions of different constraints. In this section, most examples are from situations where the competition is most pronounced, in sports.

In using a constraint-based framework to understand RAE, the birth date can be classified as an *organismic structural constraint*. Previously, genetic material and hereditary characteristics of the athletes have been termed *primary factors* (Baker & Horton, 2004). The variability between chronological and biological age is a very important individual constraint since the onset of puberty is highly variable (Wormhoudt et al., 2017). The chronological age describes the number of years and days a person has been alive, while the biological maturity age often uses the onset of peak height velocity as an indicator of biological maturity (Mirwald et al., 2002).

Having an early onset of puberty means that you are early mature, and that is often regarded as advantageous in selection processes. This was confirmed among ice hockey players (Lauren B Sherar et al., 2007), where every one-month increase in age at peak height velocity (later matured) decreased the probability of being selected to play for the ice hockey team by 17%; thus the team selectors appear to prefer earlier matured players in their squad. In an individual sport, Müller, Müller, Hildebrandt, et al. (2016) found that alpine skiers who were biologically early matured were selected in youth ski-racing. The study showed that relatively younger skiers were selected for provincial and national teams if the skiers were biologically mature, measured from calculations on body mass, body height, sitting height, and leg length. Maturity is often displayed in terms of having more muscles and being stronger than the relatively younger individuals in the cohort. The higher the biological status the more likely the skiers are to reach the national final. Skiers who are less mature will try to compensate for this disadvantage by finding other strategies to counter the disadvantage. One strategy to compensate for the physical disadvantage was found by DeCouto et al. (2021), who

discovered that relatively younger skiers engaged more in individual and group practices in training centers than their peers. This demonstrates that if an athlete has disadvantageous constraints in e.g., organismic structural constraints, they find strategies for compensating for that constraint by other functional organismic constraints. There are findings which support that successful athletes possess some characteristics that deviate from non-experts, like higher levels of self-confidence, better concentration, and the ability to think more positively (Williams & Krane, 2001).

While organismic constraints are a vital factor in any theory of RAE, the *task constraints* are also essential. The task constraints describe the rules of the competition, which vary according to the type of sport. In a sport like basketball, where the rim is placed 10 feet (3 meters) off the ground, the height of the players is a valuable characteristic, and those athletes who are tall will be selected in the selection process (Delorme & Raspaud, 2009). In sports like ice hockey, the size of the players is significant, where strong and heavy players are superior in the tackling of other players, which promotes players that are born early in the cohort (Barnsley et al., 1988). Conversely, in sports like gymnastics, being smaller than your peers is an advantage due to biomechanical disadvantages (Baker et al., 2014). The competition rules necessitate different participant traits due to different demands from the sport. The nature of the task may also constrain some other characteristics of the tactical kind, like the advantage of being left-handed/footed in soccer (Verbeek et al., 2017), or regarding player positions in handball (Schorer, Cobley, et al., 2009). There is also research showing that being left-handed in tennis may compensate for the existing RAE (Loffing et al., 2010).

There are several characteristics that could be seen as *environmental constraints* in competitions. One of the most investigated factors is the effect of training hours in skill learning. A famous study is that of Ericsson et al. (1993) and the role of “deliberate practice”, which is relevant and requires effortful practice, is not inherently enjoyable, with the intention of improving performance. Their research with elite and non-elite musicians concludes that one primary factor that separates elite versus non-elite musicians is the number of hours spent on deliberate practice. The top musicians accumulated over 10 000 hours of deliberate practice on average, and this expresses the importance of training quality, and also the large variations in amount of practice (Ericsson, 2014). The research on accumulated effects of prolonged practice indicates that performance improves according to the power function, which is explained as the *power law of practice* (Newell & Rosenbloom, 1981). This law

expresses that the learning rate is rapid right after the onset of learning, but the improvement rate reduces over time with practice. This paper has led to a huge debate on how athletes should train to reach the expert level. While "deliberate practice" favors effortful practice, the "deliberate play" approach represents non-organized, and peer led activity with a broader range of activities. Ericsson et al. (1993) discuss and emphasize that in addition to the accumulated effect of training hours, the *quality of the training* is important in producing a superior performance. Thus, the training environment, both physically and socially, plays an essential role in developing the person's skills. An important observation is that the amount of training hours differs greatly, indicating a huge individual variation, and the individuality is an important message from the dynamical systems theory.

Another factor within environmental constraint could be the assumption that persons need some kind of resistance on their way to top performance in order to become superior in their development path, and that persons in competitions become stronger mentally if they meet some kind of resistance on their way to superiority. This has been studied within sports and is characterized as "talents need trauma" (Collins et al., 2016b) or "a bumpy road to success" (Collins et al., 2016a). Having an environment that is challenging seems to be important, and the advantage is mostly on the psychological level where the athletes are enabled to cope with the ups and downs in the development (MacNamara et al., 2010). What seems to characterize athletes who have become super champions is that they approach a challenge with an attitude and a proactive approach in terms of 'learning from the challenge', even prior to their start on the rocky road of development (Collins et al., 2016b). In order to explain the disappearance of RAE among elite athletes, McCarthy and Collins (2014) explain the success in psychological growth and the fact that late bloomers have the experience of a rocky road in gaining advantage. This is what is called the underdog effect (Gibbs et al., 2012).

The *culture* of where the competition takes place, and its importance in that region, could be seen as an environmental constraint (Baker & Horton, 2004; Steidl-Müller, Müller, et al., 2019). For instance, in Kenya it is of high cultural importance to be a good runner, and in Austria it is regarded as important to be skilled in alpine skiing (Baker & Horton, 2004), or in ice-hockey in North America (Wattie et al., 2008). Support from the family is also of importance, especially from the parents (Côté et al., 2003). During the first years, parents play a role in encouraging their child, while in later stages of the career development parents are important both financially and in terms of time commitment (Côté, 1999). Yet another

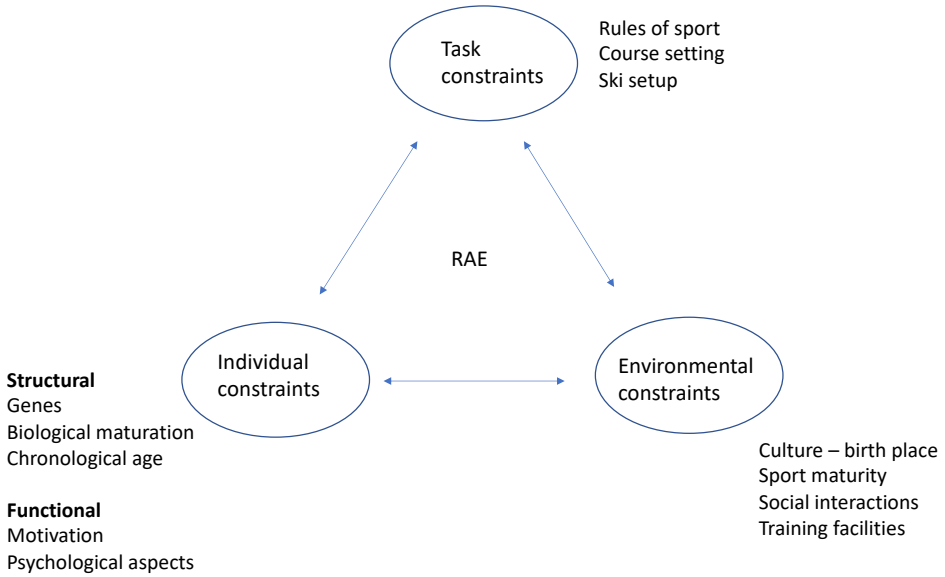
environmental constraint is the *sport maturity* (Baker & Horton, 2004). In sports which are relatively new or less developed/established the athletes can become athletes and experts with less training than in sports with a longer tradition. Even the *city size* is an environmental constraint. In a study which investigated the effect of birthplace and the size of the city (Turnnidge et al., 2014) it is argued that being born in cities with a population of between 50 000 and 100 000 produces the best odds of being overrepresented at an elite level. In cities bigger than 500 000 the range of leisure time activities is great, and alternative activities and variations in activities are an option for those children dropping out of a particular sport. Competition is a necessary condition for RAE (Musch & Grondin, 2001).

While psychological factors are within the organismic constraint, there are sliding or overlapping effects between organismic and environmental constraints. One example illustrating this is the overlap between environmental and organismic constraints. While the amount of training and previous experience are viewed as an organismic constraint, the number of hours spent on training and the possibilities that surround the individual are viewed as external, thus an environmental constraint to developing the athlete. Another example is motivation as a functional organismic constraint, where motivation can be influenced by the environment, such as in appraisal from parents, peers, and trainers. There is an example of motor learning being enhanced if the learners receive (false) positive feedback (Wulf et al., 2010). This clearly implies that there is an interaction between organismic and environmental constraints.

To summarize these factors, these interactions can be explained in Figure 5:

Figure 5

The constraint model modified towards alpine skiing



The bidirectional arrows indicate that the effect of RAE cannot exist without the different constraints. The individual constraint birth date does not lead to a RAE if there are no social constructs in organizing people into cohorts. Additionally, the sport itself in formulating the rules and regulations also influences how the RAE emerges. Thus, the nature of the activity highly influences the RAE.

Most of the research on RAE has been performed in finding new areas where the phenomenon exists. The usual explanation has been linked to the maturation hypothesis, with additional explanation through the Matthew effect and self-fulfilling prophecy. The mechanisms of the variations of the findings are not explained to the same extent. Therefore, in this thesis the RAE in terms of Karl M. Newell´s model of constraints (Newell, 1986) will be further discussed and elaborated in the discussion of this thesis.

Methodology

Methodological considerations

Before outlining the methods used in the present thesis, it can be fruitful to provide some information about the methodological considerations at issue. This will be done by giving a brief description of my ontological and epistemological considerations, and by explaining the research context.

Ontological and epistemological considerations

Research aims to describe the world as it is, and researchers need to be aware of how new understanding is constructed. While ontology seeks to classify and to explain entities ("what it is" and "what is there to be known") the epistemology poses questions around the philosophies of knowledge ("what is knowledge" and "how sure are we about knowledge") (Hartas, 2015). In this construction of knowledge, a framework, or lens, is used to understand and apprehend the worldview. This worldview is also known as the paradigm, which is a general perspective that facilitates our understanding and helps us to break down the complexity of the world (Patton, 1982).

In RAE research, researchers have typically been divided over the respective importance of environmental and biological contributions to succeed in competitions (Baker & Horton, 2004). Those who are dedicated environmentalists support the view that superiority is a result of learning and experience, while those who support that biological determinism and genetic factors are determinants for success, hold personality and traits responsible for success. This worldview and debate has been portrayed as the nature vs nurture debate, first described by Francis Galton in 1874 (Baker et al., 2003) and describing the relative contribution of the genes (nature) and the environment (nurture) in a person's high levels of achievements (Davids & Baker, 2007). In the search for contributions of these worldviews, RAE research has examined a wide variety of competitions, such as education and health, but the largest contribution to this research is carried out in the field of sports. And within the sport genre, most of the research has been carried out in team sports like ice-hockey and soccer. Relatively few studies have been carried out in individual sports, some scholars even claiming that "examination of individual sports may prove more valuable to uncovering the precise

mechanisms and limits of the RAE in sport because it is easier to identify the variables that may confound the effect" (Baker et al., 2014, p. 188).

Concerning the epistemological context of research in RAE, one can argue that the research is within the paradigm of positivism, as positivism recognizes that knowledge can be derived directly from observed data (Hartas, 2015). The positivist thinks of the world in an ordered way where relationships are controllable and predictable and follow universal laws and patterns of behavior (Cohen et al., 2018). This view often includes a focus on the natural world and examines relationships between variables. Positivists favor quantitative methods and subscribe to the idea that using the correct technique will provide the correct answers (Savin-Baden & Major, 2013). Research in RAE is based on the month of birth, thus numeric data. Based on the construct of what time of the year a person is born compared with distribution of the population, and measurements of success, so the focus is on understanding and explaining the RAE based on the data.

However, the research also realizes that the observations can contain errors, and that data does not contain the absolute truth. Thus, the research can be framed and positioned in a *post-positivistic* view. In a post-positivistic view, observation and measurements are the core in the scientific attempt to understand complexity in the world (Hartas, 2015). There is additional information about the athletes, which is difficult to uncover when merely investigating the month of birth. There are familiar aspects, like support from the family, training facilities, and motivational aspects that cannot be revealed by investigating the birth dates. The post-positivistic view acknowledges that observations are loaded with theory and values (Cohen et al., 2018).

RAE research has been criticized for being atheoretical (Cobley, Abraham, et al., 2008; Cobley et al., 2009). The explanations need to be further considered in a theoretical framework. Hitherto, very few studies have explained the RAE using terms from the dynamical systems approach generally or the constraint-based framework specifically. One paper (Wattie et al., 2015) has tried to understand the concept of relative age effects from a constraint-based developmental systems model. However, their study was purely theoretical without support from data. Therefore, in this thesis, with the support of empiric data, an attempt will be made to explain the variations within aspects of relative age effects in competitive environments, using top athletes in alpine skiing.

The present thesis falls in line with the post-positivistic view since the data is interpreted and comes from theory, although the basis of the research is grounded on numeric data. The results in each paper are analyzed and interpreted from previous research and the existing paradigm of the RAE tradition. The overarching analysis is discussed from a theoretical perspective, using the dynamical systems approach. The aim of the discussion is to use theory in understanding the variations in relative age effects in competitions – using alpine skiing as an example.

Methods

The present thesis is based on a post-positivistic approach, as described in the previous section. The papers in this thesis are written based on data from a quantitative approach, which is in line with a positivistic view (Savin-Baden & Major, 2013). However, the thesis acknowledges that the data needs to be interpreted in order to make sense and to understand the mechanisms in relative age effects. Therefore, it might be said that the overarching approach to this thesis is a post-positivistic approach.

Research context

The FIS system

The International Ski Federation - Fédération Internationale de Ski (FIS) - was founded in 1910, and is the highest governing body for international winter sports, consisting of the six Olympic disciplines: alpine skiing, cross country, ski jumping, Nordic combined, freestyle skiing, and snowboarding. The federation organizes the World Cup competitions and the World Championships for all disciplines.

The World Cup in alpine skiing races contains the best skiers in the world. This is a tournament where each country can send a limited number of skiers. The tournament starts each year in late October in the same place (Sölden) and consists of approximately 40 races for each gender in different events: slalom (SL), giant slalom (GS), super-G (SG), and downhill (DH) (FIS, 2015). In addition, one event is combined, which consists of one run of slalom and one run downhill. In order to change the sport to be attractive to spectators, new events have been included, like parallel slalom (from the year 2015).

The ranking system

The ranking is based on points in the FIS system, and the ranking list is updated several times a year [1]. Based on an intricate system of performances in FIS races, the skiers can improve their FIS points, and hence their international ranking in each event. One skier can therefore have a good FIS point ranking in one event, and a low ranking in another. Each nation affiliated with the FIS system can send one competitor to the World Cup system if the skier is ranked in the first 150 racers in a valid FIS point list or have a maximum of FIS points depending on event and sex[2].

The World Cup system has its own system with points and ranking, and the current ranking system was introduced in the season 1991/1992. In this system, only the top 30 skiers are rewarded with World Cup points, whatever the event. A victory is awarded with 100 points, second-place 80 points, and third place 60 points. From place 15 the skiers drop one point with each place down to 30th place, which is awarded with just one World Cup point. From number 31 or lower among the approximately 70 skiers no World Cup points are awarded. Overall, the skiers collect points from every event and these points are accumulated through the season, producing a total overall score.

Inclusion and exclusion of participants in this thesis

When deciding on which skiers to include in this study, there were several considerations to take into account. First, a considerable change was made in the award system in FIS in 1992, which is the current and modern system. Additionally, from the beginning of the 1990s, the equipment, and especially the skis, have been through a tremendous change. The side cut was invented and changed the way skiers ski (Müller & Schwameder, 2003). Therefore, the cut-off was set to 1992. When I started the collection of data for this thesis, the 2015 season had not yet been completed, and therefore the collecting period ended with the 2014 season, ending up with 21 seasons of World Cup standings.

In order to win the overall cup, the skiers need to perform at a high level through the entire season. At the top-level this indicates that the skiers repeatedly have to perform at a high-

[1] https://www.fis-ski.com/DB/alpine-skiing/fis-points-lists.html
[2] Rules for the FIS alpine ski World Cup (https://assets.fis-ski.com/image/upload/v1565160338/fis-prod/assets/AL_WC_Rules_2020_06.08.2019.pdf)

performance level when collecting World Cup points. In each race there are around 70 qualified skiers at the start, and only the top 30 collect World Cup points. Previous studies (Müller et al., 2012) had the criterion of collecting one World Cup point through a season. At the end of the season, the overall standings were the summarized points in all events, consisting of SL, GS, SG and DH. In one season there are around 40 races for men and 40 races for women in all events; however, most racers specialize in either technical (SL and GS) or speed (SG and DH) events (Gilgien et al., 2018).

However, to be at the top level skiers need to perform consistently at a top level over many races and not just by coincidence. At the same time, there was a desire to have as large data set as possible. Therefore, the criterion of being among the top 50 in the World Cup was set. To be in the top 50, the skiers need to collect around 140 points through the season, which means that the skiers need to perform consistently at a very high level, and not just by luck. There are approximately 150 different skiers who score World Cup points across all events per season. The top 50 criterion has later been seen as an appropriate number of participants in investigating RAE among international ski jumpers (Hammer, 2020). Obviously, a skier who has had a successful season will most likely continue in the next season if there are no injuries or other limitations occurring.

General design

To gather knowledge on how the RAE varies in competitions, it was necessary to take a closer look into a specific group where the competition is hard. One design for studying this is use of a case study. A case study design can include several types: an individual case study, a set of individual case studies, a social group study, studies of an organization, or studies of events, roles, and relationships (Cohen et al., 2018). Further, case studies provide unique illustrations of real people in real situations, which can contribute to understanding ideas more clearly than abstract theories and principles. Yin (2014) argues that case studies allow investigators to focus on one case and retain a holistic and real-world perspective (pp. 4). Hamilton et al. (2012) describe the longitudinal case study as appropriate to capture changes over time, and also the cumulative case study to provide a cumulative body of data about a phenomenon, situation, or topic. In order to study how RAE varies in competitions, the case in this study was the World Cup system in alpine skiing. To catch potential variations of the effect, it is

necessary to study this over time, and the participants at different ages, different sex, and in different events.

Data collection

Data was collected from the FIS website (http://www.fis-ski.com/) skiers' birthdates, total World Cup points, and points from each individual event (slalom, giant slalom, super-giant slalom, downhill, and combined[3]) were included. Based on the athletes awarded World Cup points in different events, the athletes were categorized as either speed or technique specialists, which is a typical categorization in alpine skiing (Neumayr et al., 2003; Vermeulen et al., 2017). Skiers with more than 90 % of their points awarded in downhill and super G were categorized as speed-specialists. Consequently, skiers with more than 90 % of their scores awarded in slalom and giant slalom were considered to be specialists in the technical sub-disciplines. The reason for this categorization follows previous research (Vermeulen et al., 2017) and the acknowledgement that skiers need to specialize in order to succeed in one of these two categories, since they represent the best international level of skiers.

The skiers' birthdates were extracted and categorized according to the cut-off date of January 1st, which is the international cut-off date for youth skiing (FIS, 2015). Skiers born between January and March comprised Quartile 1, Quartile 2 ranged from April to June, Quartile 3 from July to September, and Quartile 4 from October to December. The use of four different quartiles is very common in the field of RAE because it takes monthly variations into account. However, the use of six-month blocks have also been used (Baxter-Jones & Helms, 1994), and even monthly distributions if the samples are large (Helsen et al., 2005), depending on the aim of the study. In this study, the use of quartiles (blocks of 3 months) was considered to be appropriate due to the cohort size.

In addition to date of birth, each individual skier's performance in the overall World Cup for each season, operationalized as World Cup points, was extracted from each of the 21 seasons. This latter measure comprises points collected from all individual events (slalom, giant slalom, super-G, downhill, and combined) throughout a complete season. As skiers can

[3] The combined is an event in alpine ski racing that consists of one slalom run and one downhill run, and there have historically been three or four races per season, with several changes in the format. The World Cup points are part of the overall world cup standings.

accumulate World Cup points from several seasons, a summarized World Cup points measure was computed for each individual skier (WCPsum).

In the second study, the skier's year of birth (YoB) was collected from male and female alpine skiers participating in three different FIS Junior World Ski Championships in alpine skiing, together with the results (ranking) in each competition. In the technical events (SL and GS) there are two runs, while only one run in the speed events (SG and DH), and the number of did not finish (DNF) skiers was calculated. The three championships selected for the study comprised Sochi 2016, Åre 2017, and Davos 2018. This included a total sample of 1188 male skiers and 859 female skiers within an age range of 17 – 21 years at the time of the competition. Figure 6 shows an overview of the two included studies in this thesis.

Participants

Study 1 (paper I and paper II)

The top 50 male and female skiers each year in the total World Cup ranking list during the period 1993/1994 season through to the 2013/2014 season were selected for the present study, a total of 1050 skiers in both sexes. Since skiers participate over multiple seasons, the skiers who were repeatedly represented on the list were removed in such a way that these skiers were only represented once. This means that only unique names were used. Because of the overlap of skiers within this period, the number of skiers in this period were reduced from 1050 skiers in each sex category to a sample of 234 male and 235 female alpine skiers, respectively.

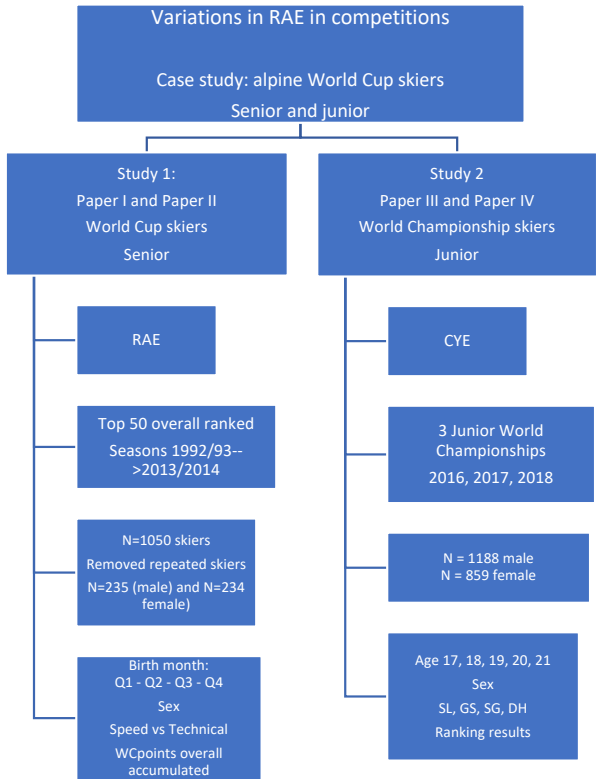
The data was collected from the FIS website (fis-ski.com) and included the variables of skiers' birthdates, total World Cup points, and points from each individual event (slalom, giant slalom, super-giant slalom, downhill, and combined). The data was exported to Excel, where the data was trimmed, meaning that space before or after numbers were eliminated. Additionally, birthdays were checked because FIS automatically set January 1st as a default if the skier's birthday was unknown. The birthdays were checked with other sources on the internet like social media, international sites from the skier's national ski federations, and on Google. The skiers were categorized as specialists in either speed or technique, based on their total world cup points in the different events, as previously described.

Study 2 (paper III and paper IV)

The male and female alpine skiers participating in the FIS Junior World Ski Championship in alpine skiing in Sochi 2016, Åre 2017, and Davos 2018 were selected for the studies. Data was obtained from the Fédération Internationale de Ski (FIS) website (www.fis-ski.com), and included the skiers' year of birth, sex, and events (slalom, giant slalom, super-G and downhill). The year of birth was applied to compute the age of each skier at the time of competition. This comprised an overall sample of 1188 male skiers and 859 female skiers within an age range of 17 – 21 years at the time of competition. In this dataset, no skiers were excluded due to overlap since we were interested in the skiers' age at the multiple-year age band.

Figure 6

An overview of the two studies encompassing four papers included in this thesis.



Analysis

General analysis

The data in this thesis was processed according to aims of the studies. The data used in the papers are presented as numerical forms, which is suitable for mathematical analysis (Hartas, 2015) as the birth dates and ranking would be. This will be described below in more detail.

Concerning the general and overarching discussion and analysis of the four papers in this thesis, the analysis is driven by a theoretical perspective, a deductive approach. This means that the discussion *across* the papers is analyzed with the view of a constraint-based framework. In this thesis, the theory will be supported by data, and the constraint-based approach was seen as a suitable theory to understand the variations and complexity of alpine skiing. The discussion of the papers included in this thesis is based on a post-positivistic approach since subjective meanings from the researcher are attributed to the data and there are several interpretations of what these results could imply (Charmaz, 2006). Since this is a case design studying variations in the relative age effect, the phenomenon will be discussed with reference to other assessment situations and competitive environments, like the education system.

Statistical analysis in the papers

To assess differences among relative age quartiles in the first study, the observed distributions were analyzed against distributions of live births by month in the European Union (Eurostat.com) over the past decade (28 countries, 53 million births) by chi^2-tests ($\chi 2$). The distribution showed an even distribution between the quartiles. In order to examine the constituent year effects, the distribution of the participants across age, sex, and events was examined by Chi-square tests ($\chi 2$) against an even distribution, with Cramer's V (ϕ) as a measure of effect size interpreted according to Cohen (Cohen, 2013) as small <0.05, medium ≥0.06 to <0.24, and large ≥0.25. Predictive Analytics Software (PASW, IBM, NY, US; previously SPSS) Version 25.0.0.1 was used for all statistical procedures with $p < 0.05$ as the statistical significance criterion.

In paper II and paper IV, the data was analyzed using non-parametric approaches. To examine if there was a statistically significant trend across age at competition and overall race performance, the Jonckheere–Terpstra test for ordered alternatives was applied. The Cohen's

d as measure of effect size was used for pairwise comparisons. Odds Ratios (ORs) and 95% confidence intervals (95% CIs) were calculated to measure potential differences between age cohorts in completed/not-completed races. Predictive Analytics Software (PASW, IBM, NY, US; previously SPSS) Version 27.0 was used for all statistical procedures with $p < 0.05$ as statistical significance criterion.

Ethics

This thesis is based on internet research, which raises some ethical considerations (Cohen et al., 2018). For instance, informed consent is not straightforward, and this was considered to be unnecessary because it is unlikely to identify the participants. The skiers are not identified by birth date because all skiers are placed in quartiles (not dates); hence, the identification of the skiers is impossible, thereby ensuring anonymity of the participants. On the other hand, the results are open to access on the internet; thus, it should be possible for other researchers to extract the same information. However, as a researcher, it is important to be aware of the blurred boundaries between public and private spaces in online research (Cohen et al., 2018).

Validity and reliability

The present thesis is based on two studies, which resulted in four different papers. All the papers are based on data from expert skiers, or more precisely, the best alpine skiers in the world among senior (study 1) and junior skiers (study 2). In the first study the limit was set at the top 50 ranked skiers. The top 50 skiers was set as an appropriate number because all the skiers had gained at least 140 World Cup points, and consequently had performed repeatedly to be among the 30 best skiers. In the overall ranking, there are approximately 150 skiers per season who collect at least one World Cup point. Using the top 50 skiers corresponds to around one third of all the high-performance skiers in the world, comprising the absolute top level. Hence, the cut-off had to balance that there were enough skiers, and that they also were among the top-level skiers. That the RAE exists among the majority of skiers nationally and internationally has been shown by previous studies (Müller et al., 2012; Steidl-Müller, Hildebrandt, et al., 2019). In the first study, the intention was to closely investigate the top-level skiers regarding the relative age effects.

In the second study, all the participants were included. This was because the aim was to investigate how age corresponds to participation and to performance. In this study, the

variations of RAE in competition were studied. The data consists of birth dates from competitors in real life, together with events, ranking in FIS points, and events in which the skiers perform. Collection of data was through the FIS website, where the birth dates were found. FIS puts the birth dates as January 1st as a default if they are unknown. These dates were checked against other sources on the web, like national homepages, Facebook, and other social media sources, and the correct dates were adjusted according to these sources.

Choice of sport

To investigate RAE in competitive environments, it was necessary to choose a context with a high level of competition, which corresponds to the sport context. Additionally, the competitive sport had to consist of participants whose results are due to ranking and based on numeric data, not solely on the coaches' judgement and discretionary assessment. Third, individual sports are according to Baker et al. (2014) less consistent in RAE compared to team sports, and they are argued to be valuable to uncover the mechanisms of RAE and to identify variables that may confound the effect. Alpine skiing consists of several variables that can be studied to discover these variations in RAE, and therefore satisfy the criteria. There are two main categories of events in alpine skiing: speed events that largely depend on physical characteristics, and technical events which rely on coordinative skills, and these events favor different body characteristics (Vermeulen et al., 2017).

Choice of participants

To identify the best skiers at the top level, an eligibility criterion was made whereby the skiers who had accrued most World Cup points over this period of 21 years were included in the study (Bjerke et al., 2017). World Cup points were used as a performance measure, and those skiers who had repeatedly assembled most World Cup points over a period of time were assumed to have stability in top performance. For example, if a skier assembled 700 points each season over four seasons, this skier had collected a total of 2800 points. The assembled total World Cup points over these two decades were analyzed with reference to the time of birth.

Choice of data and variables

Using the FIS system to measure performance has previously been used as a performance measure, as FIS points (Osgnach et al., 2005) and World Cup points accumulated over one

season have been used as measure for athletic performance, where the points were used to describe the length of career and to describe potential dropout from the sports among these professionals (Frick & Moser, 2021). The top 50 standings over a 21 year period have later been applied as a measure for performance when studying RAE in ski jumping (Hammer, 2020), and in analyzing career length in professional tennis (Coate & Robbins, 2001). Given the number of skiers and the evolving process of performance of the skiers, the collected World Cup points were considered to be an applicable measure for performance in this study. The data used are from highly professional athletes who attend voluntarily in the first place and are selected from their countries to represent their nation. Therefore, the group members are highly selected.

For the second study, using skiers from the JWC ensured that these were the best skiers at this age. It has previously been reported that the RAE will disappear around the age of 15-16 years and older, and an investigation of competitors of this age would discover that. A case study of the best skiers in these years corresponds to the Junior World Championship. One case was to study JWC for one year, but the cumulative effect could be seen over three championships. Additionally, including three championships provided a larger proportion of skiers to discover potential differences in ages, across events, and in both sexes.

The data in these studies are available for both sexes. The birth dates are available, together with different events across sexes and ages. In alpine skiing, there is a ranking system which makes it possible to study performances across age and events. It also is possible to study the time difference between the skiers, but this was not performed in this thesis.

Analyzing the data

The analysis was performed with similar methods as previously used in these types of studies. Chi square is a test that measures variations from the expected mean. In a population, it can be assumed that there is an even distribution in births throughout one year, especially when using quartiles. The evenly distribution of birth dates was checked with Eurostat, and the statistics showed evenly distributed birth rates in the skiers' birth years.

Results

The aims, results and conclusions from papers I-IV are presented in a short summary, and as a side-by-side table as shown in Table 1.

Paper I: Variations of the relative age effect within and across groups in elite alpine skiing

This paper aimed to examine variations in relative age effects because previous research has shown variations in the strength of the effect across and within sports, and also variations across sex, age, and skill level. The aim of this paper was to investigate whether relative age effects could be identified within the top fifty best ranked alpine skiers in the alpine skiing World Cup across two decades (21 years), competing in all events, in male and female skiers. The results show an RAE among male skiers in the speed events, no effect in technical events, and no effect among female skiers. This means that the best skiers, in terms of collecting the most World Cup points, were born in October, November or December. The paper concludes that RAE is present all the way up to the top skiers, but the effect varies with sex and event.

Paper II: An inverse relative age effect in male alpine skiers at the absolute top level

The purpose of paper II was to further examine the variations of the effects, by going further into the data from paper I. Previous research among the absolute top level in team elite sports, has shown that the advantage of being relatively older has been reported to disappear, and even to reverse, giving the relatively younger athletes an advantage. In this paper the aim was to examine whether a reversed RAE could be found in individual sports at the absolute top level in alpine skiing. The results showed that that there is an inverse RAE at the very top level among male alpine ski racers, but no such effect was found among female skiers. The paper concludes that the study may be a positive contribution to the RAE discussion, since the absolute best male skiers in the world are on average born late in the year. The study shows that those skiers who persist in a disadvantageous system eventually become on average better performers than those with the initial advantage of being born early.

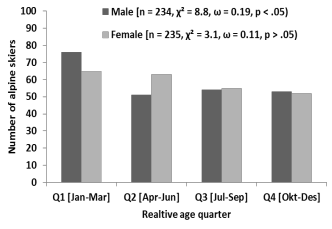
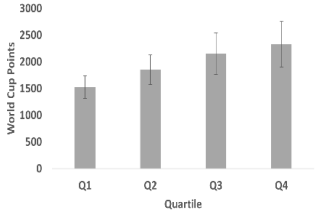
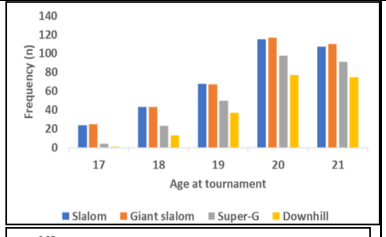
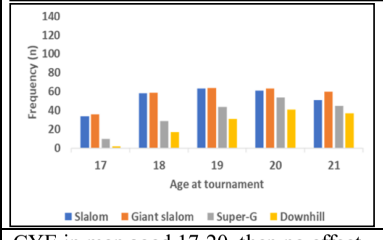
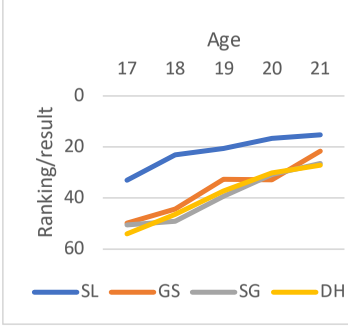
Paper III: Variations in the constituent year effect in Junior World Championships in alpine Skiing: A window into relative development effects

In paper III the purpose was to examine the influence of a constituent year effect on participation in the Junior World Championship in alpine skiing, which consists of a multi-year age-band of five years. The aim was to investigate if the constituent year effect could vary in similar ways as the relative age effect can do. The results show that the number of male participants increased with increasing age, which can be described as a CYE. For female skiers, a CYE was found, but it dissipated two years earlier than for male skiers. The CYE varied with event, and the effects were more pronounced the higher the speed of the event. The paper concludes that the results can be explained due to the development of the participants.

Paper IV: The association between constituent year effects and performance in alpine skiing Junior World Championships

The paper aimed to investigate junior ski racing where the competitors are grouped together over several age bands. The paper investigated the potential relationship between the performance and age within this group of athletes, and it aimed to study whether relative age is a good proxy for performance. The results show that CYEs are present among junior alpine skiers' performances in the Junior World Championships, with a greater magnitude in speed events. The effect is found in both genders, but at a larger magnitude among male skiers. One conclusion from this paper is that the effect of age is related to being stronger and heavier than one's peers, but also due to more training and exercise than with the younger skiers.

Table 1: *The four papers summarized.*

	Paper I	**Paper II**	**Paper III**	**Paper IV**
Title	Variations of the Relative Age Effect Within and Across Groups in Elite Alpine Skiing	An Inverse Relative Age Effect in Male Alpine Skiers at the Absolute Top Level	Variations in the constituent year effect in Junior World Championships in alpine skiing: A window into relative development effects?	The association between constituent year effects and performance in alpine skiing Junior World Championships
Participants	Top 50 ranked WC skiers (1994-2014)		Participants in alpine Junior World Ski Championship 2016, 2017, 2018	
N	N = 234 men, N = 235 women		N = 1188 men, N = 859 women	
Variables	Month of birth Gender DH, SG = speed events GS, SL = technical events	Month of birth Gender Total amount of World Cup points	Year of birth Gender Participation in events (SL, GS, SG, DH)	Year of birth Gender Completed/not completed Ranking in events (SL, GS, SG, DH)
Analysis	Chi-square, Cramer's effect size	Jonckheere-Terpstra	Chi-square, Cramer's effect size	Jonckheere-Terpstra, Odd Ratios
Results			 	
Conclusion	RAE among men in speed No RAE among women	Inverse RAE among men No effect among women	CYE in men aged 17-20, then no effect CYE in women aged 17-18, then no effect	Performance improves with age, in both male and female skiers

Discussion

This section will elaborate on the results of papers I-IV and will, discuss the findings with previous research, and attempt to discuss the results from a theoretical point of view. The aim of this thesis is to understand the mechanisms of relative age effects in competitive environments, using alpine skiing as an example. Using sport generally is applicable to understand the mechanisms of RAE because its effects are highly visible in sports and can easily be revealed in these contexts. As shown in the background and rationale for this study, alpine skiing represents a competitive environment where a wide range of variations in RAEs are found. Alpine skiing is an example of a sport that combines a spectrum of the variables to be studied, including physical demands (e.g., power, strength and endurance), and also the more technical and motor skills due to the different characteristics of different events. In addition, variations in sex, event characteristics, timing and ranking, and different organization of the cohorts can be identified in alpine skiing. Hence, by using the results from alpine skiing, this thesis aims to answer the research questions and produce new understanding within the field of competition and research on relative age effects. By collecting data from the worldwide web, the variables are unique and measurable for a great number of competitors, thereby giving valuable insight into the effects of relative age. In this thesis the following research questions were posed:

1. Is there a presence of RAE at the absolute top-level in alpine skiing, and in what ways does the effect vary across events?
2. How can the effects of relative age vary across a larger age span?
3. How can the dynamical systems theory be applied to explain the variations in RAE in competitive environments using examples from alpine skiing with top level skiers?

To answer the research questions the next section will first elaborate and discuss the results in and across the four papers by discussing some of the key variables that have been discovered. Secondly, the relative age effects will be discussed with reference to the athlete's development, and whether the RAE could be a proxy for something else, like development. Such an approach will contribute to a wider perspective within the relative age research field since development contains more than just biological maturation, which has been the major explanation for the RAE illustrated by skewed distribution of birth month. Third, the results in this thesis will be discussed within the theoretical framework of the constraints-based approach. Using this framework can contribute to understanding the complexity and the variability of relative age effects in competitive environments.

Is the relative age effect present among top level skiers?

The first study established that a RAE exists all the way to the top level of World Cup alpine male skiers in speed events, which means that there is an advantage to being born early in a cohort (Bjerke et al., 2016). However, the results reveal variations in the effect, as the results vary according to sex and event. The results show a significant RAE in the speed events, namely DH and SG. No such effect was found in the technical events (SL and GS), and no effect among female skiers in any event. The reason why this is found only among males and in speed events are elaborated in the following sections in this discussion. This is an important result, since it shows that the RAE proceeds all the way to the top level of world class skiers – with variations, and that the effect does not fade out at the top level, as has been previously implied (Cobley et al., 2018; Cobley et al., 2009; Ostojic et al., 2014).

Another finding from the first study is that when analyzing the very best performances, the RAE is inverted at the absolute top level among males, whilst no such effect exists among female skiers. RAE has been previously found to exist among World Cup skiers by Müller et al. (2012), but in that study it was with skiers who had assembled at least one world cup point, which consequently included skiers at a lower performance level than the present study. The first study in this thesis included skiers who had a considerably higher level of performance since they had collected at least 140 world cup points per season, which means that the skiers have repeatedly performed at a high level. The results from this study, shown in paper I and paper II, indicate that the RAE will vary according to competition performance level, sex, and event. This will be further discussed in the next section.

The second study reveals variations according to age, as this study discovered a constituent year effect (CYE). The second study investigated skiers in a cohort consisting of a five-year age-band between the age of 17 and 21 years. The CYE works similar as the RAE but it works like a magnifying lens on relative age as the effect could be seen over multiple years. According to Cobley et al. (2018), who investigated swimmers who have competed in the National Age Swimming Championships in Australia, the RAE dissipated at around 15-16 years, while the RAE inverted at around 17-18 years as the relatively younger swimmers were overrepresented. The findings in the present thesis performed on junior alpine skiers in the World Championship (JWC), does not show the same decline or transition. Rather, the results show a *variation* in the CYE, and the results vary with sex and event, both between

sexes and within each sex. The results from this study show a two-year difference between males and females, demonstrating that the advantage of being relatively older dissipates two years earlier for females. Additionally, the results also reveal that the CYE varies with event, where the advantage of age increases with speed. This effect is found both in the total number of skiers participating in the JWC and when the performances were analyzed.

In the next step, some of the variables across the papers will be elaborated on and discussed related to previous research.

RAE varies with sex

The results in this thesis clearly show differences according to sex. The first study investigated the 50 best female and male skiers in the overall ranking. Among male skiers, the results show that these skiers are almost three times more likely to be born in the first quartile of the year than the last quartile. This effect was not present among females. Additionally, when studying the absolute best skiers during these years in terms of most collected world cup points, an inverse effect was found only among male skiers, while no such effect was found among females. Possible explanations for this align with previous explanations found in the meta-analysis by Smith et al. (2018) where context, competition level, and sport type are moderators for the RAE.

One explanation is that RAE can be reduced after completion of puberty as suggested as possible explanation for the findings in the second study and further explained in paper III. The second study investigated the best junior alpine skiers in the world, competing together as a multiple age cohort between the ages of 17 to 21 years where the CYE varied significantly according to sex. For both the male and female skiers, the older the skiers were, the more likely they were to participate in the JWC. This means that a first-year junior at the age 17 is less likely to participate in the JWC than the older skiers. However, there were a significant difference between the sexes in the results. For male skiers, the number of participants in each age category increased for each age, but at age 20 and 21 years, the likelihood to participate in the JWC are alike. For female skiers, only the youngest skiers (17 years) were less likely to participate in the JWC compared to 18 to 21 year-old skiers. Thus, the effect dissipated two years earlier for female skiers than for the males, which was explained by females being two years ahead in physiological maturation due to completion of

puberty. As discussed in the paper, these results need to be aligned with the selection processes in early years. In a cohort consisting of 17, 18, 19, 20, and 21-year-old skiers, it is less likely that the national team will send a 17 year-old skier to the JWC. The skiers need to be eligible in their own nation, and the criteria for participation are performances in their home country.

Another explanation for the lack of RAE among females is a less selection pressure for females in alpine skiing. In the second study there are fewer female participants than males in the JWC, which may be due to fewer participants, and with increasing age it is suggested that females are less interested in high-performance sport resulting in decreasing participation hence, smaller selection pressure (Müller, Hildebrandt, et al., 2017). Less selection pressure also corresponds to previous research (Baker et al., 2010; Schorer, Cobley, et al., 2009). A third explanation could be the individual risk management and competition level at the races. In paper four, females have higher completion rate than male, which can be explained by male skier taking higher risks to achieve better performance, which results in fewer males completing the races. This is of course speculations, but historically there seem to be differences between males and females willingness to engage in sensation seeking activities based on Zuckerman´s Sensation Seeking Scale (Cross et al., 2013).

The results from both these studies in this thesis are in accordance with previous findings, which show that the RAE magnitude is greater among male athletes than among female athletes (Baker et al., 2010). One of the first meta-analyses of RAE performed by Cobley et al. (2009) showed little evidence for an overall sex difference in pooled OR estimates, although only 2% of participants were tested for RAE in female sports. However, in many studies no evidence for RAE in females was found, or at least the magnitude of the effect was greater among male athletes. In a study by Baker et al. (2014), who studied individual sports, there was no RAE for females in ski jumping and Nordic combined and only small effects in alpine skiing and cross country. The systematic review and meta-analysis by Smith and colleagues (2018) conclude that the RAE is prevalent across the female sport contexts, however, moderated by interactions between developmental stages, level of competition, and the physical demands of the sport. Alpine skiing consists of different events that favor certain somatotypes.

In alpine skiing, the existence of RAE has previously been found among male and female skiers for smaller competitors under 10 years of age (Raschner et al., 2012), and also for older children and at the junior World Ski Championship (Müller et al., 2012), and in all results presented in the review by Steidl-Müller, Hildebrandt, et al. (2019). Many of these studies were performed in Austria and Switzerland as the sport is culturally important in these countries. This means that there are a lot of participants in the races, and consequently a massive selection pressure in these areas. It is well-known that one consequence of higher performance level and selection pressure is the emerging relative age effect (Baker et al., 2014; Musch & Grondin, 2001).

The difference between sexes has been explained by less competition among females, and less selection pressure for the available positions in regional handball (Schorer, Cobley, et al., 2009). For example, in the latter study, 40% of male regional handball players were born in Q1, whilst the same proportions for female were 30% in Q1. The differences between sexes must be seen together with the depth of the competition. The same study indicates that when the selection pressure intensifies by the competition level, the representation from Q1 among females increases. Similar conclusions are supported by a review of female sports, where it is concluded that RAE exists in female sports, but the magnitude of the effect is moderated by interactions between stages in development, level of competition, and the demands of the sport context (Smith et al., 2018).

RAE varies with event

The results in this thesis show that RAE varies with event, and the effect of being relatively older is greater in speed events than in technical ones. Alpine skiing consists of four different events: two speed and two technical events (Turnbull et al., 2009). These events have proved to favor different body characteristics, where the technical specialists are lighter and have less fat mass relatively to those who are speed specialists (Vermeulen et al., 2017). Variation in body characteristics contribute to understanding the different aspects of RAE, especially when it comes to the absolute highest level of performance. The presence of RAE in the speed events is explained by the skiers' physical characteristics, where heavier, stronger, and physically more developed skiers are advantaged due to the gravity forces that work on the skier (Turnbull et al., 2009). The technical events favor lighter skiers who possess technical-

motor skills that override the physical contribution. This has previously been suggested in a technical sport such as dance (van Rossum, 2006) and in gymnastics (Baxter-Jones et al., 1995), where the advantage is reversed.

The second study in this thesis shows that performance increases with age, and especially in speed events, where nearly all the athletes are from the oldest age categories. This corresponds with the importance of being the most physically developed athlete, being biological mature with higher body mass and strength (Müller, Müller, Hildebrandt, et al., 2015; Müller, Müller, Hildebrandt, et al., 2016). Being early matured is perhaps more important in team sports, where it is important to impress the coaches and those responsible for selecting players for a team. This was shown recently in the Football Association of Ireland's national talent pathway, where between 46-72% of the selected players were biologically early matured and 0% were late matured at the age of 15 and 16 years.

In previous research on RAE, the most usual way is to investigate RAE in the sport alpine skiing, without separating different events. One exception is a recent study on French alpine skiers, where male and female skiers between 13 and 30 years old were included (De Larochelambert et al., 2022). In that study RAE in different events were found in French alpine skiers participating in the FIS circuit from 2004/2005 up to the 2014/2015 season, also with a higher proportion of relatively older skiers in the speed events SG and DH. Among younger skiers DH was excluded from that study. However, the results from the present thesis show that it is necessary to investigate the characteristics and demands of the sport to reveal the dynamics of the relative age effects.

Another reason why the RAE was significant in speed events can be explained by biomechanical factors. These are, according to Supej and Holmberg (2019), the kinematic variables (ground reaction force, airdrag) and the kinematics (racing time, trajectory, and speed). One obvious factor is the gravitational forces, with the higher the weight, the more potential energy. On the other hand, there must be some kind of sweet spot between a high body mass and being too heavy. The forces involved in turning techniques and being too heavy will increase the ground reaction force and increase the ski-snow friction, which will have a detrimental effect on the skiing performance (Supej & Holmberg, 2019). However, within this group of high-performing skiers, the results indicate that in speed events there are

advantages to being heavier than your peers. This is supported in findings where the body characteristics are linked to events (Vermeulen et al., 2017).

Experience may also explain why the RAE is more pronounced in speed events than in technical events. A relatively older skier has more experience than a younger athlete, which can be very valuable when the speed increases up to around 130 km/h. With age comes more experience, and high-performing alpine skiers make almost 60 days, or 5500 turns, in one year in the speed events (more in the technical events) (Gilgien et al., 2018). This means that older skiers perform hundreds of turns more at high speed compared to skiers who are several years younger. This means gaining experience and increasing the perceptual-motor skills under different conditions. More experience can be one of the factors that contribute to RAE (Musch & Grondin, 2001). Also, the higher the speed, the more risk there are of injuries in alpine skiing (Gilgien et al., 2014), and the fear of injuries can prevent a skier from taking the necessary risks to win a race. If a skier has more experience than a competitor, the experienced skier may benefit from this.

RAE varies with performance level

The results in the present thesis show that the RAE varies with the level of performance. This becomes really clear in the first study examining senior alpine skiers. In the first study of this thesis, the 50 best male and female skiers in the overall ranking over 21 seasons were analyzed. As shown in paper I, the RAE is present among male skiers in the speed events. No effect was found in technical events or at the high-performance level among females.
That the effect still exists at the absolute top level is interesting. From previous research in RAE, the effect is present in almost all development stages, from kids or youth onwards (Müller, Hildebrandt, et al., 2017; Romann & Fuchslocher, 2014) and also at national and international levels (Müller, Müller, & Raschner, 2016). Some researchers have found that the RAE diminishes at a certain performance level (Cobley et al., 2018) explained by biological maturation being less significant for the performance. In this study, when examining very high levels of performance at the senior level, the effect is still there, though only among male skiers and in speed events.

The second paper from the first study shows an inverse of the effect at the absolute top level when analyzing the performance of skiers (Bjerke et al., 2017). In this study the total

accumulated World Cup points were used as a performance measure. The results show an *inverse relative age effect*, meaning that skiers who had accumulated the highest number of World Cup points were skiers born in the last quartile of the cohort, i.e., the absolute best performing skiers were born in October, November, or December. The results also showed that variations exist, as the effects are significant among males in speed events, while not among female skiers. Consequently, this means that the traditional RAE exists in alpine skiing during the development stages among kids, youth, and junior ages. It partly diminishes among the top level, though not in speed events. Among skiers at the absolute top level, the effect reverses, and those skiers who succeed in the end are those born late in an annual year.

These results align well with recent research on RAE which explains this inversion with the relatively younger athletes developing a larger repertoire of skills. The relatively younger skiers are found to compensate at different levels. It is found that relatively younger skiers attend training centers to a larger extent than the older ones (DeCouto et al., 2021). The psychological explanation for this is explained by "the underdog hypothesis", whereby the relatively younger skiers have a psychological advantage in approaching the best skiers (Gibbs et al., 2012). Additional explanation is provided by the "rocky road hypothesis" (Collins et al., 2016b), showing the importance of experiencing resistance on the way to excellence. Another explanation could be that athletes who are at the top as children and adolescents have a larger possibility of dropping out of the sport (Penna et al., 2018). This could be due to extra training, or a perception of the sport being too serious, leading to drop out.

The reversal effect has been shown in several studies at top level, but research and literature in the field are divergent in explaining what will occur in different competitive environments. In one study, relatively younger football players in the German professional league are found to receive higher salaries, indicating a higher level of performance (Ashworth & Heyndels, 2007). Ford and Williams (2011) investigated award winning athletes, in which relatively younger athletes are overrepresented. The reversal is found in ice hockey, where athletes born in the last quartile scored on average 9 points more than those born in the first quartile (Fumarco et al., 2017). The same study concludes that the relatively younger players earn 51% more than those born in the first quartile.

RAE varies with age

The results from the second study in this thesis show a very clear effect of age with a higher representation of the oldest skiers, identified as the constituent year effect (Bjerke et al., 2020). For male skiers, the results show an almost linear effect with age, with an increasing number of skiers aged up to 20 years, and no difference in the number of participants between 20 and 21. For female skiers there were few participants among the youngest skiers, and no significant difference in the number of participants between the age of 18-21 years, as previously discussed with reference to RAE and sex. The results show that the CYE among male skiers disappeared two years before female skiers. This two-year difference coincided reasonably well with the difference in onset of puberty between the genders.

In a meta-analysis by Cobley et al. (2009), it was found that the likelihood for participating decreases with age across sport. This meta-analysis shows that for every two participants born in the last quartile of a cohort, over three are participating from the last quartile in the same age group. This meta-analysis included different types of sport, and the difference in ages is argued to be due to physical differences between athletes born early and late in a cohort as previously argued by Musch and Grondin (2001). One usual perception has been that late maturing athletes will catch up with their early maturing counterparts when reaching 15-16 years or older when it comes to performance measures (Ostojic et al., 2014). This is because the physical differences are thought to even out, and therefore the RAE fades away. Other research reports that relatively younger athletes enjoy a longer career at the senior level, e.g. in ice hockey (Gibbs et al., 2012), and that the later maturers score more points in ice hockey (Fumarco et al., 2017).

On the other hand, because children are placed in cohorts at an early age, this established difference due to relative age will be reinforced over time, and therefore the selected athletes will stay in this unfavorable system (Baker et al., 2012). In alpine skiing, the RAE is found throughout all ages from kids' level to the national level, as shown in the review by Steidl-Müller, Hildebrandt, et al. (2019). The early established differences among children are reinforced when the skiers enter boarding schools because the physical tests used in these schools favor skiers who are physically developed early. (Müller, Müller, Kornexl, et al., 2015). The relatively younger athletes might 'only' have a chance for selection if they matured early: nearly half of them (43.3%) were early maturing, whereas among relatively older athletes only 13.2% were early maturing (Müller, Gonaus, et al., 2017).

A summary of the results shows that the RAE is present at the top level of performance in alpine skiing, but it varies with age, sex and event. It also varies with performance because the effect turns around among skiers at the absolute top level. The effect is more pronounced among male skiers than female skiers, and the effect becomes stronger as the speed of the event increases. As the effect of being relatively older than the peers in the same cohort varies with the sport, level of performance, and sex, it might be due to differences in the development rates. This will be discussed in the next section.

Is the RAE a proxy for development?

The relative development effect (RDE) is strongly related to the maturation selection hypothesis (Baker et al., 2010). The maturation selection hypothesis, though, mostly refers to the effect of extended chronological age reflecting greater *physical maturation*. It could be argued that maturation is a passive mechanism resulting from bodily and hormonal changes at a cellular level, e.g., puberty (Malina, 2014). Using the term "relative development effect" embraces a more holistic approach that encompasses both the inherent bodily changes *and* changes due to trainable development, which corresponds to the primary and secondary factors in previous literature (Baker & Horton, 2004). There has been a vast amount of literature that has identified the effect of being born late in a cohort, as addressed in research like "Born too late to win" (Baxter-Jones & Helms, 1994). However, it is not the birth month per se which is the actual problem, but rather another rate of development in each individual. The RAE is therefore a proxy for something else, and that proxy is *development*. As seen in the results of this thesis, the ranking is closely connected to development, especially in speed events, where the size and weight of the skiers is a significant constraint. This was found in paper I, since the RAE was only found in speed. Also in paper III, and especially in paper IV, the importance of development is obvious: the more developed, the better the results. Since the effect varied with event, and increasing with speed of the event, the explanation to performance cannot be age alone. In fact, since speed has a profound effect on performance, other variables affected by the speed of the event are important. This can be variables and abilities to cope with higher speed, as experience and training history, together with physical development and other individual constraint that will be discussed in the next section. Development in a holistic approach is not only the physiological understanding of being

developed, but also in terms of psychological development and being more experienced. In the following section, this rationale will be elaborated.

The most common explanation of maturation is in terms of biological maturity status (Lauren B Sherar et al., 2007), where biologically mature persons are more likely to be selected for competitions (Lovell et al., 2015). The selection of competitors is strongly influenced by the maturity status, and in alpine youth skiing the selection of relatively younger skiers is dependent on their early biological maturation status (Müller, Müller, Hildebrandt, et al., 2016). In paper III in this thesis, it was found that the difference between genders was a skewed two-year distribution between male and female skiers, which can be interpreted to fall in line with the physiological difference in development. The RAE could also be seen as an expression of maturity and development for both the physiological *and* psychological factors. Being older means potentially having more time for training. This corresponds to the Power law of practice (Newell & Rosenbloom, 1981) and the finding that expertise is a result of 10 000 hours of training to reach expert level (Ericsson et al., 1993). Being born nearly one year before your competitors will, most likely, result in more experience and time for training. In modeling the development pathways for alpine ski racers, performance ranking is associated with time spent on ski-activity, especially among younger skiers (Cowan et al., 2021). For top athletes like Olympic skiers, a training season corresponds to 130-150 days skiing per year, and additional physiological training (Gilgien et al., 2018), which gives more time to practice compared to peers in the same cohort. The effect of training days will increase in a multi-year age cohort and may explain some of the differences found in paper III and in paper IV. The lack of training is documented in a study where relatively younger athletes are trying to bridge the gap between skills/performance and their relatively older peers (DeCouto et al., 2021). In this study, athletes born late are found to engage more in practice at training centers than those athletes born early.

In addition to training, being born early in a cohort also means that you have more lived experience than your peers (Musch & Grondin, 2001). The amount of experience may explain some of the differences found in different competitive contexts since experience is a crucial part of learning, in areas like both education and sport. Development could therefore be seen as a synthesis of physical and psychological maturation, lived experience, and hours of training in the specific skill. Physical development is closely related to performance in competitive environments, and the advantage is identified in sports where physical capacities

are advantageous. In the present thesis, there are no anthropometric measures of the athletes, but based on previous research, skiers born early are found to be more biologically mature than those born late in a cohort (Müller, Müller, Hildebrandt, et al., 2016). Physical development is found to be closely related to performance in sports like soccer (Helsen et al., 2005), ice hockey (Barnsley et al., 1985), rugby and basket (Delorme & Raspaud, 2009), track and field (Brustio et al., 2019), tennis (Moreira et al., 2017), and swimming (Medic et al., 2009). Also in environments that rely on cognitive skills more than physiological capacities, e.g. chess, RAE is present (Helsen et al., 2016), which can imply that those athletes who have had time to practice more, and being more psychologically mature, have an advantage. Similar patterns are found in educational settings, such as in reading skills (Lawlor et al., 2006) or grading in physical education (Dalen et al., 2017). To put it simply, it seems like competitors are assessed by their maturity and not by their skills.

The results in this thesis show that RAE are found only among men. This is in line with most research on RAE, where the effect is less expressed among females (Cobley et al., 2009). In a recent review of RAE across and within the female sport context, the RAE is prevalent also among women, but to a smaller extent than men, moderated by interaction between the competition level, developmental stages, and the demands of the sport (Smith et al., 2018). Since much of the research on RAE is framed within one year, some of the variations of RAE may be difficult to discover. Studying the CYE is a suitable way to discover the variations of RAE since CYE *is* RAE, but the effect works over a larger age band. In paper III, which investigates participation in the Junior World Championship in alpine skiing, the CYE is almost linear with age for both male and female skiers in the youngest age categories. For women, the effect decreases two years before male skiers, and these two years could represent the difference in physiological development between males and females. By studying the CYE in a cohort that contains several age groups, and by studying adolescents who are in late puberty or early adulthood, it is possible to discover how biological maturation works over a larger time scale using performance as a variable. By using the performance of female and males (paper IV), it is possible to compare gender differences. By comparing speed events with technical events, which require different qualities (strength and power vs motor skills), a further understanding of the variations of RAE could be described. In the next section the RAE will be discussed using a dynamical systems approach.

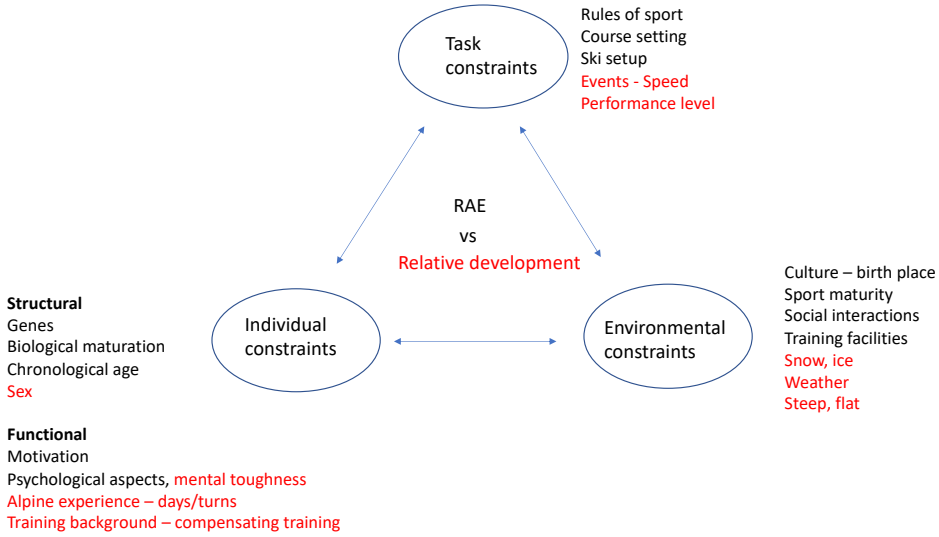
Understanding variations in RAE from a constraint-based framework

The variations in the results in this thesis clearly show that the RAE is a complex phenomenon. One critique of the RAE research field is that it has hitherto been rather atheoretical (Cobley, Abraham, et al., 2008). One theory that could be applied to understand the complexity is the constraint-based framework, which is a dynamical theory for performance. This theory describes how stable patterns emerge as a consequence of self-organization principles. The stable pattern emerges as a result of different constraints that are typically categorized as individual, environmental, or task constraints (Newell, 1986). In this thesis, the main focus is on understanding RAEs in competitive environments, using alpine skiing as an example. As the results show, the variation in RAE demonstrates that this topic is a complex phenomenon; hence, the dynamical systems approach could be an appropriate framework explaining this complexity. In discussing the results of this thesis, a closer look into the three categories of interacting constraints will be taken. However, as Newell states; "*Environmental constraints and task constraints are not mutually exclusive as their definition depends on the nature of the task*" (Newell, 1986 pp. 350). Since the task in this competitive environment is alpine skiing, the theoretical framework will be used in understanding the performance in alpine skiing. In other competitive environments, the theory could be used according to that task.

To summarize, the model presented in Figure 7 could be expanded as follows to explain RAE in alpine skiing.

Figure 7

The expanded model of RAE in alpine skiing considering individuality in the sport.



The **environmental constraints** are those external to the organism, and cannot not be manipulated by the experimenter (Newell, 1986). In alpine skiing sport these would comprise the snow conditions, light, and gravity. The vertical drop of the course would affect the gravity force. Imagine a course going straight down, without turning gates, with similar skis and equipment: the result would probably reflect the weight of the skiers due to gravity. The courses consist of gates that need to be passed correctly, and the biomechanical forces depend on speed, the radius of the turn, together with the skier's weight (Supej & Holmberg, 2019). The snow conditions are, of course, closely connected to the skier's equipment and the set-up of boots and skis, which are the skiers' task constraints, and this clearly illustrates the mutual interaction between the environment and task constraints. Being older means more experience in handling the changing conditions and self-confidence since the skiers may have experienced similar conditions. The constraints of the sport in terms of events have a clear impact on the skier's conditions, and the individual qualities of each skier clearly reflect the sport. Age is one factor, which actually reflects the skiers' physical, psychological, and individual development. Skiing is an outdoor sport, and the conditions will vary during a race, in weather conditions, snow conditions, and conditions on the slope. The race

organizers use water to turn the snow into ice, to make the slope conditions as identical as possible.

One of the environmental factors affecting RAE is social constructs, like socio-cultural environments, policies, and the influence of important people on the skier's life (Cote et al., 2006). Alpine skiing is an expensive sport, so people really need some financial support. In Austria, the RAE is much more pronounced, and the sport is culturally important, exemplified by the status of ski boarding schools in the Austrian nation (Müller, Müller, & Raschner, 2016). The availability and infrastructure of ski resorts also affects the availability of skiing, which is a huge environmental constraint. In this region of the Alps, alpine skiing means a lot to people and to the country´s financial and tourist system, making the ski resort a great political and cultural constraint. Since a lot of people are somehow involved in the skiing, and it is directly or indirectly a part of their income and lives, the skiing gives social acknowledgement and value to those who succeed in the sport. In fact, Hancock et al. (2013) argue that social agents and sociocultural factors are the most important factors that influence the mechanisms of RAE. In the present study, environmental constraints affect both which countries participate in the competition due to its cultural importance and the policies in each country, and also more locally in each country, in terms of regions and local clubs.

Newell (1986) divided the different **task constraints** into three categories. The first one is task constraints related to the goal of the task, the second relates to the rules, and the third includes implements or machines that constrain the response dynamics (p.353). For the latter, one of the most important constraints is the ski setup. One of the major task constraints is the invention of carving skis, which were introduced in the early 1990s. This had a major impact on the sport and is one of the reasons why the data was collected from 1994. This constraint is very important for skiers, and skiers use several days in testing skis and boots that fit together, and especially top ranked skiers spend a lot of time on this in pre-season (Gilgien et al., 2018). Skiers who perform at a high level will get support from ski factories and access to better equipment. This difference will increase with age as the more established skiers become well known to the sponsors.

Newell´s (1986) task constraints are related to rules and regulations. In alpine skiing this is an obvious task constraint in alpine competitions, especially associated with the distance between the gates, the number of gates, and time used in the competitions, which differ in the

four main events, SL, GS, SG and DH. A usual categorization in alpine skiing is speed events and technical events (Gilgien et al., 2018). The technical complexity involved is very different in each event, with different biomechanical forces, various turning techniques, tactics, and ski equipment (Supej & Holmberg, 2019). These biomechanical forces play a major role in the skiers' anthropometric composition, since the speed in the speed events is greater due to greater distance between gates and to less turn, which greatly favors skiers with higher potential energy in terms of higher weight. Rules for starting positions influence the results in the competition largely since the conditions of the slope become more challenging to those with a late starting number, and it is the FIS rules and regulations which decide that. In the technical events, the start number could influence the final ranking in the race, even among competitors who started in the top 15 (Lešnik et al., 2013). Several rules influence the starting position, like FIS points, previous results, drawing (among the top 15), and the number of skiers allowed in the different races. As shown in the results of this thesis, speed is a variable that affects performance. Speed could work as a proxy for performance, and this is due to individual constraints, which will be discussed in the next section.

Another major and obvious constraint in studying RAE in competitive environments is **organismic** or individual **constraints**. Chronological age is an obvious individual constraint in RAE research. Organismic constraints were originally separated into structural and functional organismic constraints (Newell, 1986). *Structural organismic constraints* are genes and constraints that change rather slowly in development, like muscular strength, height, and age-specific adaptations. Several studies show the importance of being born early in alpine skiing, and that early born skiers are more likely to attend, for example, boarding schools, and that successful skiers in Austria attend these schools (Müller, Müller, Hildebrandt, et al., 2015). The impact of being early matured is one of the main explanations of the relative age effects (Musch & Grondin, 2001). The importance of being born early is underpinned by the fact that the relative age effects continue all the way to the top level, and that those skiers born early in a cohort get a flying start compared to their peers in the first year of competition. The importance of maturation was also supported in paper III, where male and female skiers follow a similar pattern in participation in the JWC. The two-year skewedness between the genders falls in line with the two-year difference in onset of mean puberty, which may illustrate that the breaking point for development is around 18 years for women and 20 years for men.

Functional organismic constraints are constraints that are time dependent, like motivation and synaptic connections. The nature of competitions is to be better than your peers. If you succeed in that, this affects the motivation as you achieve what you want to achieve. The winners receive gratitude and attention from peers, trainers, and parents – a talent identification and development route described by Baker et al. (2012), and also explained by the Matthew effect (Hancock et al., 2013). Motivation is important, and as long as the system encourages winning, the RAE will probably exist. However, this thesis also shows that there is a reverse of the relative age effect at the very top level. The inverse effect may be explained by two factors (Fumarco et al., 2017). One is "the underdog effect", which is a psychological effect, where later matured athletes have learned to work harder to overcome the obstacles on the way to top performance. At some time, all athletes meet resistance, and the later born have a psychological benefit by having higher resilience than their older peers. The other factor is superior ability, which is a biological explanation. To overcome a system that disfavors some athletes (because they are born later), these athletes develop skills that are unique and above average in talent (Ashworth & Heyndels, 2007), and they possess more grit and determination (Fumarco et al., 2017).

The road to excellence has received a lot of interest as a research area, in trying to understand why someone becomes a champion (Güllich, 2014, 2017). One of the theories is that athletes need some kind of trauma on their way to the top, or what has been explained as the "rocky road to the top" (Collins & MacNamara, 2012). Within this expression lies the assumption that it is advantageous for athletes to face greater challenges through their developmental phases, an argument known as the "underdog effect" (Gibbs et al., 2012). The underdog effect was discovered as the RAE reverses in elite ice hockey, and where the relatively younger players developed strategies and compensatory techniques to compensate for physical disadvantages compared to the relatively older players.

Why use the constraint-based framework?

The factors explained with the constraint-based framework show the complexity of becoming a top athlete, and to understand this complexity this framework can explain the variations and the dynamics of the complexity. Much of the research has considered the RAE to exist in a vacuum, being a result of biological maturation, as part of the maturation selection

hypothesis. Other models emphasize social interactions, such as the social agent model (Dixon et al., 2020) and do not consider the dynamics and interactions between organismic, task, and environmental constraints. The relative age effects are probabilistic in terms of effects as one of the constraints influences the other, and this was elaborated in the dynamic model (Wattie et al., 2015). Central in the constraint-based framework is that the organization of the system is influenced by the constraints acting upon the system, and that any change may influence the organization of the system (Renshaw & Chow, 2019). A small change may have a large impact on the organization. Another central factor in these dynamical approaches to understanding behavior is the multi-stability that exists in the organization studied. In skiing the stability is expressed as a person's skiing technique down the course. Experienced and skilled skiers are those who have established a stable technique, are resistant to changes and perturbations, but at the same time flexible in making adjustments in order to make successful turns if something disturbs the skier. These skiers can adapt their technique to different snow and weather conditions. Skilled skiers are more resistant to perturbation like external pressure, audience, and changing speed in the event, while less skilled skiers will fail due to these variations. This could maybe explain some of the variations found in the CYE, where older skiers finish the race more successfully than younger ones.

One of the challenges in addressing the RAE using the CLA is that that all variables influence the skills and results in the competition, and the performance is a consequence of the interactions between the individual, environmental, and task constraints. This can be exemplified by two persons born the same day having different developmental experiences. The complexity is a challenge, but at the same time it is a strength in terms of acknowledging the complexity of relative age effect research.

The results in this thesis show that there is a prevalence of RAE among male skiers, and no significant effect among females. Secondly, the RAE is mediated by the events in alpine skiing, which means that the effect occurs in speed events, and to a lesser degree when the average speed decreases as in slalom and giant slalom. This thesis also shows that when examining the very best performances at the top level, the RAE inverses in male skiers. The skiers who manage to stay in the unfavorable system and to find solutions and develop skills, manage to reach the very top performances. These results show that there are variations of RAE that need to be studied and understood. By using a constraint-based framework, the variables that influence the RAE can be identified. Previous research on the topic RAE shows

the advantage of being born early an annual year, and the argument is basically physical maturity. By using multiple years cohorts to identify constituent year effect, this works as a magnifying lens to study the relative age effects, thus, it is easier to study variables that influence the effect. The occurrence of the CYE in this thesis states that participation and performance increase with age among junior alpine skiers in the World Championships. One interesting result is that the CYE diminishes two years ahead with the females, which coincides with the typically two-year difference in sexual maturity (Malina, 2014). This effect cannot be explained by age only. Rather, it is explained by development in terms of experience, training history, and physical development. It is also shown that the variable speed of the event can be a proxy for development and performance. Based on understanding of this complexity, the framework of constraints contributes to understanding the variations in a competitive environment, which is necessary to understand the phenomenon of relative age and its impact on competitions.

Future solutions for solving the RAE problem.

Following the awareness of RAE in competitive settings, there have been several suggestions proposed to address the phenomenon. One of them is rotating the cut-off dates (Hurley et al., 2001), implementing player quotas (Barnsley et al., 1985), or basing the categories on biological age and not chronological age (Cobley et al., 2009). Categories based on height or weight have been suggested to reduce some of the problem (Romann & Fuchslocher, 2014). Some of the suggestions are very context-dependent, and in sports some suggestions are task-specific. In alpine skiing it has been suggested that the youngest skiers should start the competition since the slope and racing conditions are best at the beginning of a race (Romann & Fuchslocher, 2014). However, as seen in the present thesis, it may not be the chronological age that is the problem, since the speed events are associated with weight.

Another solution is to apply a correction factor in the performance results or a formula to adjust for the differences in maturation. The latter has been suggested in French alpine skiing (De Larochelambert et al., 2022). However, awareness of the existence of RAE has not changed in magnitude in alpine skiing over the last 10-15 years, neither in anthropometric characteristics nor in selection (Steidl-Müller, Müller, et al., 2019), so that the solution is not simple. Additionally, there is a lack of research investigating the proposals suggested (Brustio et al., 2019).

Implications of this thesis

In this thesis, the phenomenon of RAE has been studied using alpine skiing as an example. As shown historically in a plethora of research, the effect of date of birth plays an important role in contexts where selection takes place, or where people are compared and assessed with each other. This occurs both in team competitions and in individual competitions. The effect of date of birth and the effect on performance occurs not only in sport, but in many areas. Understanding the mechanisms is therefore important at all levels of competition as the RAE has several implications for the society. For example, the birth date effect has a great impact on many aspects of education. The phenomenon exists in the assessment in physical education, where early born students receive better grades than those born in the last quartile (Dalen et al., 2016), or as better reading skills in children (Lawlor et al., 2006). Additionally, there is a higher risk of receiving ADHD medication if you are born in the last quartile of a year (Karlstad et al., 2017), which can be a misinterpretation of children's behavior in school. The teaching coincides with the children's maturity, and the relatively younger children who do not adapt to this system are more likely to receive medication for being restless. Being born 364 days later than your friend when you are a 6-year-old school starter is a significant difference in terms of physical and psychological maturity.

The effect has also been shown to have implications for students' choices of education tracks. In Norway, a country considered to have a homogeneous school system, it is found that the relatively older students in school tend to go onto the academic track, while the relatively younger students choose the vocational track (Oterhals et al., 2023). The RAE emerges as so pervasive that it impacts people's educational routes, and that it occurs even though Norway is considered to ensure equal opportunities with quality and to support adapted learning in school. The effect is also found in people's participation in organized versus unorganized physical activity. In one study, the prevalence of children participating in organized team sports was higher in those born in Q1 and Q2, though not in individual sports (Smith et al., 2022). A higher chronological age was associated with decreased participation in organized sport and in non-participation. Since the effect occurs in team sport, it was discussed whether the participation reflects the selection processes that are found elsewhere in team sports. Hence, the RAE clearly has a great impact on everyone's life and behavior.

The present thesis does not solve a particular problem, but it adds something to the puzzle of RAE. It suggests that the main issue is not RAE as such, but rather it represents something else – a proxy, and this thesis has shown that this proxy is development. The complexity in competitions is very high, but the insight into alpine skiing as a case for studying the effects may help to reveal some of the variations.

Another implication of this thesis is that using a case study from alpine skiing could also be used to understand the education system. Education takes place within a flexible, dynamic and multifaceted complex system (Jess et al., 2011). Schools are viewed as organizations that are non-linear and dynamic in an unpredictable and changing environment, and therefore need to adapt to the changes that takes place. Moreover, the education system can be seen as an area of competition since there are a limited number of places for students, and the education system assesses students based on their performance in different subjects. In such a system the RAE will exist, and knowledge of the dynamics of the phenomenon would be beneficial for those who work in that system. One of the key messages from this thesis is that it is not age per se which is the issue, but rather individual development. Children are very different both at the biological level, and also in terms of experience and amount of training. The practical implication of this thesis is that teachers, trainers, or parents who assess children or youth, need to be aware of how much feedback they are giving and supporting the children´s individual development. Further, by selecting players or individuals at an early age, the selection is basically a selection of development. Therefore, the use of tests or assessments scales should take several variables into account since the RAE is a result of multiple factors that could be explained by the CLA.

This thesis contributes to broader understanding of the RAE. By using alpine skiing from the top level as a case study, and by studying the variables, it is possible to unveil some of the mechanisms. In this thesis, the RAE (or CYE which is a term used in multiple age bands) can be explained by speed, as speed represents a proxy for the skiers' development. A new term is therefore launched, which is *relative development effect* rather than relative *age* effect. Additionally, development encompasses a broader understanding as it includes the experience in that context, the training history, together with the biological and psychological maturity.

Methodological limitations and further research

In the methodology section in this thesis there is a description of different aspects of how the research was conducted. Investigating complex systems usually has no simple answers. This is also the case in this thesis.

One major overall challenge in using dynamical approaches and theories concerns the fact that it is difficult to test one hypothesis due to the changing constraints. A CLA includes many parameters and how they impact and influence each other; hence, it will never be possible to conduct a controlled experiment. There is also criticism of the process of self-organization, because, in a strict sense, this process has only been demonstrated in very specific actions like the in-phase- anti-phase movement shown by Kelso (1995). On the other hand, a strength is that this theoretical framework actually explains the complexity and acknowledges that the world is not straightforward and linear. Is it possible that this approach could be used as a Grand Unified Theory, as suggested by Glazier (2017)?

Another concern is that it is a theory usually applied to the acquisition of motor skills in motor learning research and did not originate in understanding the complexity of relative age effects. However, the theory has previously been used as a model to explain RAE. That paper only served as a theoretical model, while this thesis has attempted to show the same aspects using data from alpine skiing.

The limitations in the two studies concern the information from the world wide web. The variables that are chosen are birth dates, sex, events, and ranking. Alpine skiing is a sport where ranking is one variable, and the ranking could split one hundredth of a second or several seconds between the racers. The time difference was not taken into consideration in the present study. However, in one second in speed events with an average speed of 110 km/h, the skiers move around 30 meters per second. When discussing other parameters that could influence the results, such as different body characteristics, accumulation of training hours, and how many years the skiers have competed, there is no data on these variables. It is only based on previous findings and by synthesizing existing research into new insights. Since one of the conclusions in this thesis is that individuality needs to be considered, it would be worthwhile to take a closer look at each skier's background and individual parameters and take them into consideration in the RAE research area.

Another limitation might be the number of participants in these two studies. However, the two first papers in this thesis have studied the best of the best skiers. Therefore, including too many skiers would not correspond to the absolute best skiers. Hence, there was a need to balance enough participants with the inclusion criteria of the best skiers. Further limitations could be how the performance is measured. Using World Cup points is one method, and in paper IV the performance measure was whether the skiers managed to complete the race. For example, there could be a high performing skier in one race, but in the last turn they did not complete the race due to hooking. In this study, if the skiers did not complete the race it was defined as no performance. By investigating other parameters of performance, other results could have emerged because there are several ways to measure performance.

The limitations of the present study call for further research. The complexity involved indicates that there is a need to investigate individuality in RAE research. Most research on RAE includes a large number of persons, which corresponds to quantity. Going beyond quantity, studying individuality may also discover some new aspects of RAE. For instance, in a recent paper (McCarthy et al., 2022) interviews has been conducted to understand mechanisms of RAE.

Conclusions

The aim of this thesis is to understand the mechanisms of relative age effects in competitive environments, using alpine skiing as an example. This thesis has shown that the RAE exists all the way to top level skiers, but only for male skiers and in speed events. Further, it shows that the relative age effect inverses at the absolute top level when the skiers' performances are analyzed. This thesis also shows that the RAE exists at junior level, and that the main explanation for this is the speed of the event, which can indicate differences in development.

In conclusion, the research in this thesis contributes to the research field by putting the RAE phenomenon into a theoretical framework, hence, it contributes to a deeper insight and understanding of relative age effects in competitive environments. Further, the thesis has introduced a new term in the RAE field, the relative development effect. This term embraces the individual development to a greater extent than the relative age effect. Even if relative age effects are previously found in a wide range of competitions, including alpine skiing, the present thesis reveal new insight by studying the variations of the effect. This has been done by analyzing variables like event, sex, performance level, and age. One important finding is how different events influence the RAE in alpine skiing and how this can be associated with different body characteristics.

As a practical implication, coaches need to be conscious of the RAE, and how the selection processes of athletes are a result of the individual development, and not necessarily the skills. This development is a product of training experience, training history, biological and psychological development. These findings can also be transferred to other competitive environments, such as education and assessment situations.

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Paper I-IV

Paper I

Bjerke, Ø., Lorås, H., & Pedersen, A. V. (2016). Variations of the relative age effect within and across groups in elite alpine skiing. *Comprehensive Psychology, 5*, 1-6. doi:10.1177/2165222816648077

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Variations of the Relative Age Effect Within and Across Groups in Elite Alpine Skiing

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Abstract

The term *relative age effect* (RAE) refers to age differences between athletes within the same cohort, and is frequently found within a plethora of sports. Less clear than the actual occurrence of the effect has been the strength of the effect across, and within, different sports, and also variations across sex, age, and skill level. In this study, we analyzed birth dates among the fifty top ranked alpine skiers in the World Cup system over the last twenty years. The analysis included both male ($n = 238$) and female skiers ($n = 235$) grouped into either a speed group (downhill and Super-G) or a technical group (slalom and giant slalom) based on World Cup points. The results show an RAE among the male skiers in the speed disciplines. No significant RAEs were found in men specializing in technical disciplines, and none at all in women. This finding demonstrates that the RAE can vary across subdisciplines within alpine skiing at the elite level.

Keywords

individual sports, performance, talent development, gender

Introduction

To avoid developmental discrepancies, sport federations and administrations typically group children based on their annual age. Although the grouping is well intended, it leads to a possible twelve months difference within the same-age cohort. Grondin, Deschaies, and Nault (1984) were among the first to assess the consequences of such annual-age grouping in sport, where their results identified significant and repeated overrepresentations of children born early in the cohort (i.e., the first three months after age-group cutoff dates). This difference in proportion of athletes born in the first quartile is commonly referred to as the "relative age effect" (RAE; Musch & Grondin, 2001).

While the RAE has been consistently demonstrated across sports and across sex and age, thus we know a lot about the actual occurrence of the effect, less is known about the variations in strength of the effect across, and within, different sports, and also variations across sex, age, and skill level. In a recent meta-analytical review, Cobley, Baker, Wattie, and McKenna (2009) demonstrated that the RAE in sport is a relatively consistent feature across the thirty-eight included studies published in the period 1984 to 2007. However, the authors also identified age category (youth vs. adult), skill level, and sport context as moderators of RAE magnitude. Specifically, young athletes (<18 years) in team sports such as basketball, soccer, and ice hockey appear to have the most pronounced RAE. As for skill level, the RAE is observed early in the development of athletes and the effect is stronger among pre-elite athletes than among elite athletes (Cobley et al., 2009; Schorer, Cobley, Büsch, Bräutigam, & Baker, 2009). Some researchers claim that the effect may be reversed at the elite level because relatively younger athletes develop superior skills to remain in the sport (Schorer et al., 2009) and that relatively older elite athletes drop out of sport earlier (Bäumler, 1998; Schorer et al., 2009). The RAE has been shown to be less prominent in women compared

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with men, and sometimes altogether absent (Cobley et al., 2009; Goldschmied, 2011). In general, there seems to be a paucity of studies examining the RAE in individual sports compared with team sports and the reported datasets were also conflicting (Cobley et al., 2009; Raschner, Müller, & Hildebrandt, 2012).

The proposed theoretical explanations for the RAE have commonly suggested greater likelihood of more advanced physical characteristics (e.g., body mass index, aerobic and anaerobic power, muscular strength) among relatively older athletes (Baker, Schorer, & Cobley, 2010; Schorer et al., 2009). This maturation hypothesis suggests that the chronological age reflects greater maturation at any given time and therefore contributes to developmental advantages (Baker et al., 2010). Being relatively older than the other participants might contribute to higher individual performance in many sports, especially sports requiring power, speed, and endurance (Schorer et al., 2009). A complementary explanation involves the process where the oldest athletes in their cohort are more likely to be selected by coaches partly due to their physical advantages, which in turn influences the volume of training and competition compared with the relatively younger athletes (and perhaps nonselected) peers (Musch & Grondin, 2001).

Although the maturation hypothesis can be applied to team and individual sports, physical differences can be counterweighed when there is a substantial degree of technical skills involved. RAEs have not been found in studies on technical sports such as figure skating, gymnastics, and golf (Baker, Janning, Wong, Cobley, & Schorer, 2014; Cobley et al., 2009). Indeed, a reverse RAE is found in sports where low weight and short height is an advantage, for example, rhythmic gymnastics and shooting (Baker et al., 2010; Delorme & Raspaud, 2009). In this regard, it has been suggested that the ski sports provide a particularly appropriate context to examine RAEs, given that both anthropometric characteristics and learned skills contribute to high-level performance (Baker et al., 2014; Turnbull, Kilding, & Keogh, 2009). Ski racing in alpine skiing is split into two speed and two technical disciplines, each with different physiological demands (Turnbull et al., 2009). The anthropometric demands in alpine skiing with large body masses are considered to be a competition advantage, especially in the speed events (Neumayr et al., 2003). Accordingly, alpine skiers born in the first quartile are found to be taller and heavier than the ski racers born in other quartiles (Müller, Müller, Hildebrandt, Kornexl, & Raschner, 2015).

RAEs in alpine skiing have been identified at the youngest level of youth ski racing (Müller, Hildebrandt, & Raschner, 2015; Romann & Fuchslocher, 2014b) and in youth Winter Olympics (Raschner et al., 2012). The effect also exists from a national level to an international level (Baker et al., 2014; Müller, Hildebrandt, et al., 2015), and even among racers earning at least one point in the alpine World Cup (Müller et al., 2012).

When attempting to tease out the more subtle differences within the RAE in alpine skiing, a relevant variable might be the skiers' skill level. As this level increases, so does the degree of specialization and at the very top level, almost all are specialists. Thus, they specialize in either speed disciplines, within which (a large) body size is advantageous, or technical disciplines, within which the smaller athletes would be equally likely to excel.

The aim of the present study was to conduct the next step and examine whether RAEs could be identified within the very best alpine skiers ranked among the top fifty (men and women) in the alpine skiing World Cup across two decades, competing in all disciplines. These are skiers performing at the top level throughout a whole season, and not just in a single race. The hypotheses were that there would be a general effect of birth month across the sample, albeit more pronounced in the speed disciplines (Super-G and downhill) compared with the technical races (giant slalom and slalom) due to a valuable effect of being relatively heavier and taller (Neumayr et al., 2003). Furthermore, we did not expect an effect of relative age within female skiers in either subdiscipline.

Method

Participants

The top fifty male and female skiers each year in the total World Cup ranking list during the period 1995 to 2014 were selected for the present study. Because of overlap, this comprised a sample of 234 male and 235 female alpine skiers, respectively.

Design and Analysis

Data were collected from the FIS website (fis-ski.com) and included skiers' birthdates, total World Cup points, and points from each individual discipline (slalom, giant slalom, Super-G, downhill, and combined). Initial screening of the dataset indicated that an unexpected proportion of the birthdates were January 1, and several of these had to be corrected in accordance with birthdates reported on other websites (Facebook, Wikipedia, etc.). Athletes were further categorized as either speed or technique specialists based on their accumulated FIS points in the different subdisciplines: Skiers with $\geqslant$90% of their FIS points in slalom/giant slalom were designated as technique specialists, and skiers who had accumulated $\geqslant$90 % of their FIS points in downhill/Super-G were

considered to be speed specialists. The rationale for this categorization was that it might be expected that these disciplines require a substantial proportion of specialization in order to compete at the highest level (international elite level).

Analysis

In order to examine RAEs, athletes' birth dates were categorized according to the cutoff date of January 1, which is the international cutoff date for youth skiing (FIS, 2015). Therefore, Quartile 1 included athletes born between January and March, Quartile 2 from April to June, Quartile 3 from July to September, and Quartile 4 from October to December. To assess differences among relative age quartiles, the observed distributions were analyzed against distributions of live births by month in the European Union (Eurostat, 2016) the past decade (twenty-eight countries, fifty-three million births) by Chi-square tests (χ^2). Effect sizes for the chi-square tests were calculated with Cramer's V (φ). Chi-square tests were also used to assess gender- and discipline-specific differences in RAEs, and odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated according to these categorizations. The statistical analyses were performed in SPSS (Version 21.0, IBM, US) and $p < .05$ was used as statistical significance criterion.

Results

Male Elite Alpine Skiers

Distributions of birth months for male elite alpine skiers are depicted in Figure 1. Chi-square analysis indicated a significant difference in the distribution of birth months for male alpine skiers, χ^2 (3) = 8.8, $p < .05$, $\omega = 0.19$, when compared with the birth month distribution in the EU statistics. When the data were spilt into disciplines, the χ^2 analysis indicated that birth month distributions from male alpine skiers specializing in primary speed-related disciplines (downhill and Super-G) were significantly different from the expected distribution, while birth month distributions for male alpine skiers specializing in more technical disciplines (slalom and giant slalom) were not different from the EU distributions. The ORs, effect sizes, and the corresponding χ^2 for each quarter according to discipline are presented in Table 1.

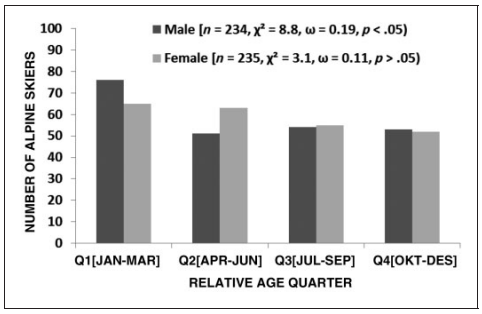

Figure 1. Relative age quartile distribution for male and female elite alpine skiers.

Female Elite Alpine Skiers

Overall, the χ^2 analysis indicated no statistically significant difference in observed birth month distribution compared with the EU distribution for the female elite alpine skiers. This was evident in the overall distributions, χ^2 (3) = 3.1, $p < .05$, $\omega = 0.11$ (see Figure 1) and for the ORs, effect sizes, and corresponding χ^2 for each quarter according to discipline (Table 1).

Discussion

As hypothesized, the RAE was present in top international alpine skiers. However, the RAE was only found in the speed disciplines for the men. No effect was seen in men specializing in technical disciplines, and none at all for women. Thus, an RAE persists all the way to the top-ranked alpine skiers in the World Cup for men in speed disciplines. This is consistent with previous findings at a national level for youth alpine skiers (Müller, Hildebrandt, et al., 2015; Romann & Fuchslocher, 2014b) and at an international level for elite skiers (Baker et al., 2014; Müller et al., 2012; Raschner et al., 2012).

In the present study, no significant RAE in men within the technical disciplines were found, which differs from previous results indicating RAE in alpine skiing for both men and women (Baker et al., 2014; Romann & Fuchslocher, 2014a). The absence of an RAE in female elite alpine skiers can probably be explained by the fact that women mature earlier than men (see Raschner et al., 2012) and that women's sports have fewer participants, which reduce the effects of the RAE (see, e.g., Romann & Fuchslocher, 2014a), thus the selection procedures are less strict (Schorer et al., 2009). The present results fall in line with most previous studies in suggesting that the RAE is less prominent in female athletes compared with male athletes (Baker et al., 2010). While some researchers have found a reverse RAE in elite sports (see Baker et al., 2010), the present study confirms that being born early is an advantage in the speed disciplines even at top level in alpine skiing.

Table 1. Descriptive ORs and Corresponding χ^2 Values and Effect Sizes (φ) Across All Relative Age Quarters for Disciplines and Separated for Gender.

Gender	Disciplines	Statistics	Q1:Q2	Q1:Q3	Q1:Q4
Male	Technical ($n = 96$)	χ^2	1.08	3.70	2.10
		p	>.05	>.05	>.05
		φ	0.15	0.29	0.19
		OR	0.77	1.27	0.548
		(95% CI)	(0.37–1.59)	(0.61–2.66)	(0.24–0.99)
	Speed ($n = 65$)	χ^2	6.94	6.70	10.80
		p	<.05	<.05	<.05
		φ	0.41	0.40	0.56
		OR	1.37	1.13	2.93
		(95% CI)	(0.63–2.99)	(0.54—2.38)	(1.21–7.12)
Female	Technical ($n = 94$)	χ^2	1.56	1.80	2.00
		p	>.05	<.05	>.05
		φ	0.17	0.19	0.21
		OR	0.89	0.93	0.79
		(95% CI)	(0.41–1.92)	(0.40–1.91)	(0.36–1.76)
	Speed ($n = 70$)	χ^2	0.51	0.40	0.20
		p	>.05	>.05	>.05
		φ	0.12	0.11	0.07
		OR	0.80	0.95	0.99
		(95% CI)	(0.34–1.86)	(0.40–2.30)	(0.41–2.31)

CI = confidence interval; OR = odds ratio;

The present findings are consistent with Baker et al.'s (2014) and Müller, Müller, Hildebrandt, et al.'s (2015) argument that ski sports require both physical attributes and skills. The findings further suggest that the RAE is largest in those subdisciplines in which physical attributes are especially important (here, the speed disciplines), while being less prominent in those subdisciplines requiring technique (as in the technical disciplines). This argument is in line with those of Neumayr et al. (2003).

From early on in their careers, and still at the top level, alpine skiers profit from being larger and heavier due to gravitational effects resulting in higher velocities (see, e.g., Hébert-Losier, Supej, & Holmberg, 2014; von Duvillard, Rundell, Bilodeau, & Bacharach, 2000), and the effects of being larger and heavier are well documented (Müller, Hildebrandt, et al., 2015; Müller, Müller, Hildebrandt, et al., 2015; Romann & Fuchslocher, 2014b). Such effects would be even more prominent in younger skiers due to their relatively lower average weight, and also the relatively lower velocities making it less of a problem to retain control over the skis. Furthermore, especially throughout adolescence, when the relative differences in body size are the largest, the selection process is fierce (Musch & Grondin, 2001). Earlier developed skiers (including those who are relatively older due to the RAE), thus, gain an advantage over the less developed, and smaller, skiers (Müller, Hildebrandt, et al., 2015). This gives an advantage before, for example, entering ski-boarding schools, which is important in the talent-developing system in many countries (Müller, Müller, Kornexl, & Raschner, 2015). In adults, the relative weight differences are smaller, and the velocities on snow are higher, thus requiring more muscle force in order to stay on the skis and in the course. As there is a trade-off between speed and the ability to control the body on the skis when velocities are high (larger bodies are less agile), and the relative velocities in slalom and giant slalom are lower, skiers would have less of an advantage within the technical disciplines compared with the speed disciplines (see Hébert-Losier et al., 2014). In adulthood, the advantage of a larger body would be restricted to the speed disciplines, while the more agile, smaller skiers would profit from the many rapid direction changes within the technical disciplines (see Supej, Kipp, & Holmberg, 2011).

It was hypothesized that there would be a general effect of birth month across the sample in alpine skiing, and that this effect would be more pronounced in speed disciplines than in technical disciplines. This was confirmed in the present study. The results suggest that variations in the RAE exist not only across sports, but also

across subdisciplines and genders within individual sports at the elite level.

There are obvious limitations to the present study, mostly related to the generalizability of the results. Although the RAE may be similar across studies, and across sports, it is not possible to generalize findings across sex, age, sport, and skill level. Thus, more studies are needed to conclude about the variations across such variables. Furthermore, the presence of an RAE says nothing about what may have caused the effect, chronological age, more time for practice due to being born earlier, or a Cinderella effect in which skiers are given extra opportunities due to their initial advantage. Further studies may shed more light on explanatory variables as well.

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Paper II

Bjerke, Ø., Pedersen, A. V., Aune, T. K., & Lorås, H. (2017). An inverse relative age effect in male alpine skiers at the absolute top level. *Frontiers in Psychology, 8*(1210). doi:10.3389/fpsyg.2017.01210

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An Inverse Relative Age Effect in Male Alpine Skiers at the Absolute Top Level

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The Relative Age Effect (RAE) can be described as the advantage of being born early after a certain cut-off date within a group of selection. The effect has been found across a wide range of sports and is particularly evident in pre-elite sports and team sports with a high selection pressure. At the absolute top level in team elite sports, the advantage of being relatively older has been reported to disappear, and even reverse, so that the relatively younger athletes are advantaged. In order to further examine such a reversal of the RAE, we investigated the performance of the overall top 50 skiers each year in the alpine World Cup, over a period of 20 years, among men ($N = 234$) and women ($N = 235$). The data indicated that the relatively younger male athletes at the absolute top level had accumulated, on average, more World Cup points compared to the relatively older skiers. No such effect was observed among the female skiers. This finding suggest the existence of a reversed relative age effect in male elite alpine skiing.

Keywords: individual sport, performance, elite level, alpine ski racing, talent

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INTRODUCTION

The relative age effect (RAE) refers to the advantage of being born early after a cut-off date in an annual group. Such grouping is a usual way to organize sport activities (Musch and Grondin, 2001). The RAE increases the likelihood of both performance and selection advantage (Schorer et al., 2013). Especially in sports with a high degree of competition and selection pressure, an overrepresentation of the relatively older athletes within a cohort is usual (Cobley et al., 2009). One explanation for the RAE, is that the relatively older athletes are born nearly 1 year before the youngest in a cohort, being more mature, stronger, and faster than their counterparts (Musch and Grondin, 2001). Consequently, these athletes receive more attention, better training facilities and more training time compared with their peers (Helsen et al., 2005). This explanation is supported by findings of junior elite athletes who are higher, heavier, and stronger than their peers (Musch and Grondin, 2001; Sherar et al., 2007).

The RAE is evident within team sports, like ice hockey, football, and handball (Cobley et al., 2009; Schorer et al., 2009b). Within individual sports, the effects are less consistent, but it is argued that examinations of the RAE in individual sports may uncover the mechanisms more precisely,

because the variables that may confound the effects are easier to identify (Baker et al., 2014). Furthermore, the RAE has been shown to be larger within male sport compared to female sport, probably due to stronger competition during developmental stages (Schorer et al., 2009b).

Once established, the RAE is upheld and strengthened by several other factors, such as the fact that selected athletes get access to better training facilities, better coaches, better equipment, etc. (Helsen et al., 1998), known as the Matthew effect (Merton, 1968), and the Pygmalion effect, by which expectations produce changes in achievement (Rosenthal and Jacobson, 1968). Together, with the initial maturational advantage, selection processes affect an individual's possibilities to invest in sport. Thus, the RAE carries over into adulthood, and has been demonstrated in several studies within a number of sports (Schorer et al., 2009b; Till et al., 2010; Fleming and Fleming, 2012; Steingröver et al., 2017). The RAE found in adults, does naturally not reflect maturational differences in the same way as in adolescent years, since athletes are no longer annually grouped. Rather, it reflects the fact that selection processes during adolescent years, along with the mentioned additional effects, leaves fewer athletes within each cohort who are born late in the year.

While the RAE is often large at the younger levels of sports, the effect is smaller among adults, and may even disappear completely at the elite level (Cobley et al., 2009; Ford and Williams, 2011). Some researchers have even reported an inverse RAE, also within sports with high degree of competition and selection pressure (Schorer et al., 2009b). Ford and Williams (2011) found that the most award-winning athletes and the most valuable players in team sport (e.g., soccer, ice hockey, and baseball players) were more likely to be born late in the selection year. Gibbs et al. (2012) found that the RAE reversed at the most elite level in ice hockey, and that relatively younger players endured a nearly 1 year longer career than their older peers did. Gibbs et al. (2012) reported even that being born at the start of the year reduces the chances of elite play in NHL by Canadian-born players, as they found relatively lower percentages of players born in the 1 months among those selected for NHL All-star rosters, or Olympic rosters. This effect has been referred to as the 'Underdog-effect' (McCarthy and Collins, 2014). Another study concluded that relatively younger players in the German soccer Bundesliga earned significantly higher wages compared with relatively older players (Ashworth and Heyndels, 2007), and there are examples that the draftees in ice hockey are relatively younger than their non-drafted peers (Baker and Logan, 2007). One possible explanation for this inverse RAE is that the relatively younger athletes develop superior skills that help them to persist in an unfavorable system.

In alpine skiing, the RAE is also present across all ages and levels. The effect ranges from the youngest national level (Müller et al., 2015), via the youth level in Winter Olympic Games (Raschner et al., 2012) up to the World Cup level (Müller et al., 2012), and even the top World Cup level (Bjerke et al., 2016). The RAE in alpine skiing is well documented in a recent review (Müller et al., 2016b). However, the RAE seems to diminish within the technical disciplines for World Cup skiers, while being more prominent within speed disciplines for men, with no such effect among females (Bjerke et al., 2016). Thus, like other similar studies, the RAE seems to be smaller at the elite level in alpine skiing than among younger skiers. Previous studies of the RAE at the top level, have included skiers who have had earned at least one World Cup point (Müller et al., 2012) or skiers among the overall top 50 ranked skiers each year (Bjerke et al., 2016). Since the RAE has been shown to diminish at the top level in alpine skiing, and may not even exist within the technical disciplines, the aim of the present study was to examine whether we could find a reversed RAE at the absolute top level in alpine skiing. The present study hypothesized that the RAE might reverse among the very best performances in alpine skiing, defined as the athletes collecting the most World Cup points. Thus, we would see an effect similar to previous studies at the top level (Schorer et al., 2009b; Ford and Williams, 2011). To that end, the data from Bjerke et al. (2016) were re-analyzed in order to tease out a possible inverse RAE.

MATERIALS AND METHODS

Participants

The sample consisted of the top 50 male and top 50 female skiers from each year in the total World Cup ranking list from the period 1995 to 2014, comprising 234 male and 235 female alpine skiers, respectively. The skiers originated from 19 and 21 different nationalities for men and women, respectively, Data were collected from the Fédération Internationale de Ski (FIS) website (FIS, 2014).

Variables

The skiers' birthdates were extracted and categorized according to the cut-off date January 1st, which is the international cut-off date for youth skiing (FIS, 2015). Skiers born between January and March comprised Quartile 1, Quartile 2 ranged from April to June, Quartile 3 from July to September, and Quartile 4 from October to December. In addition to date of birth, each individual skier's performance in the overall World Cup each season, operationalized as World Cup points, where extracted from each of the 20 seasons. This latter measure comprises points collected from all individual disciplines (slalom, giant slalom, Super-G, downhill, and combined) throughout a complete season. As skiers can accumulate World Cup points from several seasons, a summarized World Cup points measure was computed for each individual skier (WCPsum).

Analysis

The summated World Cup points demonstrated considerable positive skewedness and non-normal distribution according to a significant Kolmogorov–Smirnov test across both male and female sub-samples. Thus, statistical analyses proceeded with non-parametric approaches. In order to investigate whether there was a statistically significant trend between quartiles and overall World Cup points (WCPsum), Jonckheere–Terpstra tests for ordered alternatives were applied with Cohen's d as measure of effect size for further pairwise comparisons. The statistical

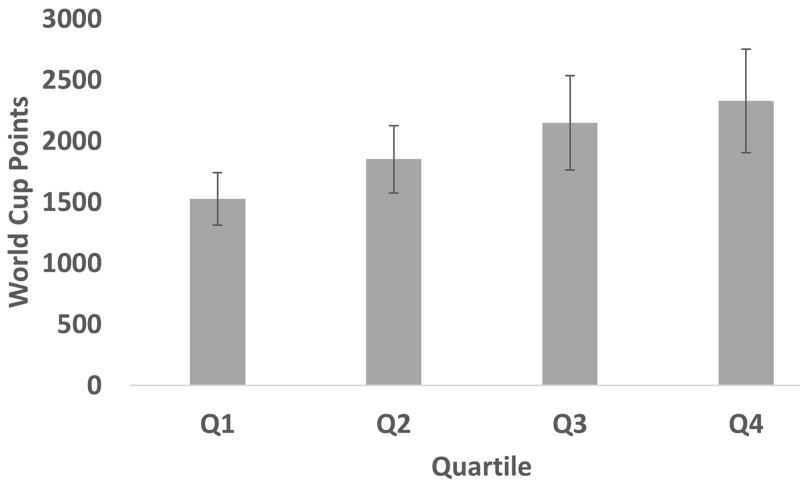

FIGURE 1 | Mean (SEM) World Cup points across quartiles for male elite alpine skiers.

analyses were performed in SPSS (Version 21.0, IBM, United States) and $p < 0.05$ was used as statistical significance criterion.

RESULTS

Male Elite Alpine Skiers

In the cohort of male elite alpine skiers, the average number of World Cup points was 1871 ($SE = 154$) with $SD = 2359$ and median = 998. The distribution of collected WC points, across quartiles, is depicted in **Figure 1**. As is evident, the distribution was not similar with, on average, more points accumulated by skiers born in later quartiles. Consequently, a Jonckheere–Terpstra test for ordered alternatives showed that there was a statistically significant trend of higher median WCPsum scores with later month of birth (from first to fourth quartile) in male skiers, TJT = 569.96, $z = 2.01$, $p < 0.05$, $d = 0.27$. In pairwise comparisons, effect sizes amounted to Q1 vs. Q2: $d = 0.16$; Q1 vs. Q3: $d = 0.26$; Q1 vs. Q4: $d = 0.32$; Q2 vs. Q3: $d = 0.13$; Q2 vs. Q4: $d = 0.20$; Q3 vs. Q4: $d = 0.06$.

Female Elite Alpine Skiers

For female elite alpine skiers, the World Cup points amounted to a mean of 1807 ($SE = 159$), $SD = 2474$, and median = 825. The distribution of World Cup points across quartiles for female elite alpine skiers can be found in **Figure 2**. Here, the distribution of points appears to be more similar across quartiles. Indeed, the Jonckheere–Terpstra test for ordered alternatives showed that there was no statistically significant trend of higher median WCPsum scores with later month of birth (from first to fourth quartile) in female skiers, TJT = 582.34, $z = 1.04$, $p > 0.05$, $d = 0.14$. In pairwise comparisons, effect sizes amounted to Q1 vs. Q2: $d = 0.18$; Q1 vs. Q3: $d = 0.01$; Q1 vs. Q4: $d = 0.16$; Q2 vs. Q3: $d = 0.18$; Q2 vs. Q4: $d = 0.03$; Q3 vs. Q4: $d = 0.16$.

DISCUSSION

The results of the present study demonstrate that there is an inverse RAE at the very top level among male alpine ski racers, previously referred to as the 'Underdog-effect' (see Gibbs et al., 2012). Male skiers born late in the year collect, on average, more World Cup points than their earlier born peers. No such inverse effect was found among female skiers. The present data include all skiers placed among the top 50 in the overall World Cup (WC) in any season between 1995 and 2014, and consequently it can be claimed that the data are not only representative for the top level within the sport, but that N, in fact, equals everybody within this particular group of skiers (see Gibbs et al., 2015). As far as we know, this seems to be the first time such a reversal of the RAE has been shown within an individual sport. The same dataset has previously shown a RAE among the male skiers, which was due to the speed discipline specialists (Bjerke et al., 2016). Traditionally, studies of RAE have merely counted the number of subjects belonging to the highest level of performance born in the respective quartiles of the year, while the present study counted the amount of World Cup points collected by skiers born in each quartile. The analysis reversed the RAE such that more points (on average) were collected by skiers in the later quartiles compared with the earlier quartiles.

There is probably several possible reasons why the inverse RAE within alpine skiing at the highest level has not been discovered earlier. Firstly, previous studies have not included skiers at the absolute highest level, and secondly, the measures have not been sufficient for teasing out rather subtle differences. Müller et al. (2012) examined skiers below the absolute top level

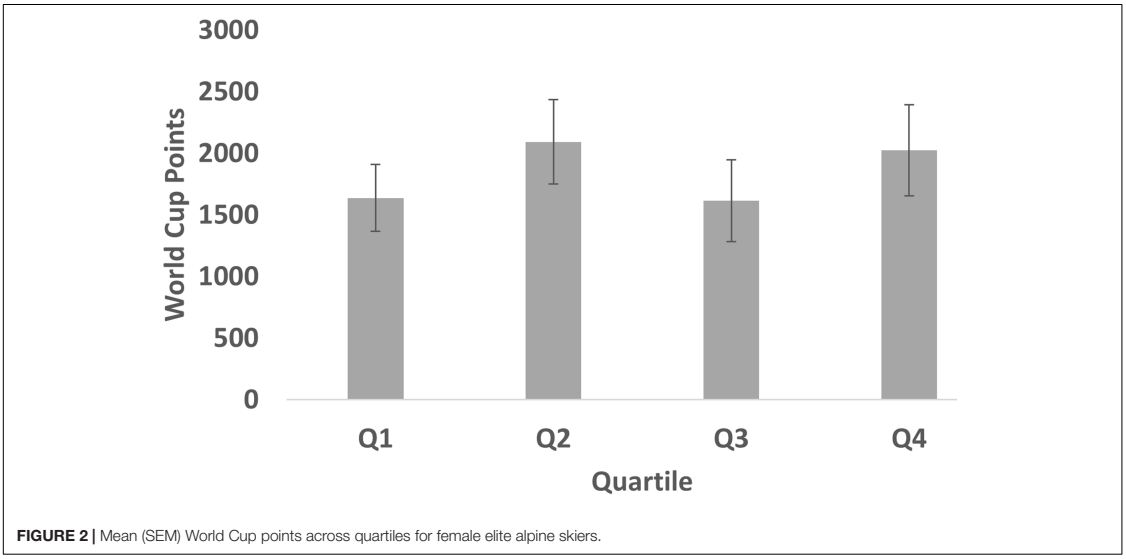

FIGURE 2 | Mean (SEM) World Cup points across quartiles for female elite alpine skiers.

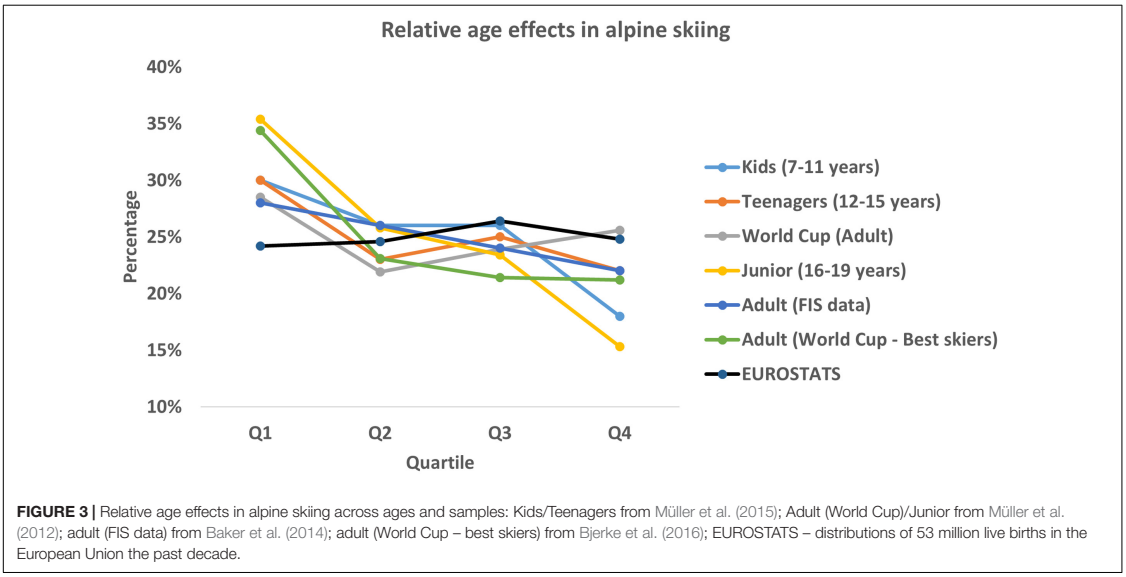

FIGURE 3 | Relative age effects in alpine skiing across ages and samples: Kids/Teenagers from Müller et al. (2015); Adult (World Cup)/Junior from Müller et al. (2012); adult (FIS data) from Baker et al. (2014); adult (World Cup – best skiers) from Bjerke et al. (2016); EUROSTATS – distributions of 53 million live births in the European Union the past decade.

by including every skier that had taken at least one World Cup point over five seasons from 2006 through 2011. These data included, thus, 742 male and 621 female World Cup skiers. Bjerke et al. (2016) included only skiers who had been among the top 50 in the overall World Cup at least 1 season out of 20, between 1995 through 2014, which reduced the sample to 234 male and 235 female skiers. Each of those skiers had accumulated a minimum of 127 (male) and 117 (female) WC points within a single season, thus representing the absolute top level. As usual in RAE-studies, Bjerke et al. (2016) computed the number of skiers born in each of the respective quartiles, and analyzed differences across quartiles. While Müller et al. (2012) reported a RAE for male WC skiers, Bjerke et al. (2016) reported an overall relative effect for male WC skiers, although the effect disappeared for those skiers specializing in technical disciplines when data were analyzed by skiers' specialties (speed or technique). We reiterate that the present dataset included the same skiers as Bjerke et al. (2016), but the data were re-analyzed in order to measure the average amount of points collected by skiers born in each respective quartile. Thus, it was possible to detect differences across quartiles

for the skiers belonging to the same general (absolute top) level. This procedure is similar to that of Ashworth and Heyndels (2007), who reported an inverse RAE in top level soccer based on the yearly earnings of Bundesliga soccer players, instead of merely counting the number of Bundesliga players born in each quartile, and the study of Ford and Williams (2011), whose data included only award-winning athletes within some of the top competitions.

As was shown for handball, by Schorer et al. (2009b), the RAE varies with a number of factors. The RAE was stronger in younger age groups, stronger for male athletes, and weaker or even absent for females. At the absolute top level, the effect was almost non-existent indicating, according to the authors, that non-selected players who stayed in the game had a relatively larger chance of ending up at this level. Similar results were presented for ice hockey by Nolan and Howell (2010), although somewhat rebutted by Gibbs et al. (2012). In alpine skiing, the RAE has been shown to be stronger in younger skiers (Müller et al., 2012, 2016b), and weaker for adult skiers, see **Figure 3**, as well as non-existent for female skiers (Müller et al., 2012; Bjerke et al., 2016). At an even higher level, the effect was non-existent also for male WC skiers specializing into technical disciplines (Bjerke et al., 2016). The present results go even further, and demonstrate an inverse effect for WC skiers at the absolute top level, although not for females.

There are several possible explanations for a reversal of the RAE. Firstly, it has been hypothesized that the effect wanes when the initial physical advantage disappears, and that those who manage to keep up despite their disadvantages do so because they have developed different skills from the relatively older. (Schorer et al., 2009b, 2013). Schorer et al. (2009a) examined, in handball players, whether technical skills could be such a factor, and whether late born players had better technical skills than their earlier born peers, but could not find support for their hypothesis. Their measure of technique, however, included only speed and accuracy of throws so it would seem a bit too early to conclude on technical skills as such. Other studies have focused on variables like perceived competence (Musch and Grondin, 2001), or the age at which athletes begun practicing the sport (Côté et al., 2012) as contenders for explaining why relatively younger athletes overcome the RAE, but no consensus has been reached so far.

Whatever the reason is, it seems that many of the absolute top athletes have come through the ranks despite disadvantages, or adverse incidents, previously in their careers (McCarthy and Collins, 2014; Collins et al., 2016a). It is not, however, possible to conclude from the present data whether the late born skiers have experienced what Collins et al. termed a 'rocky road,' and certainly not whether such a 'rocky road' is in any way beneficial to athletes, such as sometimes speculated (Schorer et al., 2009b; McCarthy and Collins, 2014; Collins et al., 2016b).

The present inverse RAE is further illustrated, although not statistically backed, by the fact that a large number of the absolute top skiers of all time were, in fact, born in the last (fourth) quartile, contrary to the assumption based on the original RAE. The ski-database ranking system (Alpine Ski Database, 2017) publishes "the super ranking," a list of the greatest alpine skiers of all time. This list is based upon points calculated together from Olympic Games, World Championships, and World Cup (overall titles, discipline titles, and individual top 10 results). The present top 10 includes seven skiers from the period in question (the last 20 years), who were also included in the present dataset, of whom four (Maier, Svindal, Tomba, Miller) were born in the fourth quartile and have thus defied the RAE. Only one of the seven (Hirscher) was born in one of the first 6 months of the year. Other recent World Cup overall winners, born in the fourth quartile include Kostelic (won the WC in 2011; born in November), and Janka (won the WC in 2010; born in October).

What, then, are the consequences of the RAE, and what might be the consequences of a reversal at the top level? One important consequence of the RAE, is that athletes born early in a cohort are selected based on physical maturity, and that the relatively younger athletes only have a chance of selection if they are early maturing athletes (Gorski et al., 2016; Müller et al., 2016a). Athletes born in the later quartiles are less likely to be selected, and will not have the same access to training facilities and to skilled coaches (Helsen et al., 1998) or to participation in various competitions (Schorer et al., 2009b). This, in turn, may lead to a loss of "talents" in the later adult elite sports because of dropout in the teenage years. The present study, however, may be a positive contribution to the RAE discussion, because the best skiers in the world are on average born late in the year. Instead of a demotivating effect of being born late, this study shows that the persisting skiers become on average better performers than those with the initial advantage of being born early. However, the underlying mechanisms why a reversal occurs are still unclear, and more studies focusing on the mediators of the effect are needed.

AUTHOR CONTRIBUTIONS

Conception and design of study: ØB, AVP, TKA and HL; acquisition of data: ØB; analysis and/or interpretation of data: ØB, AVP, TKA and HL; drafting the manuscript: ØB, AVP, TKA and HL; revising the manuscript critically for important intellectual content: ØB, AVP, TKA and HL; approval of the version of the manuscript to be published: ØB, AVP, TKA and HL.

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Paper III

Bjerke, Ø., Lorås, H., & Pedersen, A.V. (2020). Variations in the constituent year effect in Junior World Championships in alpine skiing: A window into relative development effects? *PloS one, 15*(4), e0231384. doi:10.1371/journal.pone.0231384

PLOS ONE

RESEARCH ARTICLE

Variations in the constituent year effect in Junior World Championships in alpine skiing: A window into relative development effects?

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Data Availability Statement: All data is publicly available at the Fédération Internationale de Ski (FIS) website: www.fis-ski.com, and can be accessed by anyone through any regular web

Abstract

While research on the effects of 'birth month' is usually referred to as relative age effects, the study of the effects of 'birth year' is described as the constituent year effect (CYE). In the present study we examined the impact of the CYE on participation in the Junior World Championship in alpine skiing. Based on previous research, we expected to find increasing numbers of participants the older the age-group, and that the CYE would be stronger in the speed events compared to the technical ones. The sample in the present study consisted of 1188 male skiers and 859 female skiers within the age range of 17 to 21 years at the time of competition. The results show that the number of male participants increased with increasing age, which can be described as a CYE. For female skiers, a CYE was found, but it dissipated two years earlier than for male skiers. The CYE varied with event and was more pronounced the higher the speed of the event. The findings thus suggest that a constituent year effect exists among skiers participating in the FIS Junior World Ski Championship in the alpine skiing championships, and that the effect varies with gender and event, rather unrelated to age. Thus, it seems that the effect may not be a relative age effect, but instead a relative development effect.

Introduction

In recent years, a vast amount of literature has been produced on the relative age effect (RAE) in sports or terms related to this topic [shown in a number of studies, e.g. 1]. The term RAE denotes the "overall difference in age between individuals within each age group" [2]. Grouping children chronologically by age induces a potentially large difference in age, which has shown to have a great impact on selection biases in sports competitions as well as affecting school results [3, 4]. The RAE was first described by Barnsley et al. [5] in ice hockey, whilst the effect attracted public interest after it was discussed in Malcolm Gladwell's *Outliers* [6]. The RAE has been detected, and most often reported, in team sports like soccer [2, 7], ice hockey [8], and handball [9, 10]. In addition, the effect has been found in individual sports like swimming and tennis [11], and in alpine skiing [12–14]. The RAEs are more pronounced in sports

browser. Thus, the authors did not have any special access privileges. All data is collected and available at this website: www.fis.com.

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that are deemed culturally important due to stronger selection pressure, like alpine skiing in Austria [7, 14, 15]. Sometimes variations in the RAE have been described, such as an inverse relative age effect [9], indicating that there is an advantage in being born late in a cohort. Some researchers even claim that relatively younger rugby players selected for a talent program during adolescence have a greater possibility of future career success [16].

The main mechanism underlying the RAE is usually suggested to be the physical advantage of being born earlier compared to the remaining members of the same cohort, commonly referred to as the maturation-selection hypothesis [7]. Furthermore, being born up to one year earlier than one's peers allows time for extra practice, which can be a large percentage of the child's total practice time in that particular sport. In turn, the initial developmental advantages will affect sociological and psychological processes and advantages, which are explained and related to the Pygmalion effect and self-fulfilling prophecy (see Musch & Grondin, 2001 for a review). Another mechanism that could also explain the increasing advantage is the Matthew effect, which means that for individuals who gain an advantage not possessed by many of their peers, these advantages will accumulate over time (see Hancock et al. [17]).

While these secondary effects (notably, the Pygmalion effect and Matthew effect) have been studied in detail, also with testing of the theoretical tenets of the concepts, the RAE itself seems so far to have evaded any real explanation and could be described as rather "atheoretical" [18]. Studies on the RAE have mainly reported the occurrence of the effect within a steadily increasing number of domains, while its variations have received less attention. In order to better understand the mechanisms that interact in producing the RAE, Wattie et al. [18] proposed a theoretical model grounded upon Newell's [19] framework of interacting constraints (individual, environmental and task). Newell based his work on dynamical systems theory [20], a principle which Thelen also attempted to incorporate in her theory of development [21, 22].

The usual understanding of the effects of relative age includes age differences within a given annual year, also known as the within one year effect [23]. Less known is the constituent year effect (CYE), which concerns the effects of relative age when several within-one-year cohorts participate in multiyear age bands, i.e. 16 to 19 years of age. When multiyear age bands are kept constant across development, the effect is termed the constant year effect [23]. Such effects, were originally studied in Masters sports, where the cohort grouping often has a five-year band [24]. While youth systems often show an overrepresentation in the oldest age cohort, the opposite effect is typically evident within the Masters sports. If the age band works over a larger age span, the impact of the constituent year effect is stronger [25]. The relative age effect is undoubtedly present among the youngest athletes, and at a particular point, the effect will diminish (and even turn), at least typically at the Masters level. In fact, studies performed on Masters athletes indicate that performance declines with age after age-related peak performance due to reduced physical capabilities [24]. In a systematic review of age of peak performance, Allen et al. [26] found that in explosive power/sprint sports, the peak performance is around 27 years, while the age for peak performance increases in endurance sports.

In alpine skiing, the RAE has been reported in several studies [13, 14, 27]. The effect has been well documented among youth alpine skiers in Youth Olympics [28] and in skiers at the World Cup level [13]. However, among the best World Cup alpine skiers there are variations in relative age effects according to discipline and sex [29]. At the absolute top level there seems to be an inversion of the relative age effect, as the relatively younger skiers perform at a higher level, collecting on average more World Cup points [30]. As the effects of relative age are well known and thus less interesting per se, merely reporting the effects in various sports or other domains may not advance knowledge of the RAE very much or bring us closer to an understanding of the mechanisms underlying the effect. Even though the effect is well known, nothing indicates that the effects have disappeared in alpine skiing in the last decade [31].

If the RAE were mostly about maturation (initial advantage) compared to, e.g. extra practice, it would be more prominent in the speed discipline, where the effect of body size is largest, as indicated by Bjerke et al. [29]. If, on the other hand, the RAE were more about practice, or the Pygmalion or Matthew effects, we would see a more even distribution of birth years across disciplines, as these effects would be more similarly distributed among those who were initially selected and would enhance differences to a lesser degree.

Both the RAE and CYE lend themselves well to scientific studies, as data are available in abundance on the internet. However, as differences and variations may be subtle, very large datasets would be required in order to study the RAE properly. The CYE would work in similar ways to the RAE, but it would be even more pronounced, as it works on a larger time span. Individuals are competing, and are thus compared across intervals of two years, or even five years, as in the Masters case.

Steingröver et al. [25] found a constituent year effect among elite German youth basketball players, where the age band ranges from 13 to 16 years (JBBL), but such effects were not evident among players of 17 to 19 years of age (NBBL players). In their study, only 5% of JBBL players belonged to the youngest age cohort, which was explained by the maturational differences across the age band, as the players enter the talent development system with a delay. Similar results were found in soccer [32], where data from soccer players under the age of 17 were analysed. In another study, Cobley et al. [33] found the constituent year effect to be evident among males between 12 to 15 years of age. In this study, at the age of 15 to 16 years, the effects had dissipated, and at the age of 17 to 18 years, the effects actually invert, so that the relatively younger athletes are more represented within the actual age band. These studies show a variety in how the CYE appears in sports. Examination of individual sports is claimed to be valuable to uncover the mechanisms of the RAE since variables that may confound the effect are easier to identify [34].

The aim of the present study was to investigate whether the constituent year effect would vary in ways similar to the relative age effect. The present data were collected from the Youth World Championship in all events in alpine skiing, and included both sexes. The athletes were from 17 to 21 years old, and the effects were studied across all alpine skiing events. Based on previous research, the hypothesis was that the CYE would be evident by more participating skiers being born early in the cohort, and more pronounced in males than in females. Furthermore, it was hypothesized that the CYE has a greater impact in the speed disciplines compared to the technical disciplines.

Methods

Participants

The male and female alpine skiers participating in the Fédération Internationale de Ski (FIS) Junior World Ski Championship in alpine skiing in Sochi 2016, Åre 2017, and Davos 2018 were selected for the present study. This comprised an overall sample of 1188 male skiers and 859 female skiers within an age range of 17 to 21 years at the time of competition.

Study variables

Data were obtained from the Fédération Internationale de Ski (FIS) website (www.fis-ski.com [35]), and included the skiers' year of birth, sex and events (slalom, giant slalom, super-G and downhill). The year of birth was applied to compute the age of each skier at the time of competition.

Statistical analysis

In order to examine the constituent year effects, the distribution of the participants across age, sex and events was examined by Chi-square tests ($\chi 2$) against an even distribution, with Cramer's V (ϕ) as a measure of effect size interpreted according to Cohen [36] as small <0.05, medium ≥0.06 to <0.24, and large ≥0.25. Predictive Analytics Software (PASW, IBM, NY, US; previously SPSS) Version 25.0.0.1 was used for all statistical procedures with $p < 0.05$ as statistical significance criterion.

Results

Male junior alpine skiers

As is clearly visible in Fig 1, the younger male junior alpine skiers were substantially under-represented in the 2016–2018 World Ski Championships ($\chi 2 = 408.89$, $df = 4$, $p < .0001$, $\phi = 0.59$). This pattern of results was also found across the four events ($\chi 2 \geq 87.30$ $df = 4$, $p < .0001$, $\phi \geq 0.49$). Furthermore, the proportion of 17-year-old male skiers was systematically under-represented compared to the older skiers ($\chi 2 \geq 4.77$, $df = 1$, $p \leq 0.029$, $\phi \geq 0.26$), the proportion of 18-year-old male skiers was systematically under-represented compared to the older skiers ($\chi 2 \geq 5.24$, $df = 1$, $p \leq 0.022$, $\phi \geq 0.22$), and the proportion of 19-year old male skiers was systematically under-represented compared to the 20-21-year-old skiers ($\chi 2 \geq 12.07$ $df = 1$, $p \leq 0.0005$, $\phi \geq 0.26$). However, no significant differences were found in the proportion of 20-year-old compared to 21-year-old skiers ($\chi 2 \leq 0.29$ $df = 1$, $p \geq 0.59$, $\phi \leq 0.04$). These latter patterns of results were similar across the four events.

Female junior alpine skiers

As can be seen in Fig 2, examination of the female junior alpine skiers' age at competition indicated a certain degree of over-representation of older skiers. Indeed, the Chi-square analysis indicated a significant overall difference in frequencies across the ages in female skiers ($\chi 2 = 68.28$ $df = 4$, $p < .0001$, $\phi = 0.28$). Conducting the analysis event-by-event, the distribution across age at competition in slalom was significantly different from an even distribution ($\chi 2 = 10.36$ $df = 4$, $p = 0.035$, $\phi = 0.20$). A similar pattern of results was observed in giant slalom ($\chi 2$

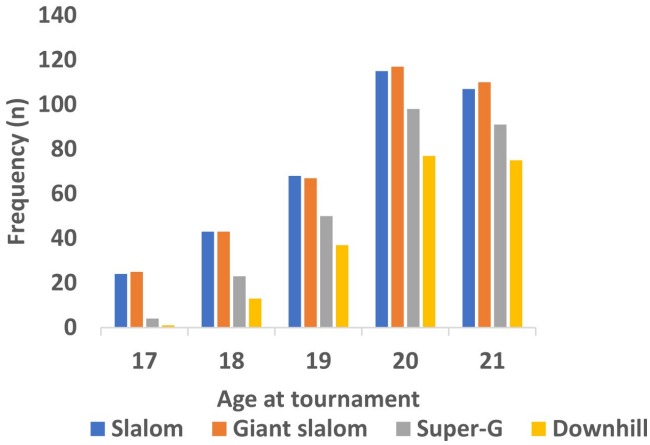

Fig 1. Frequency of participants across age cohorts and events among male alpine skiers participating in the 2016–2018 Junior World Championships ($n = 1188$).

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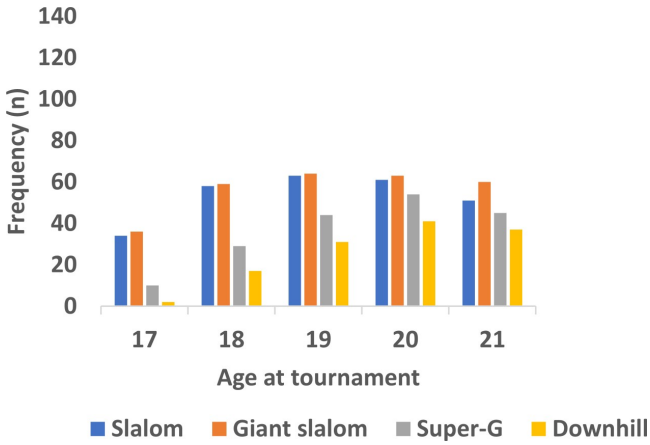

Fig 2. Frequency of participants across age cohorts and events among female alpine skiers participating in the 2016–2018 Junior World Championships (n = 859).

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= 9.53 df = 4, p = 0.0492, ϕ = 0.18), super-G ($\chi 2$ = 32.78 df = 4, $p < .0001$, ϕ = 0.42), and downhill ($\chi 2$ = 40.13 df = 4, $p < .0001$, ϕ = 0.56). Across events, the proportion of 17-year-old female skiers was under-represented compared to the older skiers ($\chi 2 \geq 6.26$ df = 1, $p < 0.01$, $\phi \geq 0.26$). Conducting further analysis across the 18-21-year-old skiers, no significant differences in distributions were found in either slalom or giant slalom ($\chi 2 \leq 1.42$ df = 3, $p \geq 0.70$, $\phi \leq 0.08$). In super-G and downhill, the distributions across 18-21-year-old female skiers were significantly different from an even distribution ($\chi 2 \geq 32.13$ df = 3, $p < .0001$, $\phi \geq 0.48$).

Discussion

The results of the present study show a clear and strong CYE among male skiers, in that the number of participants increased with increasing age up to 20 years in the FIS Junior World Ski Championship in alpine skiing. Thereafter, the CYE was not evident, as no difference was found between 20 and 21-year-olds. For the female skiers, a difference (CYE) was found between 17- and 18-year-olds, in that more 18-year-olds participated. After the age of 18, there were no differences (thus, no CYE) between any age groups. We should keep in mind that the present results include only *participation* in the Junior World Championship, and not their actual results. However, all the skiers were selected by their national federations to represent their countries in these competitions. Thus, they were judged to be worthy of such participation in (sometimes fierce) competition with other athletes, who may have been up to four years older. It would be reasonable to assume that their selection would reflect their chances of a reasonable result in competition with the other, similarly selected, participants.

The present findings were not surprising, and they fall in line with predictions based on previous findings on the CYE and the RAE [24, 37]. This was, however, not the scope of the current paper, other than laying the ground for our second predictions and acting as a check that our data are valid for further exploration.

As was suggested in the introduction of the present paper, the CYE seems to provide a sort of magnifying lens on relative age effects making any variation more clearly visible. The CYE is, in principle, the same effect as the RAE; in fact, the CYE *is a RAE*, only stronger, since it

defines RAE more broadly over a longer time span [1]. This makes it, as mentioned above, ideal for studying smaller variations within the bigger picture of the effect.

Bjerke [29] showed an effect of discipline (technique vs. speed) within the general RAE in male alpine skiers at the highest level that on by closer inspection turned out to be an opposite or inverse RAE [30]. The RAE was present in the speed disciplines (super-G and downhill racing), but not in the technical disciplines (slalom and giant slalom). In that study, no effect whatsoever was found among female alpine skiers.

In the present dataset, the results show a neat and orderly effect of discipline within the overall CYE, in that there were almost linearly decreasing numbers of participants with increasing speed in the event (in the order: slalom, giant slalom, super-G, downhill), irrespective of age. The age trend was similar across events, but grew stronger with the increasing speed of the event; hence, it can be argued to be an effect of speed. This trend was evident in both males and females (Figs 1 and 2). In fact, for males, there were almost equally as many 17-year-old participants in the slalom competition as there were 21-year-olds in the downhill competition. When remembering that the overall trend was the expected effect of (relative) age, both in males and females, our data support the general RAE/CYE [shown in a number of studies; e.g. 1, 9, 14], as well as the variations of the effect with discipline, as shown by Bjerke [29]. However, in the present dataset, these variations can be studied in more detail, and the data show that in addition to the differences between technique and speed events, there is an almost linear relationship between the relative age of participants and the speed of the event.

Had the RAE (CYE) resulted merely from maturation, and not from extra practice or additional effects (like the Pygmalion effect or the Matthew effect) affecting the initial RAE, one would expect the effects to disappear at a more similar rate across events after the maturation difference had been equalled out. On the other hand, if the effect was due to an "extra practice" effect, the difference would persist longer, as it is hard to compensate for up to one year more of practice. Also, in that case, the effect would be more similar across events.

The most common explanation of the RAE is the maturation hypothesis, favouring the early-born who are, on average, stronger and larger than their peers [7, 38]. Research on alpine skiing has demonstrated that relatively older athletes have an increased likelihood of being selected for teams if they are taller and heavier [27]. This takes place despite the fact that there are no differences in physical motor skills among ski racers at an adolescent age (14–15 years), indicating that there are other mechanisms responsible for the difference in skiing performance as the skiers get older [39]. It has been shown that the RAE dissipates or disappears in the longer term, and even an inverse effect has been reported among the oldest cohorts [16, 30, 33]. The disappearance of the effect is usually explained by the equalization of physical factors like body size, weight and height [33], and by the "underdog effect" [40].

In a typical winter sport like alpine skiing, the co-occurrence of the beginning of the calendar year and the winter (hence the alpine skiing) season would enhance the advantage of being early-born relative to many other sports. For the CYE, however, when the (relative) age effect works over a longer time span (five years), there would be no such overall advantage of the season, and thus the "winter-effect" would be eliminated. Another possible explanation was put forward by Moreira [37], who argued that relatively younger athletes may have a poorer motivational orientation since they are competing against more established skiers and hence have a lower expectation of success in relation to their peers.

The present results show that there is a point of culmination, and this varies across sex and event. Previous research on the RAE explains such differences across sexes, with male sports being more competitive due to the higher number of participants [41, 42]. The CYE among female skiers in the present dataset disappeared between the ages of 18 and 19 years, and no difference in the numbers of participants was present from 18 to 21 years of age. For males, the

CYE lasted two years longer, and differences in participation were demonstrated between all age groups up to 20 years. A two-year difference would coincide reasonably well with the differences in the onset of puberty between the two sexes [43] and would further suggest that the advantages of puberty-related variables would be greater in boys. During puberty, the height and lean body mass increase, resulting in further anthropometric and physical advantages [33]. Speaking against the puberty explanation is the fact that the effect of the event was somewhat independent of age and was relatively similar across sexes.

The Matthew effect [17] seems to be somewhat institutionalized in alpine skiing, as there is a ranking system based on FIS points, which benefits those skiers who have been in the FIS points system over time. The best-ranked skiers are given the most favourable starting positions, and hence the best-prepared course, whereas the youngest skiers are disfavoured in the system. The advantage of the ranking system will accumulate over time, corresponding to a Matthew effect in starting position.

The current study illuminates some of the complexity and directs some explanations of the RAE and CYE. Additionally, it shows that further insight into the variations in RAE/CYE is needed. That the existing CYE follows the general trend of the RAE, but at the same time is stronger, would make it relevant to also speculate whether also the same variations with the event would be found within the RAE, as would also be suggested by the mentioned findings of Bjerke et al. [29]. In fact, based on the results in this study, there is reason to suppose that the same mechanism could be present in the RAE. In order to reduce the relative age effects several possible solutions are suggested, e.g. rotating cut-off date and expanding the age bands, using competition groups based on height and weight or delaying the process of talent identification [7]. All these are based on the assumption that age itself, or the relative birth date, is in fact the cause of the discussed problems with the RAE. The present results indicate that such solutions may not be particularly appropriate, as age per se is not the relevant constraint or underlying mechanism.

As was proposed by Wattie et al. [18], the study of the RAE has appeared somewhat "atheoretical", lacking explanations of the phenomenon outside stating that those born early in the year are on average bigger and stronger. The present data has several features that make them better suited for testing the theoretical tenets of the RAE and possibly explain the variations by other factors than age per se. Firstly, as mentioned, the present CYE works over five years instead of one year as is usual for the RAE. Secondly, variations of the effect can be studied across four events instead of between two disciplines (speed and technique) as in Bjerke et al. [29]. Finally, by including both sexes, it is possible to study the effect of physical development (notably puberty) since the development is similar across sexes only skewed by some two years. Studying the latter was made possible by means of the "magnifying effect" of the CYE relative to the RAE, as the RAE has usually been small in female skiers; hence, it has been less frequently studied compared with males.

The present data, thus, suggest that relative age may not be the real constraint on performance, but a mere proxy. There was an effect of age, but this was not equal for the different events; it was even almost linearly related to the speed of the event. Furthermore, age effects varied with sex, however systematically skewed with about two years suggesting that sex was not the relevant variable but instead the relative difference in development (puberty) was. Thus, from a constraints-based perspective [19], it is possible to argue, with Wattie et al. [18], that relative age may not in fact be the relevant constraint, but that relative development is. From this, one could argue that the RAE should rather be called the relative development effect (RDE).

Limitations

The skiers participating in the various junior World Championships, included in the analysed sample, are selected by their respective national ski-federations. The nature of the selection process within each federation is not known, and there might be many types of considerations involved in such a process. Given that each nation can register a limited number of skiers for the championship, federations might nominate skiers evaluated to be candidates for winning medals or simply for gaining experience in tournaments at the highest international level.

Also, competition results from the various championships have not been analysed in relation to the constituent year effect. Further studies including this analysis might indicate whether the oldest skiers are over-represented amongst the highest-ranked skiers, which could provide another line of evidence for relative age effects in junior elite alpine skiing.

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Formal analysis: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

Investigation: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

Methodology: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

Project administration: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

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Visualization: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

Writing – original draft: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

Writing – review & editing: Øyvind Bjerke, Håvard Lorås, Arve Vorland Pedersen.

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