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**THE PERFECT
ELITE GYMNAST,
DOES HE EXIST?
A SYSTEMATIC REVIEW**

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ABSTRACT

The aim of this review was to create an all-round profile of the elite artistic gymnast. Therefore, an extended literature search was performed in PubMed and PsycINFO databases. The main inclusion criteria were that the content of the article was about artistic gymnastics and that the gymnasts were of elite level and senior age. The extended literature search resulted in a total number of 22 articles, which were split up into 2 domains: the physical domain included 13 articles and the psychological domain included 9 articles. Results of the physical domain showed that the elite gymnast is small and has a low body mass, an athletic posture, a good postural control and balance and a high explosive muscular performance. Results of the psychological domain showed that the elite gymnast has a high intrinsic and achievement motivation, good concentration and confidence, strives for perfection and excellence and uses psychological strategies. These characteristics seem to be important for an elite gymnast although it is not clear yet which characteristics are most important, neither is the relation of the several characteristics to each other.

KEYWORDS: artistic gymnastics; elite level; multidimensional; profile; senior.

INTRODUCTION

Gymnastics is a sport that is governed by the Fédération Internationale de Gymnastique and consists of several disciplines: Artistic Gymnastics, Rhythmic Gymnastics, Aerobic Gymnastics, Acrobatic Gymnastics and Trampolining. This review is about Artistic Gymnastics (by using the term gymnastics, Artistic Gymnastics is mentioned). Artistic gymnastics has developed enormously over the last decade. A lot has changed, for instance an increased complexity in movements on apparatuses. For example, in 2001, the traditional vaulting horse was replaced by a new vaulting table. This new vaulting table is more elastic, bigger and more stable. This resulted in a safer apparatus than the old traditional vaulting horse. Therefore, the routines that gymnasts perform could become more difficult and spectacular;

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higher difficulty scores and more twisting. In addition, in 2006 the code of points changed whereby the scores are no longer limited to 10 points. The score of the routine consists of an execution score and a difficulty score. The execution score (ES) evaluates the performance of the routine. The base score is 10 points and the judges distract points for every error the gymnast make. The difficulty score (DS) has no base score. It is based on the difficulty of the routine and this score is open-ended. Because of the change in the code of points, routines can become more difficult and this results in a higher difficulty score. Because of these developments gymnastics is becoming more and more spectacular.

Artistic gymnasts competing at the highest level perform difficult and complex routines, trying to reach the highest score with the ultimate goal to win the competition and being the best. In order to reach these goals artistic gymnasts have several characteristics in both physical and psychological domain. Still unknown, however, is which of these characteristics are most important fore an elite artistic gymnast. The physical domain consists of characteristics of the 'body' such as anthropometrics (stature and body mass) and strength, power, postural control and balance (Sands, 1999; Bressel, Yonker, Kras, & Heath, 2007; Lavallee & Robinson, 2007; Gautier, Thouvarecq, & Larue, 2008). The psychological domain consists of characteristics that are more related to the mind. These include concentration, motivation, striving for perfection, dealing with anxiety and the use of psychological strategies (Waples, 2005; Lavallee & Robinson, 2007; d'Arripe-Longueville, Hars, Debois, & Calmels, 2009). Some of these characteristics will be especially important during training (like motivation, striving for perfection and dealing with anxiety) while others will be more important during competition (concentration, confidence and coping with pressure and nerves). Besides several important physical and psychological characteristics, athletes appear to be exposed to substantial training volumes. According to Ericsson and colleagues (1993), intensive training over approximately 10 years is needed to become an expert (Ericsson, Krampe & Tesch-Römer, 1993).

The aim of this study is to create a profile of an elite artistic gymnast. First the classification of levels of competitions and the age limits will be briefly described. In artistic gymnastics, a standardized level system is used to distinguish between the levels of competition. The classification ranges from level 1 (lowest) to level 10 and then the elite level follows (highest). The levels 1 to 3 are generally considered to be recreational and there is no official competition at these levels (fun and experience is central). From level 4, the gymnasts can take part in competition and the levels 4 to 6 are called compulsory levels. All gymnasts perform the same routines on all events, whereby the difficulty of the routines will increase by level. Level 7 is the first 'optional' level in which a gymnast can create his or her own routine. Each routine is original and a gymnast can fit the routine to his or her style and skills. In this way gymnasts can display their talents and strengths, while minimising their weaknesses. The levels 8 to 10 are also optional levels, but the difficulty of the routines are increasing and the requirements are getting higher and higher. In level 8, the gymnasts can participate in regional competitions and the gymnasts can participate in national competitions at the levels 9 and 10. As already mentioned, the level that follows is the elite level. This is the highest level a gymnast can reach. Elite gymnasts compete in major events

like World Championships and Olympic Games. A minimum age limit is imposed on gymnasts competing in these events. The female gymnasts must be at least 16 years, or become 16 years within the calendar year, to be allowed to participate. For the male gymnasts the minimum age is 18 years, or the calendar year in which they will become 18 years. These female and male gymnasts are called seniors and they are allowed to participate in all events.

METHOD

An extensive literature search in the online search machines PubMed and PsycINFO was performed. The search terms were 'gymnast' in combination with the terms 'motivation', 'performance', 'physiology' and 'psychological' and the search term 'gymnastics' in combination with the terms 'artistic', 'balance', 'expertise', 'motivation', 'power' and 'requirements'.

This literature search was limited to English language articles only with publication date from 2001. Inclusion criteria were:

– The content of the articles is about artistic gymnastics or characteristics of artistic gymnasts.
– The level of competition is intermediate level. The following classification was used:
    Level 1-3: beginner (non-competitive)
    Level 4-7: intermediate (compulsory, first-optional level)
    Level 8-10: advanced (9-10 = national level)
    Level 11: elite (international level / World Championships / Olympic Games).
– All articles of at least advanced level were included.
– The age of the participants is at least 15 years for female and 17 years for male gymnasts.
– General characteristics of gymnasts are mentioned. Articles about specific apparatuses were excluded.

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A total number of 22 articles were included in the study; 13 articles in the physical domain and 9 articles in the psychological domain. These selected articles were reviewed on the following points; number of participants, gender, age, level of competition, years of experience and the main outcome of the study. The methodological quality of the studies was examined (see table 1). The scores on the several features were scored as completely fulfilling the criterion (+) or not. The total score indicated the overall quality of the study. The articles were examined on 17 features, but 3 features were not applicable and therefore the maximum score was reduced to 14 points. A total score of 7 or lower was indicated as being low to moderate. A score between 8 and 10 was indicated as being moderate to good and a score between 11 and 13 was indicated as being good. The maximum score of 14 was indicated as excellent.

Table 1. The methodological quality of included studies.

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Physical domain																		
Vuillerme et al. 2001	+	+	+							/	+	+	/	+	+	/		7
Bencke et al. 2002	+	+	+		+	+				/	+	+	/	+	+	/		9
Davlin 2004	+	+	+		+	+		+		/	+	+	/	+		/		9
French et al. 2004	+	+	+		+	+		+		/	+	+	/	+	+	/		10
Vuillerme & Nougier 2004	+		+		+	+	+			/	+	+	/	+	+	/		9
Jemni et al. 2006	+	+	+		+	+	+			/	+	+	/	+	+	/		10
Bressel et al. 2007	+	+	+		+	+	+	+		/	+	+	/	+	+	/	+	12
Carrick et al. 2007	+	+	+	+		+				/	+	+	/	+	+	/		9
Čuk et al. 2007	+	+	+		+	+				/	+		/	+	+	/		8
Gautier et al. 2007	+	+	+		+	+				/	+	+	/	+	+	/		9
McNeal et al. 2007	+	+	+		+	+	+	+		/	+	+	/	+	+	/		11
Gautier et al. 2008	+	+	+		+	+	+			/	+	+	/	+	+	/		10
Croix et al. 2010	+	+	+		+	+	+			/	+	+	/	+	+	/		10
Mean physical domain																		9,5
Psychological domain																		
Grandjean et al. 2002	+		+			+				/	+		/	+	+	/		6
Ryska et al. 2002	+	+	+			+	+			/	+	+	/	+	+	/		9
Cartoni et al. 2005	+	+	+			+		+		/	+	+	/	+	+	/	+	10
Chase et al. 2005	+	+	+		+	+	+	+		/	/	+	/	+	+	/	+	11
Waples, 2005	+	+	+			+			+	/	+	+	/	+	+	/	+	10
Hars & Calmels 2007	+	+	+		+	+	+			/	/	+	/	+	+	/	+	10
Lavallee & Robinson 2007	+	+	+		+	+	+			/	/	+	/	+	+	/	+	10
Martin et al. 2008	+	+	+		+	+	+	+		/	+	+	/	+	+	/	+	12
d'Arripe-Longueville et al. 2009	+	+	+		+	+	+			/	/	+	/	+	+	/	+	10
Mean psychological domain																		9,8
Mean total																		9,7

Critical Review Form – quantitative studies, Law et al. (1998). 1, Purpose clearly stated; 2, Literature review relevant; 3, Research design appropriate to answer aims; 4, No bias introduced into study; 5, Sample described in detail; 6, Sample size justified; 7, Informed consent gained; 8, Used reliable outcome measures; 9, Used validated outcome measures; 10, Intervention described in detail; 11, Results reported in terms of significance; 12, Analysis appropriate; 13, Clinical importance reported; 14, drop-outs reported, 15, Conclusions appropriate; 16, Clinical implications reported; 17, Acknowledgement of limitations of the study.

Note: + means completely fulfils criteria / means not applicable

RESULTS

The results are divided into two parts. The first part will cover the physical characteristics (13 articles) and in the second part, the psychological characteristics (9 articles) will be discussed.

Physical characteristics

The first part of the results is about the physical characteristics of gymnasts. First the anthropometric data will be discussed, followed by the results of the remaining articles.

Anthropometry characteristics

Female gymnasts

The results of the anthropometric data are presented in table 2 and it can be seen that the level of these gymnasts was high (elite or advanced level). Some articles indicated the years of experience in gymnastics and the results showed that gymnasts had a lot of years of experience and it can be assumed that these gymnast started performing gymnastics at a very young age (around the age of 6 years).

The anthropometric data showed that the mean stature and body mass of the gymnasts seem similar with respect to the various investigations. The mean stature and body mass of female gymnasts was about 153 cm and 44 kg with a mean age around 14,5 years (Davlin, 2004; McNeal Sands, & Schultz, 2007). The mean age of the gymnasts that participated in the study of Davlin (2004) was 13,7 years. The mean stature and body mass of the gymnasts in the study of French and colleagues (2004) were higher, but the mean age of the gymnasts was also higher (4 years older) (French, Gómez, Volek, Rubin, Ratamess, Sharman, Gotshalk, Sebastianelli, Putukian, Newton, Häkkinen, Fleck, & Kraemer, 2004). Bencke and colleagues (2002) found that gymnasts (mean age 11,7 years) were the smallest and lightest athletes who participated in their study, among them handball players, tennis players and swimmers (Bencke, Damsgaard, Saekmose, Jørgensen, Jørgensen, & Klausen, 2002).

Male gymnasts

The results of the anthropometric data of male gymnasts are also presented in table 2 and it can be seen that the level of the male gymnasts was high (elite or advanced level) or the level was not specified (Vuillerme et al., 2001). Some articles indicated the years of experience in gymnastics and the results showed that gymnasts had a lot of years of experience and it can be assumed that the male gymnast started performing gymnastics at a very young age

(around the age of 7 years). The mean age of the gymnasts was around 21,3 years, the mean stature of these gymnasts was about 169 cm, with a mean body mass of 67 kg (Vuillerme, Danion, Marin, Boyadjian, Prieur, Weise, & Nougier, 2001; Davlin, 2004; Vuillerme & Nougier, 2004; Jemni, Sands, Friemel, Stone, & Cooke, 2006; Gautier, Thouvarecq, & Chollet, 2007; Gautier et al., 2008). The mean shoulder width of the gymnasts varied between 40,1 – 45,1 cm (Davlin, 2004; Čuk, Korenčić, Tomazo-Ravnik, Peček, Bučar, & Hraski, 2007).

Table 2. Anthropometric characteristics of female and male gymnasts.

Reference	Age (years)	Stature (cm)	Body mass (kg)	Level of competition	N and gender	Experience (years)	Shoulder / pelvis width (cm)
Females							
French et al. 2004	19,7	167,6	55,1	Advanced	20 female	-	-
McNeal et al. 2007	15,5	151,0	44,5	7 elite 6 advanced	13 female	7,7	-
Males							
Vuillerme et al. 2001	20,6	172,3	65,3	Not specified *	6 male	10-13	-
Vuillerme & Nougier 2004	20,1	170,0	62,0	Advanced	7 male	10	-
Jemni et al. 2006	18,5 22,7	170,1 168,5	66,0 68,1	Elite Advanced	12 male 9 male	- -	- -
Čuk et al. 2007	23,4	168,1	66,5	Elite	40 male		40,1 / 25,5
Gautier et al. 2007	22,1	171,0	68,3	Elite / advanced	10 male	-	-
Gautier et al. 2008	20,4	171,3	68,5	Advanced	8 male	-	-
Females and males							
Davlin 2004	13,7 20,7	151,9 169,6	45,5 68,3	Elite / advanced Elite / advanced	28 female 29 male	8,6 14,2	35,2 / - 45,1 / -
Females and males around the age of 12							
Bencke et al. 2002	11,7 12,6 11,8 11,7	146,2 141,1 146,1 147,1	35,5 34.4 37,1 35,3	Advanced Intermediate Advanced Intermediate	11 male 6 male 13 female 20 female	- - - -	- - - -

* expert level, level was not specific enough to classify (probably advanced or elite level)

Table 3. Results of the articles of the physical domain: characteristics of the gymnasts (participants) and the main outcome.

Reference	Participants					Main outcome
	N	Gender	Age (years)	Level of competition	Experience (years)	
Females						
French et al. 2004	20	Female	19,7	Advanced	-	Body stature and body mass, muscular power
Bressel et al. 2007	12	Female	21,2	Advanced	-	Static and dynamic balance
Lavallee & Robinson 2007	5	Female	23,8	Elite / advanced	17,6	Body control
McNeal et al. 2007	13	Female	15,5	Elite / advanced	7,7	Body stature and body mass
Males						
Vuillerme et al. 2001	6	Male	20,6	Not specified*	10 - 13	Body stature and body mass, postural control, sensory modalities
Vuillerme & Nougier 2004	7	Male	20,1	Advanced	>10	Body stature and body mass, attentional demand, postural control
Jemni et al. 2006	12 9	Male Male	18,5 22,7	Elite Advanced	- -	Body stature and body mass, strength, peak power, anaerobic power, lactate threshold
Čuk et al. 2007	186 40	Male Male	21,9 23,4	Elite Elite	- -	Differences between 1933 and 2000. Body stature and body mass, shoulder and pelvis width.
Gautier et al. 2007	10	Male	22,1	Elite / advanced	-	Body stature and body mass, postural control, vision
Gautier et al. 2008	8	Male	20,4	Elite	-	Body stature and body mass, postural control
Females and males						
Bencke et al. 2002	13 20 11 6	Female Female Male Male	11,8 11,7 11,7 12,6	'Elite' 'Non-elite' 'Elite' 'Non-elite'	- - - -	Body stature and body mass, explosive muscular performance, jumping capabilities
Davlin 2004	28 29	Female Male	13,7 20,7	Elite/advanced Elite/advanced	8,6 14,2	Body stature and body mass ,dynamic balance
Carrick et al. 2007	166	Female and male	15,3	Elite	-	Postural stability and adaptability
Croix et al. 2010	8 9	Female and male Female and male	22,0 20,2	Advanced Intermediate	15,6 8,7	Body stature and body mass, vision, postural control, sensory modalities

1 expert level, level was not specific enough to classify (probably advanced or elite level)

Physical characteristics

Besides the anthropometric characteristics there are several other physical characteristics, these are presented in table 3.

Female gymnasts

The level of competition of almost all female gymnasts was high, elite or advanced level, although some gymnasts were of intermediate level (study of Croix, Chollet, & Thouvarecq, 2010). From articles that reported the years of experience in gymnastics, it could be suggested that these gymnasts started around the age of 6 years with performing gymnastics. The mean age of all female gymnasts was around 15,8 years (including gymnasts under the age limit of 15 years, studies of Bencke et al., 2002 and Davlin, 2004).

Davlin (2004) found that female gymnasts performed better on the dynamic balance test than all other athletes they investigated (soccer players, swimmers and individuals with no competitive sport experience), indicating that gymnasts had a superior dynamic balance. The study of Bressel et al. (2007) showed that the static balance of gymnasts was superior to that of basketball players and the difference between gymnasts and soccer players with respect to static balance was not significant. Also the dynamic balance did not differ between gymnasts and soccer players.

In the ability to maintain balance, vision played a significant role. Vision provides optimal postural adaptation and is the main source of information when maintaining the handstand. Vision seemed not to be necessary for experts to maintain the handstand (Croix et al., 2010); expert gymnasts were less affected than non-expert gymnasts (Croix et al., 2010). The results of Carrick and colleagues (2007) showed that gymnasts had a greater postural stability and adaptability than non-gymnasts (Carrick, Oggero, Pagnacco, Brock, & Arikan, 2007). Further, it was assumed that gymnasts with a higher adaptability score were able to learn and perform new motor routines better.

Gymnasts, who retired from gymnastics, noticed that they had a good control over their body, a good postural control (Lavallee & Robinson, 2007). This characteristic seemed to be useful in gymnastics although gymnasts faced also some negative aspects of their good postural control. From gymnastics they were used to control a lot of things (like their body and the movements they made), but in daily life it was not always possible to control everything and therefore the good control could hinder them when they retired.

Bencke et al. (2002) found that gymnasts had most explosive muscular performance of all participants in their study (handball players, tennis players and swimmers). The elite gymnasts (advanced level, mean age 11,8 years) were more explosive than the non-elite gymnasts (intermediate level) indicating that jumping capabilities are crucial for gymnastics

performance. Further, French et al. (2004) suggested that the ability to develop improved levels of muscular power was reflected by the potential to perform more advanced skills and acrobatics. Powers & Howley (2007) reported an estimation of the used energy systems in gymnastics. Gymnasts seem to have a predominant anaerobic energy system.

In summary, these results showed that high performing female gymnasts were young, small and had a low body-mass, they had a good postural control and balance and they were able to compensate for lack of vision while maintaining posture (multi-modal perception). Further it seems that they had a high explosive muscular power and predominant anaerobic energy system.

Male gymnasts

The level of competition of almost all male gymnasts was high, elite or advanced level, although some gymnasts were of intermediate level (Croix et al., 2010) or the level was not specified (Vuillerme et al., 2001). From articles that reported the years of experience in gymnastics, it could be suggested that male gymnasts started around the age of 7,5 years with performing gymnastics. The mean age of the male gymnasts was around 19,5 years (including gymnasts under the age limit of 17 years, study of Bencke et al., 2002).

Davlin (2004) found that the gymnasts performed better on the dynamic balance test than all other athletes they investigated (soccer players, swimmers and individuals with no competitive sport experience), indicating that gymnasts had superior dynamic balance.

Gautier et al. (2008) investigated how expertise in gymnastics influences postural regulation. They found that gymnasts were able to react quickly after destabilization by decreasing their centre of pressure by using their knees. Gymnasts could compensate more rapidly for destabilization and they got more quickly hints about their stability or instability. It seemed that the gymnasts could control their body movements better than non-gymnasts. The idea that optimal postural adaptation or regulation seems to be dependent on a multi-modality sensory organization appeared also from Gautier et al. (2007). Further, vision played a significant role in the ability to maintain balance. Vision provides optimal postural adaptation and is the main source of information when maintaining the handstand, although it seemed not to be necessary for experts to maintain the handstand (Croix et al., 2010). The removal of vision had an effect on gymnasts and their ability to maintain posture (Vuillerme et al., 2001; Croix et al., 2010). Nevertheless, it seemed that the effect of removal of vision was less for gymnasts compared to non-gymnasts (Vuillerme et al., 2001) and expert gymnasts were less affected than non-expert gymnasts (Croix et al., 2010). Expert gymnasts had a better postural performance during the handstand and they were able to use other sources of information (multi-modal perception) to maintain their posture. Also Vuillerme et al. (2001) suggested that gymnasts were able to compensate for the lack of vision in unstable postures by using the remaining

sensory modalities. Vuillerme & Nougier (2004) found that the attention demand necessary for regulating postural sway differed between expert gymnasts and non-gymnasts (experts in soccer and handball). Both groups showed that their attentional demand for regulating their postural sway increased as the task increased in difficulty. But this effect during unipedal stance was less for gymnasts, suggesting that expert gymnasts (advanced level of performance) had a decreased dependency on the attentional processes to regulate their postural sway in unipedal stance. The results of Carrick et al. (2007) showed that gymnasts had a greater postural stability and adaptability than non-gymnasts. Further, it was assumed that gymnasts with a higher adaptability score were able to learn and perform new motor routines better.

Bencke et al. (2002) found that gymnasts had most explosive muscular performance of all participants in their study (handball players, tennis players and swimmers). The elite gymnasts (advanced level, mean age 11,8 years) were more explosive than the non-elite gymnasts (intermediate level) indicating that jumping capabilities are crucial for gymnastics performance. An increase in peak power in the last 40 decades was found by Jemni et al. (2006), while the VO2max values seemed to be consistent and not very high (50 mL / kg/min). The gymnasts had a low peak oxygen output and no differences were found between the two groups (elite and advanced gymnasts) regarding their aerobic and anaerobic performance. Further, both groups had a high lactate threshold. Powers & Howley (2007) reported an estimation of the used energy systems in gymnastics. Gymnasts seem to have a predominant anaerobic energy system and these results are in line with the reported low peak oxygen output of gymnasts in the study of Jemni et al. (2006).

In summary, these results showed that high performing male gymnasts were young, small and had a low body mass, they had an athletic posture, a good postural control and balance and they were able to compensate for lack of vision while maintaining posture (multi-modal perception). Further it seems that they had a high explosive muscular power and predominant anaerobic energy system.

Physical characteristics

The second part of the results is about the psychological characteristics of gymnasts and the results can be seen in table 4.

Female gymnasts

In the studies, the level of competition of almost all gymnasts was high, elite or advanced level, although some gymnasts were of intermediate level (Martin, Polster, Jackson, Greenleaf, & Jones, 2008) or the level was not specified (Ryska, Hohensee, Cooley, & Jones 2002). From

articles that reported the years of experience in gymnastics, it could be suggested that the age of beginning of organized training in gymnasts to be around 6 years. The mean age of all female gymnasts was around 15,1 years (including gymnasts under the age limit of 15 years, studies of Ryska et al., 2002; Chase, Magyar, & Drake, 2005; Hars & Calmels, 2007).

The investigation of d'Arripe-Longueville et al. (2009) showed that elite gymnasts had a high achievement motivation. In line with this result, Waples (2005) found that elite gymnasts scored higher on achievement motivation than non-elite gymnasts. Further it was found that the motives of continuing gymnasts were more intrinsically based compared to the dropouts (Ryska et al., 2002). The motives for the continuing gymnasts were fitness ('like to exercise' and 'stay in shape'), the personal challenge ('learn new skills') and they liked the team spirit. The dropouts were older (physical result) and they had a more situational motive ('get out of house') and recognition motive ('be popular' or 'feel important').

d'Arripe-Longueville et al. (2009) reported that the elite gymnasts used psychological strategies like focusing, imagery, goal-setting and self- talk to enhance their performance. The use of imagery and self-talk was also reported by gymnasts in the research of Hars & Calmels (2007). These gymnasts used imagery and self-talk to improve their performance. Observing others and using the coach's feedback were 2 other strategies used to improve performance. Furthermore, gymnasts stated that they used psychological strategies to modify their worries or fears (Martin et al., 2008) and to overcome their fear of injury (Chase et al., 2005). Advanced gymnasts reported the use of psychological strategies like imagery and self-talk to modify their worries. Gymnasts of intermediate level used those psychological strategies less often and relied more on other strategies like 'support from others' and 'counting to three' (Martin et al., 2008). The gymnasts in the study of Chase et al. (2005) used imagery and relaxation to overcome their fear of injury. The reasons why gymnasts in the study of Chase et al. (2005) had fear of injury were 'the difficulty in returning from an injury' and 'being unable to participate in training and competition while injured'. The gymnasts also reported that they overcame their fear of injury by 'just going for a skill' and they were influenced by their coach. The ability to deal with anxiety or fear was also one of the characteristics found in the investigation of d'Arripe-Longueville et al. (2009), gymnasts reported the use of relaxation. Martin et al. (2008) showed that the female gymnasts had most fear on balance beam and uneven bars, although most injuries occurred on floor.

Female gymnasts seemed to be more anxious, less efficacious and less confident compared to male gymnasts, although the level of fear did not differ between female and male gymnasts (Cartoni, Minganti, & Zelli, 2005). The adolescent gymnasts of national level (advanced gymnasts) experienced more fear than the adolescent gymnasts on regional level ('less' advanced gymnasts). Therefore, Cartoni et al. (2005) suggested that gymnastics attracts athletes who are willing to overcome risks and that therefore could be assumed that these gymnasts experienced more fear. Further, advanced gymnasts had more intense worries *(*about body changes and performing skills*)* and more frequent worries *(*about body

changes*)* than less skilled gymnasts (intermediate level), although advanced gymnasts were using more strategies to modify their worries (Martin et al., 2008).

Waples (2005) found that the elite gymnasts scored higher than the non-elite gymnasts on the following subscales: coping with adversity, goal preparation, concentration and confidence. The study of Grandjean and colleagues (2002) also found the characteristics concentration and confidence (Grandjean, Taylor, & Weiner, 2002). The manipulation in this study (the vault was set 5 cm too low) had impact on the vault performance of the gymnasts, but it had little or any effect on later performances. It was suggested that the elite gymnasts learned to concentrate so well and had good confidence, so they were able to recover from a mishap and to refocus on the other performances during competition. The high developed psychological strategies allowed these gymnasts to regain a narrow psychological focus for their next apparatus and to perform their routine (Grandjean et al., 2002).

Aspects of the past performance experiences of gymnasts seemed to be important sources of self-efficacy (Chase et al., 2005). Aspects reported by the gymnasts were success, consistency and the communication with significant others. Cartoni et al. (2005) found that female gymnasts were less self-efficacious than male gymnasts.

Finally, Lavallee & Robinson (2007) found that gymnasts noticed that they were striving for perfection, they pursued excellence and they had the feeling that they needed to progress.

In summary, these results showed that female gymnasts had a high intrinsic and achievement motivation, a good concentration and confidence, they were striving for perfection and excellence. They used psychological strategies to enhance performance or to cope with adversity, worries, fear and injury.

Male gymnasts

In the studies, the level of competition of almost all male gymnasts was high, elite or advanced level, although some gymnasts were of intermediate level (Cartoni et al. 2005). From articles that reported the years of experience in gymnastics, it could be suggested that these gymnasts started around the age of 6 years with performing gymnastics. The mean age of the male gymnasts was around 16,7 years.

The investigation of d'Arripe-Longueville et al. (2009) showed that elite gymnasts had a high achievement motivation. They used psychological strategies like focusing, imagery, goal-setting and self- talk to enhance their performance and they used relaxation to deal with anxiety or fear.

Male gymnasts seemed to be less anxious, more efficacious and more confident than female gymnasts, although the level of fear did not differ between male and female gymnasts (Cartoni et al., 2005). The adolescent gymnasts of national level (advanced gymnasts) experienced more fear

than the adolescent gymnasts on regional level ('less' advanced gymnasts). Therefore, Cartoni et al. (2005) suggested that gymnastics attracts athletes who are willing to overcome risks and that therefore could be assumed that these gymnasts experienced more fear.

Finally, Cartoni et al. (2005) found that female gymnasts were less self-efficacious than male gymnasts.

In summary, these results showed that male gymnasts had a high achievement motivation, were less anxious and more confident compared to female gymnasts and they used psychological strategies to enhance performance or to cope with worries and fear.

Table 4. Results of the articles of the psychological domain: characteristics of the gymnasts (participants) and the main outcome.

Reference	Participants					Main outcome
	N	Gender	Age (years)	Level of competition	Experience (years)	
Females						
Grandjean et al. 2002	18	Female	-	Elite	-	Confidence, concentration, psychological strategies
Ryska et al. 2002	149 132	Female Female	13,7 16,3	Not specified* Not specified **	- -	Intrinsic motivation
Chase et al. 2005	10	Female	13,9	Advanced	8,7	Fear injury, psychological strategies, self-efficacy
Waples, 2005	38	Female	10-21	Elite	-	Coping with adversity, goal preparation, concentration, confidence, achievement motivation
Hars & Calmels, 2007	10	Female	14,8	Elite / advanced	-	Improve performance, psychological strategies, observing others, coach's feedback
Lavallee & Robinson 2007	5	Female	23,8	Elite / advanced	17,6	Set entire life to gymnastics, perfectionism, pressure to progress
Martin et al. 2008	7 120	Female Female	17-21 14,4	Advanced Intermediate / advanced	12 7,7	Worries, fears, (psychological) strategies to modify worries
Females and Males						
Cartoni et al. 2005	30 29	Female Male	15-19 15-19	Advanced Intermediate	- -	Anxiety, fear, self-efficacy
d'Arripe-Longueville et al. 2009	7 7	Female Male	15,6 15,6	Elite Elite	10 10	Achievement motivation, psychological strategies, deal with anxiety and fear

* state level, continuing gymnasts. Level was not specific enough to classify (probably advanced level)
** state level, drop-outs. Level was not specific enough to classify (probably advanced level)

DISCUSSION

The aim of the study was to create a (all-around) profile of an elite gymnast. The results of the anthropometric characteristics indicated that the gymnasts were small and light compared with reference. The female gymnasts had a mean stature of 153 cm and a mean body mass of 44 kg. These values seem to be lower compared to the mean stature and body mass of Dutch adult women in 2010; respectively 167,6 cm and 70,2 kg (http://www.cbs.nl). The stature and body mass of the gymnasts in the study of Davlin (2004) seem to be consistent with the results, although their mean age was somewhat lower (13,7 years) than the senior elite age of at least 15 years. In contrast, the stature and body mass of the gymnasts in the study of French et al. (2004) seemed to be slightly larger and heavier compared to the athletes with a mean age of 14,5 years (French et al., 2004). These differences are probably due to the higher mean age (19,7 years) of the gymnasts in the study of French et al. (2004).

The male gymnasts had a mean stature of 169 cm with a mean body mass of 67 kg. Also these values seem to be lower than the mean stature and body mass of Dutch adult men in 2010; respectively 180,8 cm and 83,8 kg (http://www.cbs.nl). The results of the mean stature and body mass of the gymnasts in the included studies seem to be consistent. In contrast, a difference was found between the shoulder width of the gymnasts in 1933 and 2000 (Čuk et al., 2007). Compared to the gymnasts in 1933, the gymnasts in 2000 had wider shoulders and a narrower pelvis. These differences in shoulder and pelvis width can be explained by the increase in difficulty of the routines today (difference code of points). Nowadays, more rotations around horizontal and vertical axis are performed as well as a higher number of summersaults and twists. These movements require an optimal body composition and probably this is reflected in an increase in shoulder width and a decrease in pelvis width. It can be suggested that these results are also applicable to the shoulder and pelvis width of female gymnasts, but because there is no data this effect cannot be demonstrated. Further, the stature of the gymnasts can influence their performance (Ackland, Elliott, & Richards, 2003). The results of this study showed that the smaller gymnasts had a higher potential to perform skills involving whole-body rotations. Despite of the finding that the larger gymnasts were able to produce more power, their performance could not match the performance of the smaller gymnasts. These results suggest that the stature of the gymnasts will influence their performance, whereby the small gymnasts have an advantage. This can be one of the reasons why female and male gymnasts seem to be (one of) the smallest athletes and this finding is also reflected in a study of Bencke et al. (2002). The gymnasts were the smallest and lightest athletes that participated in their study (team handball, tennis and swimming). At an early age (around 11 years) the gymnasts seem to be smaller than the participants of other sports and therefore it can be assumed that this can be an important characteristic of a gymnast.

Some other characteristics that emerged from the results of the physical domain are balance and postural adaptation and regulation. Both female and male gymnasts seem to

have a superior dynamic balance compared with soccer players, swimmers and individuals with no competitive sport experience (Davlin, 2004). The results of the study of Bressel et al. (2007) are not in line with this result. They found no difference in the dynamic balance of female gymnasts and soccer players, although the scores on the balance test seem to be moderate to high. The fact that Bressel et al. (2007) did not find differences between gymnasts and soccer players might suggest that the tests used were not sensitive enough to pick up differences between them. Further, no gold standard has been defined to measure dynamic balance and this could be a reason that the test used to measure dynamic balance was not good enough to detect differences between the two groups. However, Bressel et al. (2007) found some differences in static balance between gymnasts and basketball players, indicating that the static balance of gymnasts was superior. These findings suggest that gymnasts have a good balance and this can be useful on apparatuses that require a good balance, for instance the balance beam for females and the pommel horse for male gymnasts.

Gymnasts seem to have a good control over their body (Lavallee & Robinson, 2007) and this is reflected in a good postural regulation and adaptation (Carrick et al., 2007; Gautier et al., 2008). Further, the postural regulation and adaptation seems to be dependent on a multi-modal perception (Vuillerme et al., 2001; Gautier et al., 2007; Gautier et al., 2008). Gymnasts seem to have the ability to use different sources of information to regulate or adapt their posture. From several investigations it became clear that gymnasts are able to compensate for lack of vision by using the remaining sensory modalities (Vuillerme et al. 2001; Croix et al., 2010). These characteristics seem to be very useful for gymnasts because they are performing the most difficult routines and a good control over their body is thus necessary. Also, the ability to use different sources of information to compensate for a lack of vision seems to be important. For example, when a gymnast performs a summersault with rotations around several axes, it will be impossible to observe where you are and when you are going to land on the ground. Therefore, gymnasts can benefit from the ability to use other sources of information than vision to feel where they are and when they are going to land on the ground.

Further, male gymnasts seem to be less dependent to attentional processes to regulate their postural sway (Vuillerme & Nougier, 2004). So less attention is needed during the regulation of their postural sway and more attentional resources are available for other components of a task or movement. For gymnasts this means that they do not need all their attention to regulate for example balance, but they can direct their attention to other difficult components of a movement.

The remaining results of the physical domain showed that the explosive muscular per-formance of the gymnasts was superior to that of athletes from handball, tennis and swim-ming (Bencke et al., 2002). Further, the elite gymnasts outscored the non-elite gymnasts al-though they did not reach senior level yet. These results indicate that the jumping capabilities

(whereby explosive muscular performance is needed) seem to be crucial in gymnastics. The ability to develop enhanced levels of muscular power is reflected by the potential to perform more advanced skills and acrobatics (French et al., 2004). In line, Jemni et al. (2006) found an increase in peak power (maximum power generated in first 10 seconds of test) in the last 40 years. The lactate threshold of the male gymnasts was high, probably as an effect of training on a high volume of strength. Strength training seems to be important in gymnastics and strength and peak power seem to be key components of the physiologic profile of a gymnast, these are needed to perform short and explosive movements (Jemni et al., 2006). Most routines are short of duration (5 seconds – 90 seconds) and a lot of movements have to be very explosive. Therefore, it will not be surprising that gymnasts seem to have a predominant anaerobic energy system (Powers & Howley, 2007) and that their peak oxygen output seems to be low (Jemni et al., 2006).

The results of the psychological domain showed that elite gymnasts have a high achievement motivation (Waples, 2005; d'Arripe-Longueville et al., 2009). Their motivation seems to be more intrinsic, indicating that their motivation is driven by themselves instead of motivation that is driven extrinsic (like winning and rewards). Gymnasts like the personal challenge to learn new skills (achievement motivation) and this is probably one of the most important characteristics of a gymnasts. The drive to learn new skills and to repeat particular movements until they can execute them perfectly is needed to improve the skill and performance level. So, motivation is needed to progress (learn new movements), to strive for perfection (repeat over and over again), to believe in yourself by reaching your goals and to perform well.

Further, gymnasts seem to use several psychological strategies (like imagery, goal-setting and focusing) to improve their performance and also to modify their worries and fears (Chase et al., 2005; Hars & Calmels, 2007; Martin et al., 2008; d'Arripe-Longueville et al., 2009). The ability to deal with worries and fears seems to be meaningful while gymnastics is a sport in which gymnasts participate to overcome risks (Cartoni et al., 2005). Therefore, the ability to deal with anxiety (for injury) appears to be important, especially because the difficulty of the routines is increasing. To be an elite gymnast, you need to perform very difficult routines. Worries and fears can have a negative impact on performance and this could be a reason why gymnasts have developed psychological strategies so well.

It is remarkable that male gymnasts seem to be less anxious and more confident than female gymnasts and that no differences were found regarding fear (Cartoni et al., 2005). Fear is an emotional response to a known threat (Kaplan & Sadock, 1998) and probably both female and male gymnasts have a similar level of fear. It can be suggested that the level of fear is related to gymnastics, it is a sport involving athletes who have the drive to overcome risks and there will be a chance to get injured. On the other hand, male gymnasts seem to have a lower level of anxiety. Anxiety is a response to an unknown threat (Kaplan & Sadock, 1998). In comparison to female gymnasts, male gymnasts seem to be less anxious in these

situations. This is not specific to gymnastics, but it can also be seen in daily life; for example on the street when it is dark.

It seems plausible to state that gymnasts somehow have developed several characteristics (like the use of psychological strategies) to adapt their 'thoughts' in such a way that the negative aspects of worries and fears will affect their performance as less as possible, so the routines can be performed as good as possible. Therefore, these characteristics seem to be important in the profile of an elite athlete. The importance of these characteristics can be seen in the experiment of Grandjean et al. (2002) in which the vault was set 5 cm too low at the Olympic Games. This manipulation had an effect on the performance of vault, while the manipulation on vaulting had little or any effect on the performances on the other apparatuses. The female gymnasts used their psychological strategies to regain a narrow focus for the next apparatus, they had developed a good concentration and they were confident enough to perform their routines on the remaining apparatuses. These high-developed skills of the gymnasts allowed them to maximize their performance.

Aspects of past performance experience seem to be important sources of self-efficacy of a gymnast (Chase et al., 2005). Self-efficacy is an athlete's belief about his or her own capabilities to organize and execute a task successfully in order to obtain a certain outcome (Bandura, 1977, 1997). One of the important aspects reported by the gymnasts was the success in past performance (Chase et al., 2005). When a gymnast is performing well, this can lead to a higher self-efficacy which can enhance the motivation and altogether this can result in a better performance. On the other hand, if your past experiences are not successful, you can lose some self-confidence and also your self-efficacy can decrease. This can result in a decrease in motivation and probably your performance will be less good. Another important aspect that was reported by the gymnasts was consistency. When the past performances of a gymnast seem to be consistent, the gymnast got more confidence and motivation to perform well (Chase et al., 2005). This probably will lead to an increase in self-efficacy which in turn can lead to better performances. Further, a gymnast can face some less pleasant situations (for example non-successful performances or injuries) and then coping with adversity can help them to handle these situations, gaining confidence and self-efficacy to find the motivation to go for it. Motivation seems therefore a key component of an elite gymnast and it can be stimulated in several ways. As described earlier, the use of psychological strategies can help to increase performance which can lead to the perception of success. This can be used as a source of self-efficacy that can help to increase the motivation to perform better and better (the personal challenge). Also coping with adversity, worries, fears and injuries can help gymnasts to gain self-efficacy and in this way to get more motivated to go on and become better.

The results revealed that several characteristics seem to be important to be an elite gymnast. At first the anthropometric characteristics (being short and light), strength and power seem to be important. The postural control and balance of gymnasts seem also to be impor-

tant, especially with the increasing difficulty of the routines today. Beside these important physiologic characteristics, several psychological characteristics are needed. A high motivation (achievement and intrinsic motivation) is needed to perform at the elite level and to set up your entire life to gymnastics. The development and use of psychological strategies and the ability to cope with adversity, worries, fear and injury seems to be helpful to enhance performance and to increase self-efficacy. A combination of several characteristics (both physical and psychological) seems to be important for an elite gymnast, so a multi-dimensional profile seems promising. Although it will be clear that there are a lot of characteristics that probably are important to be an elite gymnast, the question still arises: which characteristics are most important? Claessens and colleagues (1999) found that the anthropometric characteristics (positive), endomorphy (negative) and age (positive) contributed 32% to 45% to the performance scores in elite female gymnasts (Claessens, Lefevre, Beunen, & Malina, 1999). So being small, light, having broad shoulders and narrow hips (opposite of endomorphy) and having experience (higher age) seem to be important characteristics that contribute to the performance score. The study of Claessens et al. (1999) did not take into account other physical characteristics like strength and postural control, neither the psychological characteristics of gymnasts were taken into account. Therefore it is impossible to determine which characteristics seem to be most important or which characteristics are definitely needed to be an elite gymnast. Although there are no studies that investigated the relationship of the different characteristics relative to each other, it seems to be required to focus on these relationships in future research. Still the results of Claessens et al. (1999) seem to be useful, especially because it is notable that gymnasts are small and light. Being small has the advantage that whole-body rotations can be performed easier (Ackland et al., 2003) and the athletic body composition (broad shoulders and narrow hips) will optimize the movements involving rotations (Čuk et al., 2007).

A variety of characteristics are found which could be used to create a profile of an elite gymnast. But is it possible that there are other important characteristics that not have been studied yet? Does an elite gymnast need all the characteristics or is it possible to compensate for missing characteristics? Maybe the perfect elite gymnast does not exist because every gymnast has his or her own characteristics with several strengths and weaknesses. The articles used in this review applied different tests to measure the same characteristics, for instance postural control. There are no gold standard measurements for postural control, making it difficult to compare the results of the several articles, even though they attempt to measure the same characteristic, postural control. Another limitation which should be noticed is that the physiological performance is influenced by body size. If studies do not correct for these influences, this may lead to misinterpretation of the results when comparing the articles to each other. In addition, the articles included in this study were assessed on their methodological quality. Although most articles achieved a moderate to good methodological quality, some limitations of the available data should be taken into account.

Creating the profile of an elite gymnast seems to be impossible at the moment, although a lot of important characteristics are already discussed. Future research should be directed to the relation of the characteristics relative to each other to determine which characteristics seem to be of greatest importance to become and be an elite gymnast.

Finally, only if a gymnast is provided the opportunities and facilities, he or she will able to become an elite gymnast. So, the road to success does not only depend on the characteristics of the gymnasts, but also to the opportunities and facilities that are available during the development of a gymnast. The best coaches, good training facilities and supporting parents and significant others are needed to develop maximally and finally to become and be an elite gymnast. Therefore, it seems to be important to start at a very young age (around the age of 6 years) and to get the opportunities to become an elite gymnast. Further, motivation seems to be a key component during the road to success. Motivation is needed to strive for perfection and excellence and to set your life to gymnastics to become one of the best gymnasts. From the other side, when a gymnast has the motivation to become a very good gymnast, but when strength, power and postural control are missing, it will also be very hard to reach the highest level of performance. Therefore, it can be suggested that the combination of several characteristics seems to be a promising profile, although further research is recommended. Perhaps it is possible to use such a profile of an elite gymnast in future to help with the tough decision which gymnast will get the opportunity to maximize his or her development and to become an elite gymnast.

CONCLUSION

From the results it can be concluded that it is not yet possible to create an all-around profile of an elite gymnast. It is possible to argue that a combination of several characteristics seems to be important in the profile of an elite gymnast. These include physical characteristics as being small and having a low body mass, an athletic posture, a good postural control and balance and a high explosive muscular performance. Psychological characteristics that seem to be important are a high intrinsic and achievement motivation, a good concentration and confidence, the drive to strive for perfection and excellence and the use of psychological strategies (to enhance performance or to cope with adversity, worries, fear and injury). It is hard to determine which characteristics seem to be most important, because nothing is found about the relation of the several characteristics relative to each other. Even so, it is difficult to assume which characteristics are definitely needed in the profile of an elite gymnast. Therefore, future research should focus on the relationships between the several characteristics relative to each other and these relationships can eventually contribute to the creation of the profile of an elite gymnast.

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