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The functional movement screen as a predictor of injury and the factors involved in its performance

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For my family, Lecturers and all my friends

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Abstract

Functional training has been one of the top ten biggest fitness trends for the past few years. With the uprising use of the functional training concept, there is another concept that becomes important, functional capacity. It was in the context of rehabilitation that the physiotherapist Gray Cook invented the Functional Movement Screen (FMS) as a way to measure functional capacity and therefore screen injury risk.

The aim of this study was to better understand if the FMS is an effective tool to predict injuries and what factors are involved in FMS performance. According to the current literature, BMI and waist circumference are negatively correlated with FMS performance, this study reinforces those findings, and both variables had a statistically significant negative correlation with FMS performance, respectively (r=-0.368) and (r=-0.369). This study was the first study, according to the author's knowledge, to look at the correlation between muscle mass and FMS performance, this correlation was not statistically significant (r=-0.284). Nevertheless, there were interesting findings seen from this variable, participants with higher muscle mass scored higher on the trunk stability push-up, with a statistically significant difference between groups, on the other hand, participants with higher muscle mass scored lower on the shoulder mobility exercise, also with a statistically significant difference.

It seems that the functional movement screen is not the injury prediction screen that is sold out to be, its ability to predict injury is still not clear in the literature. Creating a new Functional Scoring System better at predicting injury and at analyzing the causes for movement dysfunction would be highly advisable.

List of Symbols and abbreviations

FMS-Functional Movement Screen

BMI-Body mass index

BF-Body fat

MM-Muscle mass

SD-Standard deviation

PA-Physical activity

IPAQ- International physical activity questionnaire

LESS- Landing error scoring screen

ACL- Anterior cruciate ligament

ALR- Active leg raise

SFMA- Selective functional movement assessment

LL- Leg length

Introduction

Functional training has been one of the top ten biggest fitness trends for the past few years (Thompson., 2019). Before this concept became a trend, the fitness world was mostly seen as a tool to look better, either by losing body fat, gaining muscle or both, thus not focusing on its impact regarding motor skills improvement. Typically, the goal mentioned above would be achieved through the use of either resistance machines or free weights by focusing on a single plane or linear movement, of an isolated muscle group.

According to Boyle, Functional training is defined as any type of training that improves function (Boyle 2003). Hence it is not necessarily an exercise where training is done with external instability or various planes at the same time, it can be just the improvement of quadriceps strength in the elderly through the leg extension exercise before they are ready for a squat (Boyle 2003). For most populations performing an exercise such as lunges might be considered more functional than the leg extension, because it is more closely aligned to the movements, we perform in our day to day life, involving balance, one leg strength and intermuscular coordination (Boyle 2003).

Although it became a trend a few years ago, “functional training” is not a new concept and has, in fact, been widely described in the literature and put into action for a very long time. The utilization of the name "functional training" seems to be a lot more recent, though becoming more prominent used by physical therapists in a rehabilitation setting (Dias 2011). With the uprising use of the functional training concept, there is another concept that becomes important, functional capacity or functional fitness. In this dissertation this concept will be defined by "the capacity to act on, influence and/or change the surrounding environment" (Pacheco et al., 2013), the goal of functional training is to improve functional capacity.

Its usage is rising as the perception that training can be used for more than aesthetic results, or for specific sports conditioning, it can also be used in the general population for improvement of abilities like balance, coordination, agility and others involved in the day to day life (Liebenson, 2002).

A 30-year-old individual might find interesting the idea of being more prepared to play football with his friends on the weekend or to help his parents move to another house, and functional training can help him with that. A 70-year-old lady might also find interesting the idea of being able to play with her grandson or to get to the top shelf all by herself. These examples were made in order to give a practical perspective of what functional training can do for the general population, and why it can possibly be such a valuable tool to have in the fitness and exercise world.

With this idea it is essential to note that defining functional training objectively is quite hard, two phrases said by Michael Boyle that might help us understand what Functional training is were "Functional training is, in the simplest sense, a training system that applies what we now know about functional anatomy to training" he also refers to functional training as "functional training is purposeful training, function is purpose. In other words, any training with a purpose is functional" (Boyle, 2004). Has we can see here, the concept of functional training is not extremely objective, so scientific studies done on this field can easily become controversial.

After saying this, since this concept of functional training is quite recent, the scientific literature that is available examining this concept is not well developed in terms of volume of studies and depth of analysis of the effects of functional training. One of the reasons for the lack of studies on this topic may be that the specific term ‘functional training’ has only recently become commonplace. Another reason might be the fact that is hard to measure the functional capacity of someone objectively, except in the context of sports performance and, again, it has only been recently that researchers have attempted to ‘measure’ functional movement holistically. In a more general way, there are not a lot of known methods that measure functional capacity. For example, LESS measures jump landing mechanics and seems to be really good at it (Padua et al., 2009, 2015) but it is an extremely specific tool that just measures a particular functionality of movement, another example of some tests that are performed by physiotherapists are the ones in the book “Muscles: Testing and Function with Posture and Pain” (Kendall et al., 2005), being that the tests executed in there, even though they are correlated with functionality, they hardly can be considered functional tests since they are performed most of the times in a situation of joint isolation, or even the ones that are not, usually test flexibility or strength by itself and not so much in a situation close to the daily activities we perform. A study done by Pacheco (2013) and his peers measured the difference between functionality improvement with functional training vs classical strength training and found no statistically significant difference between the two methods (Pacheco et al., 2013), using these factors as indicators of functional capacity:

Table 1. *Schedule training structure of the Functional Group. Dosage of exercises is described within text.*

Exercises / Weeks	1	2	3	4	5	6	7	8	9	10	11	12
Isometric Exercises (e.g., plank, side plank)	X	X	X	X	X	X		X				
Small-Base of Support Exercises (e.g., squat with feet together, lunge in line)	X	X	X	X	X		X	X	X	X		X
Isometric Exercises + Dynamic Exercises (e.g., side plank with leg suspension, push up)					X	X	X	X	X	X	X	X
Balance (e.g., postural control in an instable surface)						X	X					
Balance + Dynamic Exercises (e.g., squat in an instable surface)								X	X	X		X
Balance + Isometric Exercises (e.g., plank with the legs supported by a ball)									X		X	
Balance + Isometric + Dynamic (e.g. push up with the legs supported by a ball)										X	X	X

Figure 1: Reprinted from (Pacheco et al., 2013)

The FMS is a screening tool that is used to measure functionality, or Functional Capacity (FC) as it will be called throughout this thesis, according to Gray Cook if our level of Functional Capacity is lower, then our risk of injury is higher, since we are going to be training the wrong movement patterns (Cook et al., June, 2014).

It was in the context of rehabilitation that the physiotherapist Gray Cook (Cook et al., 2014) invented the Functional Movement Screen (FMS) as a solution to the question that was probably around the minds of many people:
“How can we measure someone's functional capacity and therefore predict injury?”

The FMS was invented with the purpose of answering this question.

The aim of this thesis was twofold: (1) to do a brief literature review on the ability of the FMS to predict injury and (2) to study the relationship that exists between anthropometric measurements and PA levels with FMS performance.

Figure 2: Example of classic movements considered "functional".

Literature Review

FMS overview

The FMS, or functional movement screen, is a tool created by Gray Cook, designed to be an objective tool to determine if one's movement is functional or not and therefore predict injury. It is composed of seven different movements that were combined to measure various motor skills, like strength, flexibility and balance.

The screen was created based on the fundamental assumption that "Fundaments always come first" (Cook., 2010). According to Gray Cook, we should first screen the movement patterns, and only then we can start training these same movement patterns. If we train the wrong movement patterns, then wrong patterns will be reinforced and the risk of injury higher (Cook., 2010). Hence, the functional movement screen was created as a predictive system. It was designed to rank movement patterns on the functionality of active day to day people. The score is divided into three groups:

Acceptable Screen- cleared to be active without increased risk

Unacceptable Screen- at risk for injury unless movement patterns are improved

Pain with Screening- currently injured, requiring more advanced movement and physical assessment by a healthcare provider (there is a movement assessment also created by Gray Cook that can usually be used in this situation called SFMA) (Cook., 2010).

If we follow this train of thought then, one understands that low FMS scoring should be a definite indicator of a high risk of injury, but if we look at the Science analyzing the FMS as a predictor of injury risk, it doesn't look like such association is entirely true. In 2015 a meta-analysis made on this subject, found no conclusive evidence of FMS validity as an injury prediction tool, even though the authors also admitted that there were methodological and statistical limitations that could have compromise these findings (Dorrel BS et al., 2015).

A meta-analysis done by Kraus (2014) showed that a score of <14 has a correlation with a higher risk of injury in collision, team sports, firefighters, and tactical professionals, on the other hand, there seemed to be no evidence supporting its ability to improve sports performance (Kraus et al., 2014). Several other reviews of the literature and scientific papers were done on this subject, and they will be further analyzed on this paper (Kraus et al., 2014; Dorrel et al., 2015; Bonazza et al., 2016; Moran et al., 2017)

The FMS scoring encompasses the classification of seven different movements on a rank of 0 to 3, following some very specific and inflexible guidelines, which attributes to the individual, a final score between 0 and 21 (Cook., 2010).

The validity of this movement screen in predicting injury risk and sports performance doesn't seem to be very clear, even though some studies do show some correlation between low scoring and injury risk, it's only shown in a small percentage of the studies done, and most of these studies are not accepted as having high quality in the meta-analysis done so far.

From the inventor's theoretical perspective and assumptions, this movement screen seems wise. Gray Cook's perspective on functional assessment and overall FMS importance has been widely accepted and advocated worldwide .Moreover, it has been taught at universities, as a screening tool to be used on its own as a sole measure of functionality and injury prediction, nevertheless, the underpinning scientific background doesn't seem to very clear at this point (Warren et al., 2018). Furthermore, more designed cohort studies are required to understand and confirm the FMS viability as an injury predictor (Warren et al., 2018).

The FMS has been invented as a twenty-one-point scoring system nevertheless, there was another scoring system created in which the scoring goes up to a hundred points instead of twenty-one.

All thirty-three studies from the Meta-Analysis "Efficacy of the FMS: a review" (Kraus, 2014) used the 21 scoring system only, the Everard Study from 2016 examined the relationship between the Functional Movement Screen and the Landing Error Scoring System in an active collegiate population. This study was the only large study to use the 100 point system according to the author (Everard, 2016).

At this moment the 21 point system is the most recognized as valid in the scientific literature, in the strength and conditioning setting and in the clinical setting nevertheless, the 100 point system might be proven more useful and valid in the future so future research on this system could be beneficial.

Figure 3: The seven Functional Movement Screen movement.

FMS and injury prediction

Several studies have been done with the goal of understanding if this relationship really exists. The results of the studies have not been very consistent. Firstly, some of the individual studies that looked at the ability for the FMS to accurately predict injury risk are going to be discussed and afterwards the goal will be to look individually at the results given by the literature reviews made on the subject so far.

To search for studies and meta-analysis done on the subject so far the search engines used were: PubMed, SportDiscus and Web of Science, the keywords used were: functional movement screen and injury prediction.

A study done by Chorba et al. (2010) showed that in College female athletes a score of 14 points or less (the cut-off point customarily used to indicate a high risk of injury) resulted in a 4-fold increase in the risk of lower extremity injury risk (Chorba et al., 2010). This same study seems to have some limitations, according to the Meta-analysis done by Dorrel and colleagues had a poor classification, it was classified after quality assessment as a 2 out of 7 (Dorrel et al., 2015).

A study done by Letafatzkar et al. (2014) showed similar results, where 100 active students had an approximately 4.7 higher chance of injury if they scored less than 17 on the FMS (Letafatzkar et al., 2014). The cut-off point of 17 is not typically used in the literature. This might indicate an attempt of the authors to exacerbate the FMS ability to predict injuries, or possibly just because in this study, the mean FMS score was quite high (16.7 ± 1.8).

Several studies were done on this subject after the last meta-analysis was published (REF) Some examples are:

A study carried out by Pollen et al. (2018) showed a significant positive correlation between FMS scores and injury rate (Pollen et al., 2018), meaning that FMS not only didn't prevent injuries, but participants with higher FMS scores had a higher tendency to get injured.

A study done by Philp et al. (2018) arrived at the conclusion that FMS has neither the ability to predict injury or to identify it (Philp et al., 2018). It is important to note the limitations present in this study, first the sample size was quite low (24 participants), second all the participants were part of the same football team making the sample very specific.

Another study also conducted in a limited context, high school baseball players, showed the same results, the authors concluded that FMS was not able to predict injury in this context (Lee et al., 2018).

There were several reviews of the literature done on this subject, four of them according to the authors knowledge, the first one was done by Kraus et al. (2014). In this revision the authors concluded that the FMS is not a valid indicator of sports performance, but in the case of injury prediction it is supported by moderate scientific evidence, it is suggested that it can be used for injury prediction if the person evaluation the screen is educated and experienced (>100 trials) (Kraus et al., 2014).

The second one was written by Dorrel and colleagues, they found no evidence of the predictive validity of the FMS, however, as with the literature review previously mentioned, since the review was done in 2015, there was not a lot of studies done on this subject, and the ones that existed were considered as having low quality (Dorrel et al., 2015), being that for this meta-analysis a really small sample of only 7 studies was selected. This means that possibly some of the studies used on the first meta-analysis were not entirely valid.

A third one done by Bonazza and colleagues arrived at the conclusion that the FMS has an excellent inter-rater reliability (Bonazza et al., 2016), giving a more positive outlook than the review that was done by Moran and Colleagues specifically on inter-rater reliability, that just showed moderate evidence of inter-rating reliability of FMS done in live studies (Moran et al., 2015).

Also, according to the review done by Bonazza, the participants scoring lower than 14 on the FMS had a significantly higher chance of injury, nevertheless it is important to note that according to the author "Significant concerns remain regarding the validity of the FMS" (Bonazza et al., 2016).

The last meta-analysis was written by Moran and colleagues, it was conducted in 2017, it is important to note that in recent years, the number of studies examining this subject has risen quite quickly. This happened because the topic has become more recognized as important in the scientific literature, because of this, some of the studies done after Moran's literature review were and will be presented in this paper.

According to this last review, only in military personnel was there a strong evidence of FMS being a good screen to predict injury, for football, the authors even recommended against the usage of FMS for injury prediction and in all the other sports the evidence on the functional movement screen ability to predict injury was ‘limited' or ‘conflicting' (Moran et al., 2017). Moran's revision showed strong evidence of FMS ability to predict injury for military personnel. Another literature revision was done in 2018 that looked specifically at the ability for the screen to predict injury in tactical occupations, the conclusion was that even though there seems to be some evidence of the FMS ability to predict injury, it is not enough, from the authors perspective, for the FMS to be used as a sole indicator of injury risk (Kollock et al., 2018).

Looking at the literature undertaken on the subject it seems like there is not much clear evidence showing the FMS as a good predictor of injury, nevertheless it is being used in universities, gyms and clubs as a tool to do so. Is this really a good option? Should maybe the FMS be used together with other screening tools to make it more valuable and assertive at predicting injury risk?

It is important to note that just looking at the final score from the FMS doesn't give us any valuable information about the exercise prescription that should be used to increase functional capacity. The FMS only provides us with a scoring, and even though the individual exercise scores might be useful, this scoring only gives us an idea on how the athlete performs in certain movements, there is no objective measure of strength or analysis of specific muscle imbalances. So, what does the FMS give us that can be helpful in understanding how to tailor a workout routine to a certain individual? For example, in almost every sport there are rapid decelerations and high eccentric forces, and these seem to be correlated with a higher risk of injury, but these abilities are not tested in the FMS (Tabatabaei et al., 2018). The controlled and slow fashion characteristics of all the FMS tests seem to be limiting factors since they are not very close to what happens during the actual sporting events.

An example of a more comprehensive approach for screening injury risk was used in the study done by McGill and colleagues, where besides the FMS, static posture, mobility and other ‘functional' movements were used in synergy with the functional movement screen. This study looked specifically at back injuries.

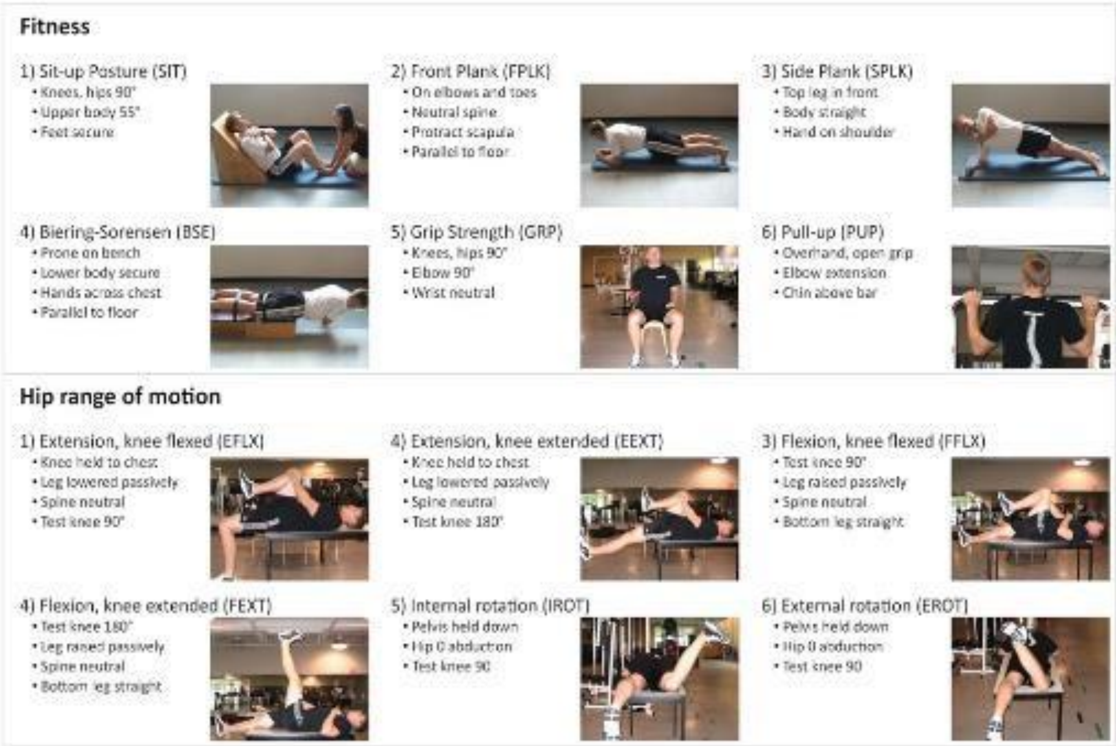

Figure 4 shows the fitness tests and the hip range motion tests used in McGill's study (McGill, 2015)

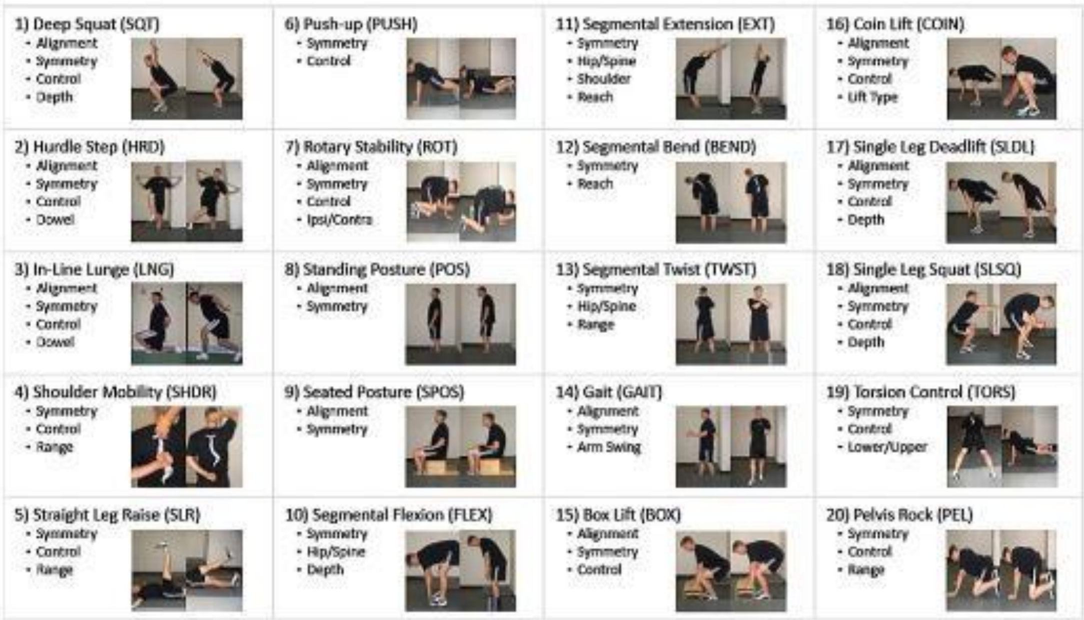

Figure 5 shows the movement competency tasks used in McGill's study (McGill, 2015)

Looking firstly at the FMS, the screen had exactly the same score for the police officers that got injured during the duration of the study and for the ones that didn't (15.1), on the other hand, some exercises showed quite a significant ability to predict back injuries. Abdominal endurance being the best predictor of injury, with a p-value of ($p=0.078$) and the second best being Shirley Sahrmann's pelvic rock test ($p=0.0839$), (Mc Gill et al., 2015).

It is mentioned in McGill's paper the fact that a lack of spine extensor muscle's strength is predictive of injury (Mc Gill et al., 2015) as was shown in a study done by (Biering-Sorensen., 1984). Looking at something as specific as spine extensor muscle strength is a lot of the times necessary and one of the downsides that the FMS has, is the fact that even though it is a tool to measure functional capacity in a general way, it might be necessary in most cases to do a more specific to body region and injury type approach. Also studying the ability for individual FMS tests to predict certain types of injury might be necessary to understand the validity of the FMS better and possibly to understand if there are unnecessary exercises in the screen.

FMS scores and body composition

In the literature to date, there seems to be a consistent correlation between FMS scores and body composition, where a higher BMI corresponds in several studies to a lower score in the FMS. A study done by Ulrike and colleagues showed that as BMI increases FMS scores decline (Ulrike et al., 2015), also studies done by Duncan and Perry & Koehle arrived to the same conclusions (Duncan et al., 2012; Perry & Koehle 2013).

A lot of studies have been done correlating BMI levels with FMS scores nevertheless, to the author's knowledge only one study compared BF% with FMS scores, this study was done by Nicolozakes and it showed that in individuals with higher body fat percentages the FMS scores had a tendency to be lower (Nicolozakes et al. 2018), because this study was done in College football players, studies done to access this relationship in a more general population might be advisable to confirm these values.

Even though it can seem that correlating FMS scores with BMI is very similar to correlating it with body fat percentage, it is possible that these values differ, since high BMI values can exist coming from higher levels of muscle mass, and higher levels of muscle mass are most likely not correlated with low FMS scores. It is important to take into consideration that BMI is not the best indicator of obesity (Goonasegaran et al., 2012), since body fat percentage and muscle mass should be taken into consideration when classifying someone as overweight or obese, this is especially important when we are looking at studies done on the FMS because most of them were done in active population and this population has on average a higher muscle mass percentage. Now a question arises, one that will be addressed for the first time, according to the author's knowledge. Is a higher value of muscle mass correlated with higher FMS scores? The study presented on this thesis will try to answer this question.

FMS scores and age

Most studies done on the FMS were conducted with populations where most participants are of similar age, this happens because most studies are done on athletes, either beginners, intermediate or elite athletes and this population typically doesn't differ a lot in age. Also, there are quite a few studies done on the FMS in school children, either primary school, high school or university students. Fortunately, even though most of the studies done on the FMS have participants with similar ages, there are still studies looking at age as a factor involved in FMS performance.

One study done on active older adults showed a negative correlation between age and FMS performance (Mitchell 2016). Another study done by Perry and Koehle showed the same negative correlation but with both middle-aged and older adults (Perry & Koehle 2013).

Age	*N*	*M*	*SD*
20–39	53	14.79	2.76
40–49	102	14.85	2.58
50–54	68	14.03	2.29
55–59	72	13.64	2.68
60–64	50	12.98	2.67
65+	50	12.56	3.27

Age	*N*	*M*	*SD*
20–39	44	15.43	2.44
40–49	66	15.17	2.93
50–54	34	14.59	2.88
55–59	44	13.66	2.63
60–64	27	12.89	3.23
65+	12	13.17	3.01

Figure 6 Reprinted from (Perry and Koehle 2013), this figure shows the mean FMS score by age group. Top image for males and bottom image for females.

Another study looked at FMS performance and age, in this case, the age range was wider, with participants from 18 to 78 years old (Bonis et al., 2017). Also, this study had a considerably lower age average (mean age + SD = 27.4+ 11.6 years).

This study arrived at the same conclusion that with age FMS performance seems to decline (Bonis et al., 2017).

It seems very clear looking at the current literature that in adults, FMS performance is negatively correlated with age, this has been shown in all age groups, and analyzing the values, this correlation tends to be quite clear. This negative correlation makes all sense since with age physical capacity tends to decline (Twomey & Taylor 1984).

FMS scores and gender

Taking a look at how gender affects FMS performance, it doesn't seem to be very relevant when we talk about overall FMS performance, but it seems quite relevant if we focus on specific FMS movements.
For example, a study done by Agresta and colleagues (Agresta et al., 2014) showed an average score of 13.1 for males and 13.3 for females, this difference is not statistically significant but, if we take a look at the mean scores of individual FMS movements, the differences are quite noticeable. In the active leg raise the mean score for males was 1.8 and for the females a noticeably higher value of 2.5, in the trunk stability push-up the situation is the opposite, where males score far better than females with an average score of 2.3 compared to an average score of 1.4. In both these situations, the difference is statistically significant (Agresta et al., 2014).

In another study performed on this subject, the results are very similar. A study done by Schneider and colleagues, showed a mean FMS score of 15.6 for females and 15.8 for males, even though these numbers differ quite a lot from Agresta's study the difference of averages is precisely the same (0.2), with the only difference that this time males scored better than females. If we again take a look into the individual FMS scores, in the active leg raise 46.3% scored a three and 43.5% scored a two while 48.5% of males scored a two and 40.6% scored a one. In the trunk stability push-up again, men scored better than women, 76.2% of males scored a three while 58.3% of females scored a one (Schneider et al., 2011).

Lastly, one study showed different results, where males scored on average 14.93 and females scored on average 14.17, in this situation, the difference was statistically significant (Abraham et al., 2015). Also, in the ALR (active leg raise) contrary to the previously mentioned studies, there was almost no difference in mean score between genders, females scored lower than males with an average score of 1.96 while males mean score was 2.00. In the trunk stability push-up, the average score was 1.58 for females and 1.76 for males, having a statistically significant difference between scores (Abraham et al., 2015).

According to the above reviewed literature, it seems like there is a tendency for total FMS scores to be similar, meaning that gender doesn't seem to be an important factor in FMS performance. Also, the two individual FMS scores where usually there is a more significant discrepancy were the ALR and TSP.

FMS and physical activity levels

There seems to be a clear correlation between FMS scores and physical activity levels, where in most populations when the levels of physical activity are higher, the FMS scores also tend to be higher. For example, in British primary school children, this was the case, as shown in figure 6.

	Total FMS score (0–21)		Physical activity (Avg steps/day)	
	Mean	S.D.	Mean	S.D.
Boys (n = 29)	13.5	3.4	17480	4818
Girls (n = 29)	14.5	2.8	15259	3585
Normal weight (n = 39)	15.5	2.2	17078	4009
Overweight/obese (n = 19)	10.6	2.1	14522	4602

Figure 7: Reprinted from (Duncan et al., 2013).

In older active adults the same relationship seems to exist between FMS scores and physical activity levels (Mitchell et al., 2016), this relationship was also shown with middle-aged adults (Perry et al., 2013).

The same was demonstrated in a study carried out by McGill, study done in elite task force police officers (McGill et al., 2015).

In this same study, an interesting point was made by McGill regarding a study made by Lisman and colleagues, Lisman's study showed a higher risk of injury for military personnel with a score lower than 14 but also for the ones who had a score greater than 17 (Lisman et al., 2013). According to McGill, in this context, possibly there might be an optimal level of fitness for injury resilience. A level too low causes tissue damage as they have not been prepared to meet the demand, while the training done to achieve a high level of fitness combined with the requirements of the job can cause cumulative trauma to run ahead of the rate of repair (McGill et al., 2015).

Materials and Methods

Participants

Following intuitional ethics approval, 34 participants, 33 of them University students, 17 females, 17 males, from Coventry University, volunteered and returned a signed consent form to participate in this study. The participants' age was 17-27 years (mean 20.6± 1.9), all of them were ‘apparently healthy' with no history of severe injury or disease. Most of the students were Sports Therapy students (30 out of 34) and most of them joined the study after it was mentioned in Sports Therapy classes. Because of this, most of them were physically active. Participants were recruited using opportunity sampling. All participants confirmed not having any severe health problems or injuries. Also, all participants signed a consent form before doing any of the study assessments.

Procedures

Anthropometry

In this study, several anthropometric measures were taken, including body mass (kg), height (m), body fat %, muscle mass (kg), waist circumference (cm), leg length (cm) and tibia length (cm). Students were accessed bare footed and lightly clothed (Coventry university sports kit) all the measurements were taken by only professionals with ‘in field’ experience and at least a bachelor's degree either in Sports Science or Sports therapy.

The height and leg length measurements were taken with a scale (Seca Stadiometer), the waist circumference and tibia length were measured in a previously agreed fashion with a tape (Seca 201 Ergonomic Circumference Measuring Tape), the weight, body fat percentage and muscle mass were measured with a Tanita scale called Body Composition Analyzer (type BC-418 MA).

Functional movement assessment

The FMS was administered by a trained rater using standardized procedures, instructions and scoring processes (Duncan 2013), the evaluator has a level 1 course on the FMS and had some of his scores compared to a more experienced rater (five years of regularly scoring the FMS) for comparison.

Video recording was made with a Casio digital camcorder (Casio inc, Japan). Each participant was given 3 trials on each of the seven tests in accordance with recommended guidelines (Duncan et al., 2013). The 21 point system was used. Each trial was scored from 0 to 3 with higher scores representing a better functional movement and 0 being pain. The criteria for the FMS scores are shown here in figure 9:

Figure 8: General Scoring of the FMS (Cook., 2010)

So, this is the train of thought behind all of the scorings for the FMS, nevertheless more specific guidelines were followed in a very precise way, specific for each movement, as it is shown in figure 9:

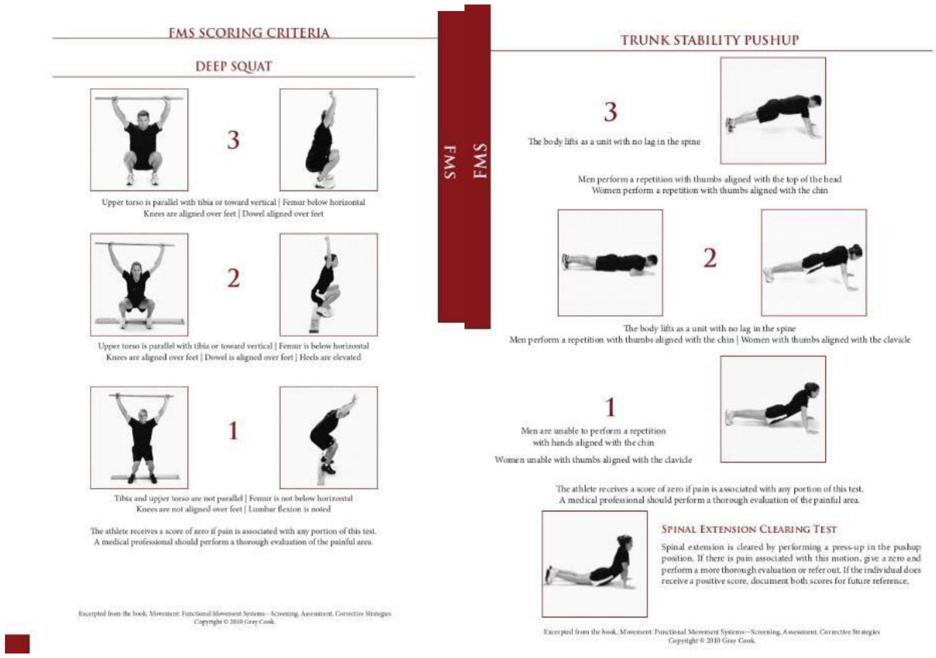

Figure 9: Examples of the specific criteria for two of the FMS movements, the Deep Squat and the trunk stability push-up (Cook., 2010)

The instructions were read out loud in every single exercise of the screen, and the participants were asked if they understood, just after confirmation of the participants understanding would the exercise begin. The same instructions were given in every situation, and video recording of the FMS was done, the analysis and scoring were made after watching the videos several times from both front and side view.

Questionnaires

To measure physical activity levels the International Physical activity questionnaire was utilized, following the guidelines from (Guidelines for the data processing and analysis of the International Physical Activity Questionnaire, 2003) the participants were asked to fill them out and had their answers answered when needed.

The International Physical Activity Questionnaire (IPAQ) is a questionnaire that determines the amount of physical activity executed by a particular individual, it is important to point out that there is no international consensus on a correct method of describing physical activity levels derived from self-report questionnaires or surveys, it was developed as a tool for cross-national assessment of physical activity and has been validated in 12 countries (Kurtze et al., 2008)

According to a study carried out by Mary K. Dinger, the IPAQ is both valid and reliable in measuring the level of physical activity in University students (Dinger et al., 2006).

The IPAQ can be scored in two ways, either on low, moderate or high levels of physical activity or in a total amount of METs per week, the latter scoring was chosen in this thesis being that it is more accurate.
To determine previous injuries, the Nordic Injury Questionnaire was utilized, asking for injuries in the last 6 months (López-Aragón 2017).

Both questionnaires were answered after all the measurements, and FMS recordings were done.

Statistics

IBM SPSS 25 was used for all statistical analysis. Basic statistics (data check for outliers and normality) and all data analysis were computed. Descriptive statistics were computed as means and frequencies. T-test and qui-square test were used for describing and examine differences between groups. Furthermore, Pearson correlations was used to tested relationship between variables. The significance value was fixed at 5

Results

All variables were analyzed, to understand if they presented a normal distribution.

Tests of Normality

Table 1. shows the normality test done on all the continuous variables.

	Kolmogorov-Smirnov(A)		
	Statistic	df	Sig
Waist (Cm)	.117	39	.192
FMS Score	.106	34	.200
Body Fat (%)	.078	36	.200
Muscle mass (kg)	.127	36	.156
Leg length (cm)	.074	32	.200
Tibia Length (cm)	.150	30	.082
PA Score	.133	39	.080
BMI	.184	39	.002

* This is a lower bound of the true significance; A- Lilliefors Significance Correction

All tests present normality except for BMI, this variable presents a p value of 0.002.

Sample characteristics

Table 2. Sample characteristics (mean and standard deviations) and mean differences between sexes (t-test)

	All Sample	Female	Male	t-test	p-value
	Mean±standard deviation	Mean±standard deviation	Mean±standard deviation		
Age	21.0±2.0	20.0±1.0	21.0±2.0	-2.230	0.033
Waist circumference (cm)	75.1±9.9	72.9±9.1	77.2±10.5	-1.281	0.209
Body mass index (kg/m^2)	24.0±4.7	24.1±4.5	23.9±4.9	0.113	0.732
Body Fat (%)	21.1±10.1	28.2±7.2	14.4±7.4	5.243	<0.001
Muscle mass (kg)	56.0±12.5	47.9±4.5	63.7±12.9	-4.592	<0.001
Leg length (cm)	86.5±4.8	84.2±4.6	88.3±4.2	-2.462	0.021
Tibia length (cm)	43.6±3.2	42.6±3.0	44.9±3.2	0.721	0.055
Physical activity score	3416.5±1918.9	3117.6±1806.9	3715.4±2034.7	-0.906	0.372
FMS score	15.09±2.0	14.71±2.3	15.47±1.7	1.099	0.280

Table 3. Descriptive statistics in physical activity and FMS (frequencies and percentages) and differences between sexes.

		All Sample	Female	Male	Chi-square	p-value
		n (%)	n (%)	n (%)		
Physical activity score	low	5 (14.7)	3 (17.6)	2 (11.8)	1.121	0.290
	medium	11 (32.4)	6 (35.3)	5 (58.8)		
	high	18 (52.9)	8 (47.1)	10 (58.8)		
FMS high and low	<14	13 (38.2)	5 (29.4)	8 (47.1)	0.513	0.774
	≥14	21 (61.8)	12 (70.6)	9 (52.9)		

Table 2 shows that the average FMS score was 15.09 (SD 2.036), being that for males, the average was lower than for females, they were respectively 14.71 (SD 2.285) and 15.47 (SD 1.736). The lowest FMS score was 10, and the highest one was 19, the most common score for males was 14 and 17 for females. There was a statistically significant difference between sexes in all variables except for Waist circumference (p=209), BMI (p=0.732), physical activity score (p=0.372) and the FMS score (p=0.280). The male means were higher in the age, waist, muscle mass, leg length, tibia length, FMS score and Physical activity score variables, the female means were higher only in the BMI and body fat variables.

Table 3 shows that there were more females scoring 14 or more than males, 12 compared to 9, also males had on average higher physical activity levels than females.

Sample distribution of the individual FMS movements

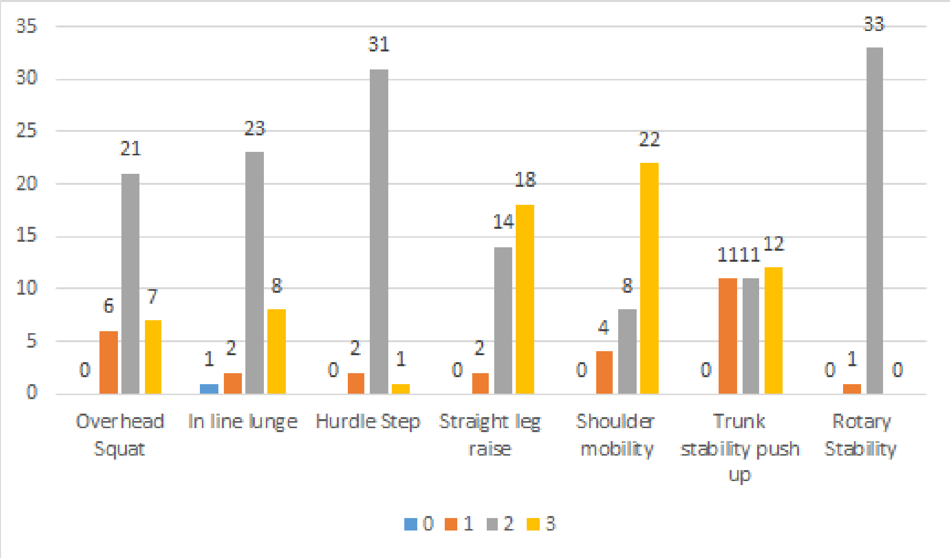

Figure 10: shows frequency for each score of all the individual FMS movements.

As shown in figure 10, there was only one situation where a 0 was scored, meaning that there was pain during that movement, it was on the in-line lunge.

A score of 2 was the most common score in the overhead squat, in-line lunge, hurdle step and rotary stability, a score of 3 was the most common score in the straight leg raise, shoulder mobility and trunk stability push up.

In the rotary stability exercise, 97.1 percent of the individuals scored a 2, it was also the only movement where no participants scored a 3. Together with the hurdle step, the rotary stability was the exercise it with the lowest mean 1.97 (SD 0.171), the hurdle step had the same mean 1.97 but a higher standard deviation (0.3).

The exercise with the highest mean score was the shoulder mobility, and the second highest being the other mobility movement, the straight leg raise.

Relationship between anthropometric measurements and PA levels with FMS performance

Table 4. Pearson correlations between FMS, PA and individual characteristics

	FMS score	Age	WC	BMI	Body Fat	Muscle mass	Leg length	Tibia length	PA
FMS score	1								
Age	0.028	1							
Waist circumference (WC)	**-0.368***	0.153	1						
Body mass index (BMI)	**-0.369***	0.039	**0,882****	1					
Body Fat	-0.176	-0.285	**0.359***	**0.539****	1				
Muscle mass	-0.284	0.374*	**0.698****	**0.579****	-0.317	1			
Leg length	-0.360	0.374	**0.509****	**0.386***	-0.060	**0.714****	1		
Tibia length	0.014	0.175	-0.016	-0.170	**-0.417***	0.386	**0.600****	1	
Physical activity score (PA)	**-0.408***	0.123	**0.366***	**0.405***	0.125	0.339	0.252	-0.170	1

*p<0.05; **p<0.01

Table 4 shows the correlation between all the variables analyzed. The variables that had a statistically significant correlation with FMS were Waist circumference (-0.368), BMI (-0.369) and physical activity (-0.408). Physical activity also had a statistically positive correlation with waist circumference (0.366) and BMI (0.405).

Table 5. Individual and behavioral characteristics differences between High and Low FMS groups

	FMS groups	N	Mean±SD	t-test	p-value
Age (years)	Low (<14)	13	20.8±2.3	0.075	0.940
	High (≥14)	21	20.7±1.9		
Waist circumference (cm)	Low (<14)	13	80.4±12.4	2.334	**0.033**
	High (≥14)	21	71.7±6.3		
Body Fat (%)	Low (<14)	13	24.7±9.9	1.785	0.085
	High (≥14)	18	18.4±9.6		
Muscle mass (kg)	Low (<14)	13	58.3±14.9	0.863	0.395
	High (≥14)	18	54.4±10.6		

Leg length (cm)	Low (<14)	12	87.6±3.1	1.118	0.274
	High (≥14)	15	85.6±5.7		
Tibia length (cm)	Low (<14)	10	43.2±3.9	-0.440	0.664
	High (≥14)	18	43.8±2.9		
Physical activity score	Low (<14)	13	3963.0±1716.7	1.321	0.196
	High (≥14)	21	3078.2±1998.3		
Body mass index (kg/m^2)	Low (<14)	13	26.2±6.4	2.353	**0.025**
	High (≥14)	21	22.6±2.5		

Table 5 shows mean values for all the variables analyzed, separated by FMS scoring, separated between high and low. The variables that had a statistically significant difference between the high and low groups were BMI (p=0.025) and waist circumference (p=0.033). Meaning that individuals with higher BMI and higher waist circumference scored less on the FMS.

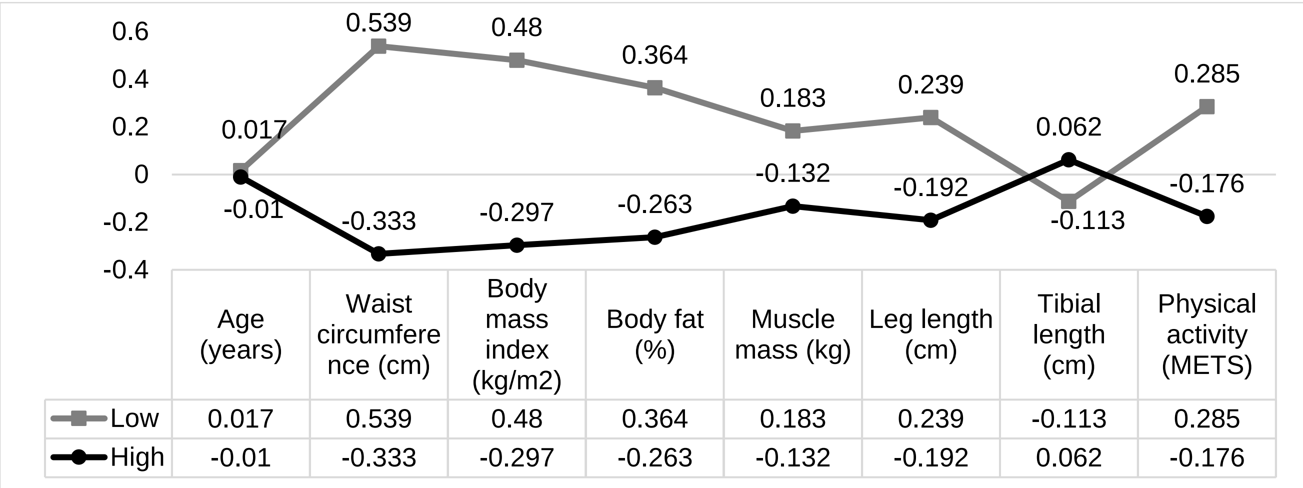

Figure 11. Individual and behavioral profiles of the Low and High FMS groups

As shown in figure 11, subjects in the High FMS group tend to have lower Waist circumference, BMI, body fat percentage, muscle mass and leg length, on the other hand subjects in the Low FMS group tend to have higher WC, BMI ,BF percentage, MM and LL.

Relationship between anthropometric measurements and PA levels with individual FMS exercise performance

Table 6. Performance in each FMS movement by category (%) and difference between sexes (chi-square)							
FMS movements	Sex	0	1	2	3	Chi-square	p-value
		n (%)	n (%)	n (%)	n (%)		
Overhead squat	Female	0 (0.0)	3 (17.6)	11 (64.7)	3 (17.6)	0.190	0.909
	Male	0 (0.0)	3 (17.6)	10 (58.8)	4 (23.5)		
In line lunge	Female	0 (0.0)	0 (0.0)	12 (70.6)	5 (29.4)	3.543	0.315
	Male	1 (5.6)	2 (11.8)	11 (64.7)	3 (17.6)		
Hurdle step	Female	0 (0.0)	2 (11.8)	14 (82.4)	1 (5.9)	3.290	0.193
	Male	0 (0.0)	0 (0.0)	17 (100.0)	0 (0.0)		
Active Straight Leg Raise	Female	0 (0.0)	0 (0.0)	4 (23.5)	13 (76.5)	8.127	**0.017**
	Male	0 (0.0)	2 (11.8)	10 (58.8)	5 (29.4)		
Shoulder Mobility	Female	0 (0.0)	1 (5.9)	3 (17.6)	13 (76.5)	2.227	0.328
	Male	0 (0.0)	3 (17.6)	5 (29.4)	9 (52.9)		
Trunk Stability Push-up	Female	0 (0.0)	8 (47.1)	5 (29.4)	4 (23.5)	3.697	0.157
	Male	0 (0.0)	3 (17.6)	6 (35.3)	8 (47.1)		
Rotary stability	Female	0 (0.0)	0 (0.0)	17 (100.0)	0 (0.0)	1.030	0.310
	Male	0 (0.0)	1 (5.9)	16 (94.1)	0 (0.0)		

Table 6 shows the frequencies of the individual FMS exercises scores separated by sex., Only active straight leg raise had a statistically significant difference between sex, where 76.5% of the female were classified with a score of 3 and 58.8% of the males with a score of 2 (χ^2=8.127, p=0.017)

Table 7. Frequencies and distributions for the OS, SM and TSP exercises separated in high and low groups

FMS movements	Groups	0 n (%)	1 n (%)	2 n (%)	3 n (%)	Chi-square	p-value
Overhead squat	Low	0 (0.0)	5 (38.5)	8 (61.5)	0 (0.0)	9.501	**0.009**
	High	0 (0.0)	1 (4.8)	13 (61.9)	7 (33.3)		
Shoulder Mobility	Low	0 (0.0)	3 (23.1)	5 (38.5)	5 (38.5)	6.524	**0.038**
	High	0 (0.0)	1 (4.8)	3 (14.3)	17 (81.0)		
Trunk Stability Push-up	Low	0 (0.0)	6 (46.2)	6 (46.2)	1 (7.7)	7.022	**0.030**
	High	0 (0.0)	5 (23.8)	5 (23.8)	11 (52.4)		

Table 7 presents the individual FMS exercises with a sample distribution big enough for group comparisons. All variables presented a statistically significant difference between low and high groups. In overhead squat 33.3% of the subjects from high group were classified in score 3 and in low group no subject had this score (χ^2=9.501, p<0.009). Related to shoulder mobility 81% of the subjects in high group had score 3 and only 38.5% of the subject classified in low group had this score (χ^2=6.524, p<0.038). Finally, in trunk stability push-up more than 50% of the subjects in high group attained the highest score and only 7.7% of the low group subjects reached this score (χ^2=7.022, p<0.003).

Discussion

The aim of this study was to better understand if the FMS is an effective tool to predict injuries and what factors are involved in FMS performance. In this study we tried to enlarge the set of variables measured and associated with FMS. To the best of our knowledge, this is the first study using muscle mass associated to FMS performance. Other anthropometric variables were measured: height, weight, body fat percentage and waist circumference. Also, two self-reports were done, to measure physical activity levels and to identify previous injuries.

According to the current literature, BMI and waist circumference are negatively correlated with FMS performance, this study reinforces those findings, both variables had a statistically significant negative correlation with FMS performance. This study was the first study, according to the author's knowledge, to look at the correlation between muscle mass and FMS performance, this correlation was not statistically significant. Nevertheless, there were interesting findings seen from this variable, participants with higher muscle mass scored higher on the trunk stability push-up, with a statistically significant difference between groups, on the other hand, participants with higher muscle mass scored lower on the shoulder mobility exercise, also with a statistically significant difference.

Factors involved in FMS performance

This study presents values not typically seen in the FMS literature regarding the correlation between the FMS score and Physical activity, where there was a negative correlation between FMS scores and Physical activity levels. As previously mentioned, there was also an unexpected positive correlation between physical activity levels and both BMI and waist measurements. One factor that can help explain these results is the fact that a self-assessment questionnaire was used and probably some of the participants had the tendency to over-report their activity levels, being that there were a lot of really high values.

Another critical factor was the fact that some of the participants that had a high BMI and high waist circumference were involved in sports where having a higher weight might not be a disadvantage like rugby and powerlifting. Nevertheless,

according to the data present in this study, FMS performance is lower when physical activity levels are higher.

When BMI was higher FMS performance was lower, this negative correlation appears to be more in line with the current literature, being that higher BMI is generally associated with lower FMS scores (Duncan et al., 2012; Allen, 2013). Also when the waist measurements were higher FMS performance was lower, this negative correlation also appears to reinforce current literature findings, being that higher waist circumference is associated with higher body fat percentage (Silva et al., 2012) and higher body fat percentage is associated with lower FMS scores (Nicolozakes et al. 2018).

This was according to the author's knowledge the first study done looking at FMS correlation with muscle mass, these two variables showed a non-statistically significate correlation of -0.284 (p=0.122), indicating that possibly, in active University students, muscle mass might not be an important factor in FMS performance, however because of this study’s previously mentioned limitations future literature should look into this subject.

There seemed to be no relationship whatsoever between past injuries and FMS score (p=0.672), nevertheless, to arrive at any relevant conclusions the sample size in this study would have to be considerably bigger since of the 39 participants only 5 had previous injuries.

The FMS mean score was also measured, separated by sex.

As with most studies done on the subject so far, the mean difference between sexes were not very high, having a non-statistically significant difference with a p-value of 0.280.

Individual FMS scores

One of the limitations of the FMS is the simplistic scoring between a 0 and a 3, this scoring sometimes ignores completely a lot of factors involved in the correct execution of the exercises, for example in the Squat, factors like knee valgus or varus, pronated or supinated feet, hip rotation, loss of the neutral position of the spine are utterly ignored to make the testing easier. This way of testing has two outstanding advantages, one of them, it makes it easier to score, and by having such a small amount of testing variables, makes the scoring a lot faster and objective. But is it really worth it, when so many other factors are overlooked? Because of the simplistic way the deep Squat is looked at, in the same example of the Deep squat 61.8% of the participants scored a 2, scoring a 1 or a 3 seems to be mostly dependent on ankle mobility (Butler et al., 2010).

Another problem associated with the 0 to 3 scoring scale is the fact that some tests seem to not measure individual differences very well, for example in the in-line lunge case, 23 out of 34 participants scored a 2 and even more noticeable is the fact that in the rotary stability exercise 33 participants out of 34 scored a 2, if such a significant percentage of the students scored the same value in these exercises (69.7% and 97.1%) this means that according to the values shown in this study, the in-line lunge and the rotary stability exercises are not very good at categorizing individuals in different levels, since a significant percentage of the values seem to be the same. Ideally tests where a more equally distributed percentage of scores should be used. In this thesis only the individual FMS exercises with a more equally distributed percentages of scores where looked at for correlations.

Regarding the correlation between the analyzed variables and the individual FMS scores, some movements had no statistically significant correlation with any of the variables analyzed. These movements were the in-line lunge, the hurdle step and the rotary stability. The main reason for this was probably the fact that all these variables had a really high percentage of participants scoring a two, 69.7%, 91.2% and 97.1%, because of this it would be less likely in these cases for the movements to have statistically significant correlations. For example, in the case of the Rotary stability, if we compare the average weight and physical activity levels of participant/s scoring a one and a two, the values have an extremely high discrepancy. The participant that scored a one had a weight of 59.2kg and the average weight of the participants that scored a two was 72kg, in the case of physical activity levels, the participant that scored a one reported a value of 6951 in his IPAQ report, whereas the participants who scored a two reported on average 3309 METS per week. If we take the example of the physical activity levels, the high level of differences between averages looks quite significant if we ignore the sample size, but because just one participant scored a one, it it becomes irrelevant. Nevertheless, if there were more participants scoring a one, possibly the correlation would be statistically significant (even though it is not very likely since it would be contrary to the current literature).

Because of this the sample size and scoring distribution the only correlations shown in the results section were the shoulder mobility, the trunk stability push up and the overhead squat.

The movement with the highest levels of correlations with the analyzed variables was the shoulder mobility exercise, having a negative correlation higher than 5 with the variables BMI (r= -0.570), waist (r=-0.593) and muscle mass (r=-0.548).

It makes sense that high BMI is correlated with lower shoulder mobility scores, the main reason is most likely because higher weight is associated with higher levels of muscle shortening (Bittencourt et al., 2017). Also, higher levels of body mass make the torso wider making the execution of the shoulder mobility movement harder.

If we take a look at gender, there are some exercises where males tend to score higher than females and also the other way around. The most apparent advantage that men appear to have compared to women is in the trunk stability push-up, in this case, 47.1% of females scored a one, and just 23.5% scored a three while only 17.6% of males scored a one and 47.1% of men scored a three. It makes sense that men score higher on the trunk stability push-up since they are on average significantly stronger than women (Kates & Pain 2016), the lower starting position for women in this exercise makes it a bit easier but still the exercise seems to be a lot easier for men even when we take that into consideration.

The most noticeable advantage that women appear to have compared to men is in the straight leg raise, where the average score for females is 2.76, and the average score for males is 2.18. It makes sense that women score higher on the active leg raise since women have on average more hamstring flexibility, this seems to happen because they have a lower passive stiffness through a common range of motion, better stretch tolerance and greater hamstring extensibility compared to men (Marshall & Siegler 2014).

Limitations

The present study presented a few limitations, first of all, the sample specificity, where the participants were almost all physically active sports therapy students, so the results might not represent the general population, another limitation was the sample size, even though it was not very small, for the purpose of presenting normative data about the FMS ideally it should be bigger. In the first day of data collection, the system for data collection was not fully organized and properly functioning, this happened because of the lack of experience from the project leader, because of this some of the variables are missing in some of the participants, a table will be used to show how many participants didn't measure which variables. Nonetheless the missing variables didn't have a significant negative effect on the study outcome, in total 3 participants didn't measure body fat percentage and 3 participants didn't measure Muscle Mass

Conclusions and recommendations for future research

The functional movement screen was invented to screen for injury risk, in this paper its ability to do so was analyzed, looking at the research done on the subject so far, we can conclude that the screen is not extremely valid in predicting injury. Also, the factors involved in FMS performance were analyzed, for the first time in the literature, the correlation between muscle mass and FMS performance was measured. This correlation wasn't significant.

Further research on the validity of the individual FMS movements should be done, possibly modifying the screen could be a good option by either removing non-effective movements or by changing the scoring system. The 100 points scoring system might be more effective at predicting injury risk than the 21 point system, also scoring the exercises with wider ranges would make a more in-depth look at the mechanisms of lack of functionality possible.

Other options for measuring functional capacity were briefly looked at, it seems like there is no scientifically valid way of measuring functional capacity. It is incredibly complex to measure functional capacity as it is an extremely broad and subjective concept, nevertheless, improving the FMS could be an option to make it more reliable at predicting injury risk.

An alternative would be to create another risk predicting system, a personal suggestion would be to create a system, where, depending on the athlete characteristics (age, previous injuries, sport, etc.) different tests would be made, and the scoring would be less relevant, even though necessary for research purposes, but after the screening there should be a relatively good idea on the risk level of the athlete, but even more importantly a good idea on how to intervene in order to reduce it. Such a system is just a theoretical hypothesis, maybe one that is not even possible to execute in reality.

Experienced fitness experts and physical therapists already have their own system for measuring functional capacity, as well as their own system to measure every physical capacity characteristic necessary for exercise prescription, but is it really possible to put it on paper in an easy but effective way? Maybe the level of knowledge required for the analysis and subsequent prescription of exercise made by fitness experts makes the usage of different systems mandatory for varying degrees of professional expertise. Also, is it really possible to give a score to something as complex as functional capacity and what practical applications will this score have? Should we create a new functional movement scoring system?

According to the findings in this thesis, the Functional Movement Screen doesn't seem to be what it is sold out to be, creating a new Functional Scoring System better at predicting injury and at analyzing the causes for movement dysfunction would be highly advisable. Possibly a flow chart system, more flexible and tailored to the athlete's personal characteristics, focusing on what is wrong and how to improve it, instead of just giving it a score according to very simplistic guidelines.

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