Initial steps towards an evidence-based classification system for golfers with a physical impairment.

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Abstract

Purpose: The present narrative review aims to make a first step towards an evidence-based classification system in handigolf following the International Paralympic Committee (IPC). It intends to create a conceptual framework of classification for handigolf and an agenda for future research.

Method: Pubmed was searched on three themes: 'Classification in Paralympic sports', 'Performance determining factors in golf' and 'Impact of impairments on golf performance'. IPC-regulations were gathered on the IPC-website and their official publications.

Results: In developing a classification system conform IPC-regulations, the main challenge is to identify the activity limitation caused by the impairment, not influenced by training, talent or motivation. Timing, accuracy and control, work per joint, range of motion, balance and flexibility are important performance determining factors in abled-bodied golf and should be considered when determining activity limitations in handigolf. Only five articles on handigolf were found, mainly addressing the asymmetric golf movement. Based on the present review, a conceptual framework for classification was developed, while a future research agenda was designated. The conceptual framework presents factors that are essential for sports performance categorized under 'technology', 'interface' and 'athlete characteristics'. It also includes impairment related factors essential for determining eligibility and classification. Ideally, measures to be used during classification need to be resistant against training, natural development of the athlete's talent and motivational changes.

Conclusions: The conceptual framework and a multidimensional scientific research agenda will support further development of the knowledge base required for an evidence-based classification in handigolf, including multi-level analysis of player statistics, experimental analyses of biomechanics and modeling studies.

1. Introduction

Disabled golf is not yet as well-known and popular among people with impairment as golf is amongst able-bodied people. It is expected that a transparent classification system, a lively competition and admission to the Paralympic programme will further promote participation in disabled golf. Golf is in origin an accessible competitive sport for people with impairments, attributable to the use of the existing standard golf handicap-system that is used in competition, enabling all golf players to compete at their own level [1]. Golf players with and without impairments are categorised based on their previous golf performance, and play in the same competition. In the course of the development of golf for persons with impairments, either termed disabled golf or handigolf[1], separate competitions were set-up for impaired golfers based on minimum impairment (eligibility)[2] criteria only [2]. The International Golf Federation (IGF) and the European Disabled Golf Association (EDGA) applied for a Paralympic status for Rio 2016 and provided the International Paralympic Committee (IPC) with the 'bidbook for golf in the 2016 Paralympic sports programme' [2]. The bidbook included the minimum impairment criteria and the classification process based on the traditional handicap-system that is currently used in handigolf and regular competition [1]. However, the handicap-system is a performance-based classification system, which categorizes the golfers based on previous golf performances by using a handicap index (HCP). HCP generally represents the number of strokes above par, in which par is the pre-determined amount of strokes a skilled golfer requires to complete a hole or tournament. The better the player, the lower their HCP. Very proficient golfers may even have a HCP below zero. As performance-based classification does not comply with the aim of classification within Paralympic sport, the classification system needs to be changed towards a functional and evidence-based classification strategy, in which the identification of activity-limitation caused by the impairment in a given sport is the central tenant [3].

In the present study, the multitude of physical impairments impacting on activity limitation and performance in different ways will be discussed. A conceptual framework will be proposed, that can be used as a general route on how to develop an evidence-based classification system conform IPC-regulations. The conceptual framework will be developed based on current scientific knowledge on three main themes: 'Classification in Paralympic sports', 'Performance determining factors in able-bodied golf' and 'Impact of impairments on golf performance'.

[1] Handigolf and disabled golf are the most frequently used terms for golf for people with impairments. Since, according to the ICF, the term 'disability' is an umbrella term for impairments, activity limitations and participation restrictions, the term handigolf is preferred and therefore used in the present review to avoid further confusion.

[2] The IPC Classification Code [3] is currently under revision (Classification Code Draft 2); in this still ongoing process 'minimum eligibility criteria' was changed into 'minimum impairment criteria'[6].

The first theme covers IPC-regulations and current classification in Paralympic sports. The second theme will identify current knowledge in the field of able-bodied golf to discover performance variables that could potentially be used to define golf activity in relation to activity-limitations caused by impairments. In the third theme, rehabilitation literature on handigolf will be examined to present the current scientific playing field in handigolf. The present study will conclude with proposing future research agenda for the further development of an evidence-based classification system in handigolf.

2. Methods

In the present narrative review, Pubmed was searched with key-words 'Classification & sport' combined with 'paralympic', 'amputation' and 'wheelchair' separately (see table 1) to provide a framework on IPC-regulations and examples of classification strategies in Paralympic sports. In addition, the IPC website and the formal IPC documents were searched for information concerning their classification policy. To identify performance determining variables in able-bodied golf, the MeSH-term 'golf' in combination with the MeSH-terms 'athletic performance', 'biomechanics' and 'task performance and analysis' and with the key-words 'golf swing', 'balance' and 'performance' in various combinations were searched (see table 1). By manually searching reference lists of relevant reviews found with the keyword 'golf', it was checked whether additional relevant articles were available. Lastly, the impact of impairment on golf performance was researched by combining the MeSH-term 'golf' with the key-words 'impairment', 'disabled people', 'disability evaluation', 'limb deficiency' and 'amputation' separately (see table 1).

The searches were conducted in 2012, without using a time limitation for any of the searches.

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3. Results

3.1 Classification in Paralympic sports

In the early days of the Paralympics, classification was medically based and athletes were assigned to a single class based on their medical diagnosis. They competed in that class for all sports, even though their impairment was not limiting the different sports to the same extent [4]. As the Paralympic movement evolved, the main

focus changed from a rehabilitation-oriented focus towards a sport-oriented focus and resulted in the development of functional classification systems. A functional classification system classifies athletes based on the impact of their impairment on functional or sport performance and can be different for different sports [4]. Though the functional classification was seen as an improvement with respect to the previous medical classification in Paralympic sports, it encountered an important problem in the use of the word functional. The term functional is defined today by the International Classification of Functioning, Disability and Health (ICF) as a general umbrella term for body functions, body structures, activities and participation [5], including the effects of training, motivation and talent [4]. Classifying the combined effects of impairment, training, motivation and talent is inherently a performance-based classification and therefore deemed to be unfair according to the current IPC position and scientific views[4].

In 2007 the IPC Classification Code was adopted [3] and revised in February 2015 [6]. The Classification Code of the IPC aims to "support and co-ordinate the development and implementation of accurate, reliable and consistent sport focused classification systems." [3]. The purpose of classification should be to "ensure that the impact of impairment(s) on the outcome of competition is minimized" [6]. Under the heading of classification research it is stated in the code that "International Federations should develop sports-specific classification systems through multidisciplinary scientific research" and "focus on the relationship between impairment and key performance determinants." [6]. The IPC position statement written by Tweedy & Vanlandewijck [4] defines evidence-based classification and provides guidelines on how evidence-based classification may be achieved according to IPC regulations.

The IPC acknowledges that no classification system is fully evidence-based yet. In the absence of research and thus an evidence-based classification, the extent of activity limitation resulting from impairment is mainly based on expert opinion. This is referred to as the current best practice [7]. The current best practice requires experts to estimate the extent of activity limitation resulting from impairment by assessing the extent of impairment, novel activities, practiced activities and training history and other personal and environmental factors affecting how well the athlete will do the activity [7]. Consequently, the procedures of classification conducted by the classifiers are described in the IPC classification code and may include three components: a physical assessment, a sports technical assessment and an observation of the athlete in a natural competitive environment [3].

The two main aims of classification are to determine minimum eligibility to compete and to group eligible athletes for competition [3, 4, 6]. The eligibility is described by the type and severity of impairment [4]. The Paralympic Movement considers three impairment types for classification: physical impairment, visual

impairment and intellectual impairment. The present review will focus on physical impairments only. Physical impairment comprises impaired muscle power, impaired passive range of movement, limb deficiency, leg length difference, hypertonia, ataxia, athetosis and short stature [8]. The overall used physical measures in the physical and sports technical assessments of current Paralympic sports for athletes with physical impairments are muscle strength, range of motion, co-ordination, extent of amputation, body length and balance [9].

The basic principle behind Paralympic classification is that eligible impairments must be sorted into a limited number of sport classes based on the extent of activity limitation resulting from the specific impairment [4]. A limited number of sport classes will increase the number of athletes competing within a sport class, which is beneficial for the competitive aspect of the sport, but must be kept in proportion in order to maintain relatively equal sport classes as well as more or less comparable activity limitations following different persons with varying impairments.

The performed literature search on classification in Paralympic sports resulted in six reviews and fifteen original articles. The articles showed that only five out of 26 Paralympic sports in which athletes with physical impairments compete, made a start to support or improve their classification system, based on scientific evidence: athletics [10, 11], nordic sit-skiing [12], wheelchair racing [13], wheelchair rugby [14, 15] and wheelchair basketball [16-19].

The overall used measures in the physical and sports technical assessments of current Paralympic sports for athletes with physical impairments are muscle strength, range of motion, co-ordination, extent of amputation, body length and balance [9]. During the development of a new classification system in handigolf, it is important to frequently compare the gained knowledge with existing knowledge in other Paralympic sports, to keep close to the practical application and facilitate the research.

3.2 Performance determining factors in golf.

Scientific knowledge defining performance determining factors in able-bodied golf can help to provide evidence for decision-making in classification. It should be kept in mind that physical impairments might be compensated by an alteration in the golf movement. Consequently, these compensatory strategies must be appreciated and understood, and ideally should be clearly separated from activity-limitations caused by the impairment. In addition, measures that are to be used during classification need to be resistant against training and skill improvement (i.e., if an athlete does a lot of training prior to reclassification he/she should not therefore perform better on the tests used in classification an thus be allocated a different class). To optimally understand activity

limitations associated with physical impairments within this context, a thorough understanding of golf biomechanics is essential. .

Golf comprises two principle movements, the swing and the putt. Both are essential in attaining the successful ball target, however applied in different phases of the game. The swing and putt can be divided into four phases; the set-up, backswing, downswing and the follow-through phase [20]. The backswing, downswing and follow through phase are illustrated in figure 1 for the swing. The set-up phase is preceding the backswing. In the set-up phase, the golfer takes position with respect to the ball and establishes the grip of the club. During the backswing the club head is rotated away from the target ball and is positioned for a proper downswing. In the course of the downswing ideally the club head should approach the ball in the correct plane and with the appropriate linear velocity. Right after impact, the follow through phase starts in which body and club are decelerated to finish the movement [20].

Please insert figure 1 about here

3.2.1 The swing

The difference between the two principle movements, the swing and putt, is that the swing is used to overcome long distances and putting is used on the green for short distances. Higher club head velocity has the potential to increase the distance traveled by the ball [21]. Therefore, a much higher club head velocity is used during the swing than during putting. The higher club head velocity is created by a larger range of motion during the swing. During an optimal swing, the entire body is used in a chain of subsequent sequential rotations to pass on kinetic energy from the bottom (ankles) to the top (wrist) of the body [22, 23]. In addition, timing of maximal club head velocity and of maximal total work on the club seem to be of great importance for an optimal swing, because most proficient golfers increase club head velocity and total work on the club to a maximum just before impact [22]. A limitation in control of timing or the range of motion is thus likely to limit performance and should be taken into account during classification in handigolf.

Following Nesbitt and Serrano (2005), most of the work during the swing is done by the back and hip joints, followed by the contribution of the shoulder and arms and the remainder of the total body work is generated by the leg joints [22, 24]. For a male golfer with a handicap (HCP) index of zero (scratch), the contribution of the mentioned joints was found to be71.8%, 24.7% and 3.6 % respectively. Fora male golfer with HCP 13 (lower performance level) this was found te be 70.0%, 26.2% 3.8% respectively [22]. Figure 2 gives a good impression of the

contribution of the different joints by providing more detailed results of work analysis per joint for 4 right handed golfers at different performance levels.

Please insert figure 2 about here

Based on figure 2, it is suggested that motor impairments of the trunk will most profoundly affect performance, followed by the right hip and the right elbow for right handed golfers. Important to notice is the dominant role for the right side of the right-handed golfer in work output. This indicates that the absence of the right elbow joint will probably limit a right handed golfer more than the absence of the left elbow. However, to what extent the absence of the right elbow joint will influence a handigolfer is hard to predict, because athletes can compensate the absence of a limb by adapting their movement. A systematic observation of handigolfers assessing how they experience their learning process and adapt their golf movement will be essential in understanding handigolf biomechanics in comparison to able-bodied golf and in relation to activity limitation caused by their impairment.

Performance is also influenced by the range of motion of different body parts. It was shown that most proficient golfers with a handicap index below zero (HCP<0) had greater shoulder, hip and torso flexibility than less proficient golfers with handicap index 10-20 [25]. Especially the X-factor (relative rotation of the hip to the shoulder) is considered to be important to achieve maximum driving distance, and there with a better performance [20]. Meister et al. [26] showed that professional golfers had a higher X-factor (56°) than novices or less proficient golfers with HCP-30 (X-factor 46-48°). As indication of the amount of angular displacement of the torso, the shoulders, the arms and the wrist, 3D simulations calculated angular displacements of 90°, 50°, 80° and 110° for the mentioned body parts respectively [24]. Angular displacements are rather large, however the whole movement of the arms and the club remain within a swing plane angle that increases only 35° in steepness, between 130° and 165° with respect to the horizontal plane [24].

Lastly, to control the large angular displacements involved in hitting the ball at the correct club head angle and speed, coordination and balance are important. Proficient golfers (HCP<0) are found to have superior balance to less proficient golfers with HCP 0-9 and HCP 10-20 [25].

Performance determining factors for the swing are range of motion, timing, work per joint, flexibility and balance. Impairments impacting on these factors most probably cause an activity limitation in golf and should therefore be considered when developing a classification system for handigolf.

3.2.2 Putting

For putting, a smaller range of motion is required than during a swing. The movement during putting mainly consists of movement of the arms and club in a pendulum way. During putting, the club head velocity must be accurately adjusted to the distance from target [27]. Club head velocity is a resultant of backswing amplitude and downswing duration. A higher peak club head velocity can be achieved by a longer backswing in combination with a shorter duration of the downswing [20, 28]. It was shown that expert golfers were able to keep the club head position in a plane parallel to the ground, whereas non-expert golfers showed a curved path of the club head, showing the importance of accuracy and control in putting [20]. An above elbow amputation of the leading arm of a golfer could affect accuracy and control, due to the missing degrees of freedom, which are normally present in the elbow and wrist joint. The effect on performance does not necessarily have to be negative, which can be explained by the finding that expert golfers positioned their leading hand almost 8 cm lower than non-experts [29]. The suggested explanation for the lower positioning of the hand was that expert golfers probably aimed to minimize the movement of the wrist [20, 30].

3.3.3 In general

Overall, it seems that range of motion, timing, work per joint, flexibility and balance are important factors for the golf swing and that balance, accuracy and control are important for the golf putt. When developing a classification system for handigolf it is important to determine whether and to what extent a motor impairment limits these factors. Knowledge of the biomechanics in able-bodied golf could facilitate studying the extent of activity limitations resulting from impairments in handigolf.

Knowledge in abled-bodied golf can furthermore challenge current ideas of classification in handigolf. For example, the minimum impairment criteria for the lower limb amputation are defined in the bidbook as being an amputation through the ankle at Syme's level, which is a disarticulation of the foot with removal of both malleoli [2]. However, a study about the forces on the big toe during the golf swing showed that a more proficient golfer puts forces on both big toes in similar patterns with the highest impulse at the top of the backswing, where less proficient golfers show a lower impulse at the top of the backswing and different patterns for the left and right big toe [31]. It has to be noted that results of the study are based on only four abled-bodied golfers and no conclusions can be drawn for handigolf. Nevertheless, it is a good example stressing the importance of collecting evidence to support decisions made related to classification and activity limitation. The

results suggest that an amputation of the big toe could cause a significant activity limitation. Therewith, it challenges the present eligibility criteria for lower limb deficiencies currently used by the IPC and EDGA. Future studies should therefore evaluate the chosen minimum impairment criteria to prevent exclusion of golfers that are in fact limited in the activity, resulting from their impairment.

Based on the results of this section, it is suggested that a motor impairment of the trunk or hips will cause the largest limitation in golf performance, followed by the arms and finally the lower body (see figure 2). Future studies should further analyse the current player information of handigolfers. Player information could show whether handigolfers with a lower body impairment have a lower handicap index, and therewith better performance than handigolfer with upper body impairments. Experimental and modeling studies could add to the evidence-base by evaluating performance determining factors in handigolf, such as ROM and X-factor (body angles), using a biomechanical experimental set-up (i.e. kinematics and force platforms). In addition, model simulations of different levels of able-bodied and motor impaired expert golf players (matched on HCP) could contribute to understand the role of motor impairment on activity limitation and golf performance.

3.3 Impact of impairment on golf performance

In contrast to golf literature, rehabilitation literature on golf and impairments was scarce. The literature search revealed one review and four original articles [32-36]. No literature was found concerning other motor impairments than limb deficiencies in the context of golf.

Kegel et al. highlighted that an unilateral lower limb amputee may achieve less distance hitting the ball due to a limited follow through[32]. Furthermore, they showed that a right-handed right leg amputee is in disadvantage and might consider playing left-handed to improve performance. An additional difference between right and left lower limb amputees was shown by Rogers et al[35]. They showed that a right handed golfer with a left trans-tibial amputation showed increased hip and shoulder rotation due to the application of a torsional rotation device in the prostheses, allowing shock absorption in the sagittal plane and torsion in the transverse plane, with respect to the golf swing without a torsional rotation device. For right-handed golfers with a right trans-tibial amputation, the use of a rotational device in the ankle prosthesis did not result in an increased rotation of the hip and shoulders. The different results between sides of amputation can be explained by the different requirements of the left and right ankle and foot of a right handed golfer. The right ankle and foot require a plantar flexion at the end of follow through, but only a few degrees of plantar flexion was allowed by the torsion device [35]. Besides the difference between the side of the amputation, the study of Rogers et al. also highlighted the impact

of the use of prosthetic devices in handigolf [35]. This was also described in the article of Nair et al. in which 1 subject with a trans-tibial amputation was able to increase the range of motion by using a prosthetic with 2 torque absorbers instead of one [34]. The study of Friel et al. (2005) showed that trans-tibial amputees have lower back extensor strength, but higher back extensor endurance than trans-femoral amputees, highlighting the importance of amputee level [36]. In addition, a study of Bhala and Schultz (1982) was found in the context of golf and impairment, focusing on the use of a golf club holder for above elbow amputee, which was according to the researchers easy to use and affordable [33].

These results show that the side and level of amputation influence the amount of activity limitation in the asymmetric golf movement. Additionally, performance can be influenced by the use of certain prosthetics, the associated assistive technologies and the fit between the technology and the athlete, the so called interface. Whether or not prostheses can be used in a given sport is part of the rules of that specific sport [6].

Please insert figure 3 about here

3.4 Conceptual framework of classification and sport performance

Reviewing classification in Paralympic sports showed that the biggest challenge when developing a classification system conform IPC-regulations is to define the activity limitation caused by the impairment and not by training, talent or motivation. Following this literature review and discussions among the authors and different external advisors, a conceptual framework was created to steer future research steps as well as to organize the current understanding of classification in handigolf (figure 3). The conceptual framework presents factors that are essential for sports performance categorized under 'technology', 'interface' and 'athlete characteristics' (Figure 3). The athlete characteristics that are relevant for golf performance have been identified in the current review and are presented here. Ideally, measures to be used during classification need to be resistant against training, natural development of the athlete's talent, and motivational changes [3, 4, 6]. Therefore, measures to define activity limitations should only measure those athlete characteristics relevant for golf performance that are limited due to the impairment. Based on a classifier-driven physical assessment, technical assessment and observation (conform current professional classification practice), eligible impairment types will be classified into sport classes (class status) based on the activity limitation they cause (see right hand side of the framework). The IPC states that adaptive equipment such as prostheses, permitted by the rules of a sport, are "an integral component of the tasks and activities required by a sport" [6]. In figure 3 the interface is

therefore presented at the left side of the framework, where it is not incorporated in the classification decision-making as presented on the right hand side. Though figure 3 clearly shows that ideally, we should aim to completely separate contributions attributed to talent, training and motivation from contributions attributed to the impairment, we realize that in reality it is more complex to identify to which extent performance determining factors are affected by training, talent, motivation or impairment. It thus should be noted that figure 3 aims to illustrate and highlight the important aspects to strive for that are essential for making decisions related to classification, while realizing that in reality, the situation is more complex.

4. Discussion

The present narrative review aims to provide an evidence-base for identifying activity-limitations caused by different impairments, relevant for developing a classification system for handigolf that is conform IPC-regulations. Based on the results of the present study and current understanding, a conceptual framework (figure 3) is proposed as a working tool for classification, as well as for the future research steps for the development of an evidence-based classification system.

4.1 Classification in Paralympic sports

The goal of an adequate classification system conform IPC regulations should be to classify athletes into a limited number of sport classes based on their activity limitation resulting from their impairment while simultaneously excluding the effects of training, motivation and talent from the actual classification process [4]. Although such a classification system is a prerequisite of the IPC to welcome a new sport as a Paralympic sport, no Paralympic sport currently meets all criteria and several challenges will be encountered during the development of an adequate classification system.

The main challenge when developing an evidence-based classification system is to scientifically underpin the relationship between impairment and key performance determining factors. The present review gives an overview of performance determinants in able-bodied golf, which will be further discussed in the following paragraphs. They have been incorporated in the presented conceptual framework (figure 3). In developing classification, firstly, minimum impairment criteria must be described in terms of impairment type and severity of the impairment, in which severity refers to the extent of activity limitation it causes. The IPC considers 10

eligible impairment types [8], including limb deficiencies. Limb deficiency (e.g. amputation) is a very palpable impairment and the classification of biomechanical activity limitation resulting from limb deficiencies may in the future serve as a pilot for other impairment types in handigolf. Minimal limb deficiencies were proposed by the IGF and EDGA for the upper and lower limb and are shown in table 2 [2]. However, these criteria are not yet evidence-based and the lower limb minimum impairment criteria could be challenged as discussed above. Future studies should aim to underpin the choice of the minimum impairment criteria. It needs to be noted that the decision regarding which impairments are eligible for competition is essentially up to the responsible international sports federation.

Please insert table 2 about here

Another important challenge for a proper classification system is the number of sport classes, which should be 'limited', but the optimal number is hard to define. Fewer sport classes, and thus a larger number of handigolfers per sport class (leading to wider classes), improves acceptance of the overall competition (i.e fewer medals), but will enhance the diversity of the different impairments within a class and could make competition within a class less fair. The challenge is to find a balance between the range of diversity and width of a class and the number of competitors within a sport class. It is assumed that a more fair and adequate competition, and better exposure due to admission to the Paralympic programme, will lead to more players competing. Therefore, an adequate and evidence-based handigolf classification system may not only be interesting from a competitive perspective, but also from an economical point of view.

The next step in the process is to classify athletes with eligible impairment types into this limited number of sport classes based on the extent of activity limitation the impairment causes [4]. Classifying impairment types should be evidence-based and followed by a procedure to assign sport classes to the athletes, the so called athlete evaluation. In current practice, athlete evaluation includes at least a physical assessment, a sports technical assessment and the observation of the athlete in a natural competitive environment [3]. These three aspects are already implemented in most Paralympic sports. At this moment, most of the assessments are developed based on valuable experience and current best practice. Future studies must use these valuable experiences and current best practice providing direction to where and how to continue to collect new evidence to support the design of objective and evidence-based classification measures and protocols. Other Paralympic sports characterized by

similar performance determining aspects as found in golf, such as the 'standing throwing' disciplines in athletics, could provide valuable input.

4.2 Performance determining factors in golf

The joints that do most of the work in handigolf are the trunk, hips and upper limbs [22], whereas it is expected that impairments affecting the upper body cause more activity limitation than impairments affecting the lower body (figure 2). Therefore, future studies must not only complement literature on lower limb amputation and golf (4 studies have been found on lower-limb deficiencies in handigolf), but also focus on the activity limitation resulting from upper limb amputation (currently, only 1 study is known by the authors on upper body limb deficiencies and handigolf). The available literature on able-bodied golf revealed that the performance determining factors are timing, accuracy and control, work per joint, range of motion, balance and flexibility. Whether all of these factors could serve as indicators for assigning sport classes should be underpinned by future scientific research. This could be done by using a 3D simulation with models used for able-bodied golfers [22, 24], but preferably also by experimental research, like 3D kinematics and dynamics of golfer and club in a standardized experimental setting, comparing biomechanics and performance of able-bodied and handigolfers matched on handicap index (HCP). It should always be taken into account that the biomechanics of able-bodied golf players is not (fully) representative for impaired golfers, because they can compensate by adopting an alternative movement. Before studying the biomechanics of the (handi)golf movement, the authors suggest to analyse current player information of handigolfers worldwide. Statistical multilevel regression models can help to link performance to various types of impairment, as well as training history and effort. Such a multidisciplinary research approach will help to appreciate the complexity of classification in handigolf, as well help to start to appreciate the underlying mechanisms of impairment in the golf actions (activity limitation) and in golf performance as a competitive sport.

4.3 Impact of impairments on golf performance

Reviewing rehabilitation literature in the context of golf and impairment hardly resulted in additional biomechanical information of the golf swing or putt for impaired golfers. All included articles were based on limb deficiencies, mostly lower-limb impairments. Though the information about golf and impairment was scarce, it resulted in some interesting attention points, such as the impact of amputee level [36] and the asymmetric nature of the movement [32, 35]. When developing a classification system, it must be taken into

account that the activity limitation could differ for impairments located at different sides of the body. It is suggested that a right handed golfer with a right leg amputation is in disadvantage with respect to a right handed golfer with a left leg amputation, because he might tend to shift his weight to the left foot[32]. Shifting weight could affect balance and therefore right handed golfers with a right leg amputation are advised to play left-handed [32]. What the impact is of playing with the non-preferred hand on the golf activity is important for future studies.

Another important issue that has been addressed in the rehabilitation literature is that prostheses impact on performance [34, 35]. Whether prostheses may be used in competition is part of the rules of the specific sport. Current handigolf practice allows prosthetic use. The role of technology in sports is a complex one. When assessing activity limitation, IPC states that the interface of the athlete with the adaptive equipment is part of the performance that should not be assessed in the context of classification. Whether this position is valid and realistic is for future debate [37, 38].

Lastly, as explained while proposing the theoretical framework in p.3.4, in classification it is crucial that measures to define activity limitation should only measure those athlete characteristics relevant for golf performance that are limited due to the impairment. If these measures are to be used during classification, they need to be resistant against training, natural development of the athlete's talent and motivational changes (i.e., an athlete does a lot of training prior to reclassification should not therefore perform better on the tests used in classification an thus be allocated a different class). The present literature review identified relevant golf performance characteristics that potentially could be used in the classification procedures. Further (experimental) research is now required to establish if these measures are indeed (partly) resistant against training, and to what extent golf performance is limited due to different impairments.

4.4 Future steps towards development of an evidence-based classification system in handigolf

Based on information presented and discussed in the present review and on the conceptual framework, the following research agenda for the development of a classification system conform IPC-regulations for handigolf is proposed:

1. Consider the IPC Classification Code and the article about the IPC position stand written by Tweedy and Vanlandewijck (2011) as guidebook through the whole development of the classification system [3, 4, 6].
2. Expand the evidence-base by scientific research:
    - Review classification systems in other Paralympic sports in order to gather information about eligibility criteria and classification methods currently in use. In particular sports with similar performance determining factors to handigolf are of interest.
    - Analyze the current handigolf databases of EDGA and other disabled golf associations.
    - Gather expert knowledge in the field of golf and in the field of classification about performance determining factors coupled with activity limitation
    - Perform questionnaire-based epidemiological analyses of performance enhancing and/or limiting factors among a large group of handigolfers world-wide.
    - Set-up experimental and modeling studies aimed at quantifying activity limitations resulting from limb deficiencies among (handi)golfers.
3. Establish the minimal eligible impairment severity of limb deficiency based on activity limitation
4. Classify the several types of limb deficiency into a limited number of sport classes based on the extent of activity limitation resulting from impairment, incorporating the width of the competitive field.
5. Set-up evidence-based methods for assigning handigolfers to sport classes. Methods should include objective physical assessments (including novel activities), sports technical assessments and observation in the sport. Methods used in other Paralympic sports could serve as an example.
6. Evaluate the newly developed classification protocol in a large representative population.

5. Conclusion

The main challenge in developing an evidence-based classification system in handigolf is to define the activity limitations caused by different impairments, not influenced by training, talent or motivation. The proposed

conceptual framework, including insight in performance determining factors in able-bodied golf, is deemed essential to steer classification and its underlying research. A multidimensional scientific research agenda is suggested to develop the knowledge base required for evidence-based classification in handigolf, including multi-level analysis of handigolf player statistics, experimental analyses of handigolf biomechanics and modeling studies.

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Declaration of interest

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Table and Figure Captions:

Caption Table 1 Combination of keywords used per search to cover the second theme of performance determining variables.

Caption Table 2 Minimal eligibility criteria for limb deficiencies as defined by the IGF and EDGA [2].

Caption Figure 1 The golf swing: schematic. A picture made by Kingsley Willis from pro golfer Will Yanagisawa, demonstrating the different phases of the golf swing. Original picture with permission from Meister et al. 2011 [26].

Caption Figure 2 Work of joints of right handed golfers with different handicap (HCP) index (Scratch= HCP 0, 5, 13 and 18 hand = HCP 5, 13 and 18 respectively). Reprinted from Journal of Sport Science and Medicine, 4, Nesbit SM, Serrano M, Work and power analysis of the golf swing., 520-533, 2005 with permission from the *JOURNAL OF SPORTS SCIENCE AND MEDICINE* [22].

Caption Figure 3 Conceptual framework of classification and sport performance. The framework is deemed essential for the organization of future research activities in the development of evidence-based classification system in handigolf. The framework presents factors that are essential for sports performance and success categorized under 'technology', 'interface' and 'athlete characteristics'. Athletic characteristics can be influenced by training, talent and motivation, but these influences must be excluded when measuring activity limitation. Only the influence of the impairment on activity limitation may be included in measuring activity limitation and subsequently the physical assessment, technical assessment and observation. The black arrows represent the effect of training, talent and motivation on sport performance, independent of impairment. The grey arrows represent the effect of the activity limitation resulting from impairment. As this is a model/schematic representation of classification, it is a simplistic representation of a complex situation, highlighting important aspects to strive for that are essential for making decisions related to classification. Though this figure clearly shows that ideally, we should aim to completely separate contributions attributed to talent, training and motivation from contributions attributable to the impairment, we realize that in reality, it is more complex to identify to which extent performance determining factors are affected by training, talent, motivation or impairment.

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