Could Prosthesis Use Provide a Competitive Advantage in Darts?

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Abstract: Competitive darts has become increasingly popular over the past few decades, and efforts have been made to have the game recognized as an Olympic sport in the future. The raised profile of the sport and the associated rewards bring up new challenges for the integrity of the game, as athletes are incentivized to exploit rule ambiguities in order to gain competitive advantages. In this research, it was hypothesized that uneven leg lengths and weights, which are comparatively easily realizable in prosthetic limbs, allow players to lean closer to the target and thus improve their throwing accuracy. This hypothesis was tested in a sample of 13 able-bodied subjects who participated in the study, with three sets of throwing trials; one to establish the baseline and two with a longer and heavier trailing leg, respectively. The findings suggest that these modifications are indeed beneficial, resulting in significantly shorter throwing distances and average accuracy improvements of up to 11%. The debate about the potential competitive advantages of prosthesis-wearing Paralympic athletes over their able-bodied peers previously focused on short track running events, where rules have been established that govern the allowable geometry and configuration of sprint prostheses. It appears that comparable regulations should be considered for darts competitions, in order to ensure fair conditions for all participants.

Keywords: artificial limbs; biomechanics; sports; Paralympics; technology doping

1. Introduction

The game of darts is said to have developed from a pub game in the 16th century called “Puff and Dart”, where players blew darts out of a hollow tube to hit a target. This game was replaced around the turn of the 20th century with the more recognizable version of the game of darts that is known today. Starting in England after World War I, darts leagues began to be established in public houses, and in 1927, the first national competition, called the “News of the World Championship”, was held in London [1]. The World Championship was revived in 1947 after the global spread of the game by servicemen during World War II [2].

Darts continued to grow throughout the 1950s, with professional leagues and international play increasing in popularity. With the advent of televised matches in the 1960s, the game of darts was elevated onto the world stage and widely recognized as a serious game with a loyal following [3]. Today, large tournaments draw thousands of on-site spectators as well as sizeable television audiences. As of 2019, the winner of the British Darts Organization (BDO)-hosted World Championship tournament earns GBP 100,000 (approximately USD 128,000), the Professional Darts Corporation (PDC) World Championship offers GBP 500,000 (USD 640,000) to the winner, and the total prize money on the PDC circuit exceeds GBP 14 M (USD 18 M) [4]. In 2005, following the avid lobbying of the BDO and the PDC, Sport England, Sport Wales, Sport Scotland and Sport Northern Ireland all pronounced darts an official sport. Lobbying has continued past this milestone, however, and darts is filing to become a recognized sport through the International Olympic Committee (IOC),
with hopes of eventually joining other disciplines that have been added to the Olympic Games portfolio [5].

At the same time, adaptive sports have experienced a similar if not greater increase in popularity, as new technologies are becoming available that allow differently-abled athletes to compete alongside, and at times even challenge, their able-bodied peers. These technological advances have frequently raised questions about the potential of “technology doping” to offer competitive advantages to users of assistive devices (e.g., the carbon fiber sprint feet of lower-limb prosthesis users). Consequently, new rules are introduced on a frequent basis to assure fairness in Paralympic (and by extension, Olympic) competition.

As the game of darts approaches one of the largest sports stages in the world, it is important that all aspects of the game are reviewed so that no players have unfair advantages over their competitors. Assuming that darts meets the regulations and rules set forth by the IOC, and hence also the basic requirements of the International Paralympic Committee (IPC), the sport will be open to Paralympic athletes. As with similar sports that the IPC recognizes, such as archery or Paralympic shooting, regulatory measures would be necessary to prevent athletes’ prosthetic devices from affecting the outcome of a competition. Due to the unique and customizable nature of prosthetic devices, there are inevitable limitations to this task. The weights of prosthetic knees or feet, for example, vary considerably, with implications for athletic performance. However, although the rules and regulations governing the game of darts are now quite refined [6], no rules that specifically govern the participation of users of assistive or prosthetic devices in official darts competitions have yet been instituted. Presumably, this omission is based on the assumption that no relevant risk of competitive advantage is introduced for contestants needing to use these medically indicated devices. No previous research on this question could be identified.

The aim of this study was to test this assumption by investigating the following hypotheses. (1) A bilateral leg weight discrepancy (which is easily achievable with a lower-limb prosthesis or orthosis) helps darts players lean closer to the target and can improve their throwing accuracy. (2) A bilateral leg-length discrepancy can shorten the throwing distance and improve accuracy.

2. Results

2.1. Participant Characteristics

Thirteen participants (eight male and five female, mean age 24.9 years) were enrolled in this study. They had varying degrees of experience as darts players and employed a variety of throwing stances.

2.2. Throwing Accuracy

Accuracy differences, expressed as the average distance of hits from the bullseye (Table 1), showed a trend in favor of the weighted and the lengthened condition, which resulted in about 11% and 5% lower deviations from the target, respectively, than the baseline condition (Figure 1). However, these differences were not statistically significant. Standardized effect sizes (Cohen’s d) were 0.36 for the weighted condition and 0.13 for the lengthened condition, compared to the baseline condition. Post hoc analysis (Figure 2) showed a weak-to-moderate inverse correlation between skill level (based on baseline throwing accuracy) and the benefits of the modifications (measured by the relative improvement in accuracy).
Table 1. Participants’ average throwing accuracy expressed as distance from the target (in cm).

| Participant | Baseline | Weighted | Extended |
|-------------|----------|----------|----------|
| 1           | 7.1      | 9.2      | 9.8      |
| 2           | 14.9     | 12.5     | 11.7     |
| 3           | 6.5      | 6.5      | 6.3      |
| 4           | 9.6      | 11.4     | 9.4      |
| 5           | 14.3     | 8.6      | 19       |
| 6           | 9.4      | 10.2     | 8.7      |
| 7           | 6.2      | 5.6      | 5.9      |
| 8           | 13.8     | 9.3      | 7.7      |
| 9           | 8.3      | 8.7      | 7.4      |
| 10          | 15.1     | 12.4     | 16.4     |
| 11          | 11.4     | 12.2     | 11.7     |
| 12          | 4.4      | 4.4      | 5.2      |
| 13          | 12.8     | 8        | 7.8      |
| Total Average (n = 13) | 10.3 | 9.2 | 9.8 |

Figure 1. Calculated mean distances from the bullseye (in cm) with standard deviations, for all three conditions (n = 13).

Figure 2. Correlation between skill level and magnitude of benefit from the modifications. $R^2 = 0.1$ for the leg extension modification and 0.4 for the added weight modification.
2.3. Throwing Reach

Technical difficulties and the peculiarities of some participants’ throwing stances prevented the use of video data for kinematic analyses for more than seven of the participants (five male and two female). Comparing the release-point distances of the intervention conditions against the control conditions (Table 2) revealed a significant advantage for the lengthened trailing leg condition ($p = 0.026$), with release points being an average of 9.2 cm closer to the target (95% confidence interval (CI) $[-0.1 \text{ cm, } 18.5 \text{ cm}]$), and this was a medium-to-strong effect (Cohen’s d = 0.67). By comparison, the weighted trailing leg yielded no significant advantage (Table 3), with an average reduction in throwing distance of merely 1.2 cm (95% CI $[-11.4 \text{ cm, } 13.8 \text{ cm}]$), for an effect size of 0.07. No significant differences were found for elbow angle, lead leg angle or release angle.

Table 2. Participants’ average release-point-to-bullseye distance (in cm) under each condition.

| Participant | Baseline | Weight | Extension |
|-------------|----------|--------|-----------|
| 1           | 179.9    | 158.5  | 168.9     |
| 2           | 180.2    | 197.4  | 182.4     |
| 3           | 184.2    | 187.8  | 167.1     |
| 4           | 148.0    | 145.1  | 147.3     |
| 5           | 187.3    | 183.0  | 177.1     |
| 6           | 183.3    | 195.9  | 181.8     |
| 7           | 196.9    | 183.8  | 170.9     |
| Total Average (n = 7) | 179.9 | 178.8 | 170.8 |

Table 3. Summary of $p$-values for one-tailed paired $t$-tests.

| Variable          | Weight | Extension |
|-------------------|--------|-----------|
| Throwing accuracy | 0.070  | 0.275     |
| Throwing reach    | 0.412  | 0.026     |

3. Discussion

The results of this study suggest that the use of an appropriately modified leg prosthesis can afford a darts player a competitive advantage. While the primary variable of accuracy did not seem to be affected by the tested interventions to a statistically significant degree, it is notable that there was, by trend, a positive effect that may be considered clinically or, in this case, competitively significant. An 11% improvement in throwing accuracy is likely to constitute a considerable advantage in a game that is often decided by millimeters. Other strategies for improving performance, such as using heavier materials for the dart arrows in order to reduce their diameter and thus allow for a tighter target pattern, are widely employed by darts players, even if they promise only the slightest of advantages.

Analysis of the release-point distances supports the part of the hypothesis that predicted that a favorable body posture would be allowed by the interventions. It appears logical that a shorter throwing distance is conduite to better throwing accuracy, especially after a player has become accustomed to the new distance and tuned his or her throwing mechanics accordingly. Due to time constraints, the latter process was probably not completed during this study, and it may be assumed that the observed benefits would become more pronounced with practice [7,8]. Additional research is needed to investigate this aspect, as well as other factors in addition to throwing reach that may affect accuracy, such as laterality (i.e., left/right-handedness), stance stability and proprioception.

Reach distance, and by extension throwing accuracy, is probably related to the magnitude of the length and weight imbalance between legs. A regular prosthesis, although its length may be a few millimeters off and its center of gravity may be shifted slightly distally, depending on the weight of the prosthetic foot, will probably not trigger any of the mentioned effects. However, it is easy to manipulate the properties of an artificial limb
(which is typically 30 to 40% lighter than the lost limb it replaces [9,10]) up to a level where
the modifications cause conspicuous gait changes. Length differences of more than one
centimeter are difficult to compensate for and will generally lead to some degree of limping.
Weight increases can be better concealed, especially considering that the distances covered
at darts competitions rarely exceed a few steps. Good prosthesis suspension, for instance
using a pin and lock system, along with strong residual leg muscles, will allow for an
almost normal gait even with a substantially heavier foot than normal. Importantly, there
are currently no rules that prohibit such a strategy, which is a gap that could be exploited
by prosthesis-wearing darts players. It may even be argued that leaving the mass of their
prosthetic leg unchanged for competition would be imprudent, considering the relative
disadvantage that is associated with the prosthesis being lighter than a similar sound limb.

The game of darts is thus one of the very few fields of endeavor where a physical
disability, which is generally not seen to be advantageous in athletic competition, actually
can be an asset. It should be noted that able-bodied athletes could achieve similar effects
by, for instance, increasing the weight or the sole thickness of one shoe. However, this
would be unambiguously interpreted as deliberate cheating, whereas for a prosthesis user
a grey area exists where the necessity of wearing an artificial limb may overlap with an
“accidental” competitive advantage. On a more general level, the ability to compete may
help make participation in sports more attractive to prosthesis users, which would result
in benefits for their rehabilitation outcomes. These would not just be due to the positive
effects of regular physical activity but also to the social aspects of training and competing
along with others, something to which the game of darts is especially conducive.

The presented findings may be interpreted within the larger topic area of “technology
doping”, which has been a concern for many years across all manner of athletic competi-
tions that utilize materials or technology of any kind, including Paralympic sports. Haake
analyzed performance improvement indices over time in four different Olympic disci-
plines [11]. According to his findings, 100 m sprint times, for instance, saw improvements
of 24% over 108 years, a level that is far exceeded by the gains in disciplines with higher
technology involvement: “ . . . pole vault, 86% over 94 years; javelin, 95% over 76 years;
. . . one-hour cycling record, 221% over 111 years . . . ” [11]. These numbers illustrate the
fact that general technological advances inevitably help to improve athletic performance.
Knowing this, athletes have always tried to stay current with, or even get ahead of, the
technical state of the art. In order to maintain the spirit of their sport and to prevent
dangerous or unfair disparities between competitors who have and have not access to the
latest technology, sports governing bodies frequently update the rule books, often after
a new intervention has been proven to be beneficial for its user. Examples include the
full-body “sharkskin” swimsuits that helped to obliterate records in the late 2000’s and that
were swiftly outlawed in 2010 [12].

In the realm of Paralympic sports, prostheses and other assistive devices cannot be
prohibited outright, which leaves many opportunities to exploit gaps in the existing rules
to gain a competitive advantage. The rules defining allowable equipment are expansive
and very detailed in order to prohibit, for instance, devices that provide “unrealistic en-
hancement of height of release in throwing events [or] unrealistic enhancement of stride
length” [13]. So far, the possibility that technology use by Paralympic athletes may raise
their performance to the level of able-bodied peers has only occasionally been discussed,
most prominently in the case of South African double-amputee sprinter Oscar Pistorius
around the 2008 and 2012 Olympics. Pistorius was initially banned from competing at
the 2008 Olympic Games in Beijing, citing concerns that his carbon fiber sprint prostheses
constituted unfair technology use. Upon appeal and extensive scientific debate, it was
concluded that Pistorius’ “running on . . . prostheses [is] physiologically similar but me-
chanically different from running with intact limbs” [14] and he was allowed to participate
in the 400 m race at the 2012 Olympic Games in London (where he did not qualify for the
final round). It can be predicted that if and when a prosthesis-wearing darts player starts
winning major championships, a similar discussion will ensue.
The data collection protocol used here had some limitations that should be taken into account when interpreting the findings. The circumstance that participants were not actual prosthesis users requires the assumption that the observed effects of the interventions translate directly into the limb loss population. This appears justified since the found effects are based on fundamental laws of physics that apply to both populations equally. Furthermore, the pseudo-prostheses used may, with some modifications, be designated as orthotic devices to manage conditions such as limb-length discrepancies (i.e., even athletes without limb loss would be able to exploit the basic function mechanism of such a device). Participants’ previous darts-playing expertise may be associated with different effect sizes. However, the underlying mechanisms that led to the presented results are, in principle, likely to apply to everyone. Since it was not viable to blind participants to the interventions, it is possible that their performance was biased in some way. The risk of this was considered minor, assuming that the competitive character of the throwing exercise incentivized participants to put forth their best effort. The nature of the interventions and the chosen color-coding approach also disallowed investigator blinding. Future work should investigate the effects of different magnitudes of prosthesis modifications, including different foot types, and combinations thereof. Given that the found effect sizes were smaller than initially assumed, future studies should have a larger sample size, to increase the probability of detecting significant effects. If throwing accuracy is the main outcome variable, effect sizes of 0.36 (for added leg weight) and 0.13 (for added leg length) would suggest sample sizes of 50 and of 368, respectively, to achieve a statistical power of 80%.

4. Materials and Methods

A repeated measures protocol was designed to allow within-participant comparison of the effects of the interventions. Ethics approval was granted by the Institutional Review Board at the University of Pittsburgh under protocol number PRO18060638. To control for some of the heterogeneity typical of the population of prosthesis users and considering the ethical implications of subjecting a vulnerable population (i.e., individuals with physical disabilities) to an untested intervention, healthy non-amputee participants were recruited for the data collection. This approach has been commonly applied in research on both upper- and lower-limb prosthetics interventions [15,16].

Upon providing informed consent, participants’ demographic information was obtained, as well as some anthropometric measurements (height, weight, arm and leg length), and they were fitted with two “pseudo-prostheses” (Figure 3). In one condition, a 4.5 kg cuff weight was attached to the ankle of the participant’s trailing leg to simulate a heavier prosthesis. In a second condition, a custom boot (VACOcast, OPED, Buford, GA, USA) connected by four-hole adapter (4R55, OttoBock, Duderstadt, Germany) to a prosthetic foot (1D10, OttoBock, Duderstadt, Germany) was utilized to simulate a 15 cm longer prosthetic leg. While this addition probably marks the limits of any leg length differences that can be concealed, it was intended to cause the most pronounced effects. The device weight was 2.0 kg. In order to make video analysis easier, colored markers were placed on four anatomical landmarks (acromioclavicular joint on the throwing arm, lateral epicondyle on the throwing arm, knee center on the lead leg and trochanter on the lead leg).

Baseline data were recorded in a control condition without any leg modifications that was also part of the randomized protocol. Participants were asked to complete trials of ten consecutive throws in each condition after having been given a few (usually less than five) minutes to become accustomed to each new intervention. Participants were instructed to aim for the bullseye on a paper target that resembled a modified dartboard and was positioned at the proper height and distance according to established darts rules. The toe line was marked with a wooden board to prevent overstepping. The same set of ten steel-tip 22 g darts were used for all participants in all trials. The ten throws in each set were conducted consecutively (typically within one minute) and no variations in throwing position were prescribed by the protocol.
Between trials, as the intervention was changed, the investigators color-coded the new holes on the paper target for subsequent analysis. After the three sets of throws were completed by a participant, the paper target was removed and digitized on a flatbed scanner. In the post-processing, throwing accuracy was determined by measuring the absolute distance of impact marks (holes in the paper target) from the bullseye for each condition in ImageJ [17], an open source image processing program, as described previously [18]. Measurements were recorded to the nearest millimeter, using the ruler tool in the ImageJ software.

The distance of the release point from the target was measured using two-dimensional video analysis based on recordings of the participants’ throws in the sagittal plane (GoPro Hero 4 Silver camera, filming at 1080 p, 60 fps). For post-processing, the video data were uploaded into Kinovea (version 0.8.15). After calibrating the software using a known segment of 30.48 cm (1 ft) that was recorded in every data file, the video was advanced frame by frame to find the release point of each throw. Once the exact release point was located, the markers on the participant’s landmarks were used to analyze the participant’s elbow angle, lead leg angle and release angle. The distance calibration allowed easy calculation of the distance from the release point to the bullseye (Figure 4). The accuracy of a given throw was not a factor in these analyses.

Distance variables for both the impact point from the bullseye (throwing accuracy) and the hand at release from the target (reach) were compared between the baseline and either of the intervention conditions by one-tailed paired t-tests with a critical alpha of 0.05. In addition to significance testing, the standardized effect sizes of each intervention were computed using Cohen’s d, which indicates how far apart (in multiples of the standard deviation) the outcomes are.

Power calculations were based on effect sizes derived from prior work [19] that compared darts performance between 40 male and 40 female participants. Female players in that study were on average 12.5 cm shorter, which resulted in an almost 6 cm shorter reach at the dart release (Cohen’s d = 1.17). It was assumed that the study interventions would at least result in a similar effect size regarding the main outcome variable of reach length. Accordingly, the sample size to achieve a statistical power of 0.95 with an alpha of 0.05 in a one-tailed paired-samples t-test was determined to be ten, using G*Power 3.1 [20].

Figure 3. (A) Leg extension device increasing the length of the trailing leg by 15 cm. (B) Cuff weight increasing the weight of the trailing leg by 4.5 kg.
5. Conclusions

Technology to assist people with physical disabilities is commonly not perceived as constituting any competitive advantage in athletic endeavors. This research investigated the potentially beneficial effects of prosthesis use on performance in the game of darts. The hypothesis that bilateral leg weight discrepancy improves throwing reach was supported by the data. However, the hypotheses that leg length discrepancy improves throwing reach and that either intervention improves throwing accuracy were not supported. If the finding of improved throwing reach with increased leg weight can be confirmed in larger samples, and it is concluded that manageable prosthetic modifications exist that allow users of leg prostheses a competitive advantage in the game of darts, adjustments in the official rules may be necessary. For instance, it may have to be specified that any prosthetic device must not exceed the contralateral limb in weight and dimensions (using anthropometric data tables).

Beyond the implications for this specific scenario, it may be interesting to consider the possible competitive advantage of prosthesis use as an example of a disability presenting a hidden “superpower”. This may help to change public perception and improve the ability of individuals to cope with limb loss.

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References
1. Chaplin, P. Darts in England, 1900–1939: A Social History; Manchester University Press: Manchester, UK, 2018.
2. Harris, L.J. Darts. In Routledge Handbook of Global Sport; Routledge: Milton Park, UK, 2020; pp. 206–214.
3. Davis, L. From a pub game to a sporting spectacle: The professionalisation of British Darts, 1970–1997. Sport Hist. 2018, 38, 507–533. [CrossRef]
4. Haigh, P. PDC prize money tops £14m as darts players’ potential earnings hit record levels. Metro, 10 January 2019.
5. Stefani, R. Olympic Sports of the Future. Sport J. 2016, 1–10.
6. Playing and Tournament Rules, 20th ed.; World Darts Federation: London, UK, 2018.
7. Deutscher, C.; Ötting, M.; Langrock, R.; Gehrmann, S.; Schneemann, S.; Scholten, H. Very highly skilled individuals do not choke under pressure: Evidence from professional darts. arXiv 2018, arXiv:1809.07659.
8. Kehoe, R.; Rice, M. Reality, virtual reality, and imagery: Quality of movement in novice dart players. Br. J. Occup. Ther. 2016, 79, 244–251. [CrossRef]
9. Mattes, S.J.; Martin, P.E.; Royer, T.D. Walking symmetry and energy cost in persons with unilateral transtibial amputations: Matching prosthetic and intact limb inertial properties. Arch. Phys. Med. Rehabil. 2000, 81, 561–568. [CrossRef]
10. Smith, J.D.; Martin, P.E. Short and Longer Term Changes in Amputee Walking Patterns Due to Increased Prosthesis Inertia. JPO: J. Prosthet. Orthot. 2011, 23, 114–123. [CrossRef]
11. Haake, S.J. The impact of technology on sporting performance in Olympic sports. J. Sports Sci. 2009, 27, 1421–1431. [CrossRef] [PubMed]
12. FINA General Rules; Federation Internationale de Natation: Lausanne, Switzerland, 2017.
13. World Para Athletics Rules and Regulations 2018–2019; International Paralympic Committee: Bonn, Germany, 2018.
14. Weyand, P.G.; Bundle, M.W.; McGowan, C.P.; Grabowski, A.; Brown, M.B.; Kram, R.; Herr, H. The fastest runner on artificial legs: Different limbs, similar function? J. Appl. Physiol. 2009, 107, 903–911. [CrossRef]
15. Haverkate, L.; Smit, G.; Plettenburg, D.H. Assessment of body-powered upper limb prostheses by able-bodied subjects, using the Box and Blocks Test and the Nine-Hole Peg Test. Prosthet. Orthot. Int. 2016, 40, 109–116. [CrossRef]
16. Vanicek, N.; Strike, S.; McNaughton, L.; Polman, R. Postural responses to dynamic perturbations in amputee fellers versus nonfallers: A comparative study with able-bodied subjects. Arch. Phys. Med. Rehabil. 2009, 90, 1018–1025. [CrossRef] [PubMed]
17. Rueden, C.T.; Schindelin, J.; Hiner, M.C.; DeZonia, B.E.; Walter, A.E.; Arena, E.T.; Eliceiri, K.W. ImageJ2: ImageJ for the next generation of scientific image data. BMC Bioinform. 2017, 18, 529. [CrossRef] [PubMed]
18. Reinking, L. ImageJ Basics, Version 1.38, Biology 211 Laboratory Manual: Millersville, PA, USA, 2007.
19. Duffy, L.J.; Ericsson, A.K.; Baluch, B. In search of the loci for sex differences in throwing: The effects of physical size and differential recruitment rates on high levels of dart performance. Res. Q. Exerc. Sport 2007, 78, 71–78. [CrossRef] [PubMed]
20. Faul, F.; Erdfelder, E.; Lang, A.-G.; Buchner, A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 2007, 39, 175–191. [CrossRef] [PubMed]