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Evolution of Racing Wheelchair: from its origin to the Paralympic Games

Paride Cavallone^[0000-0003-4715-4114], Luigi Tagliavini^[0000-0001-8925-0417],
Andrea Botta^[0000-0002-7272-7132], Giovanni Colucci^[0000-0002-2996-9013],
Lorenzo Baglieri^[0000-0002-5022-5326] and Giuseppe Quaglia^[0000-0003-4951-9228]

Politecnico di Torino, Department of Mechanical and Aerospace Engineering
DIMEAS, Torino, Italy
{paride.cavallone, luigi.tagliavini, andrea.botta,
giovanni_colucci, giuseppe.quaglia}@polito.it and
lorenzo.baglieri@studenti.polito.it

Abstract. This paper presents an overview of wheelchair evolution, focused on the racing wheelchairs, from wheelchair origins to the modern Paralympic Games. The evolution starts from the first wheeled vehicles to transport persons in ancient cultures and goes through the middle of the XIX century, when the first patent of a wheelchair, named “Invalid chair”, appeared. After World War II, Dr. Ludwig Guttman founded the “Stoke Mandeville Games”, the forerunners of the Paralympic Games, and this initiative started the evolution of competition wheelchairs described in its main steps. Lastly, an innovative racing wheelchair, named Handwheelchair.q racing, conceived and realized by the authors is described.

Keywords: Racing Wheelchair, Handwheelchair.q, Sports wheelchair, Paralympic sports

1 Introduction

The report written by the World Health Organization, WHO, in 2018 [1] shows that 1% of the global population requires a wheelchair for daily mobility. The consequences of reduced function of the lower limb span a broad spectrum, from the emergence of disorders typically associated with physical inactivity [2] to mental health problems [3]. The constitution of the WHO defines health as “...a state of physical, mental, and social well-being and not merely the absence of disease or infirmity” [4] and good health is a prerequisite for participation in a wide range of activities including education and employment [5]. [6] reveals as “...the more physical activity was associated with a lower scale value of depression and anxiety and a higher scale value in perceived social support”. Different studies [7], [8] show that daily wheelchair use is insufficient to maintain or improve physical capacity and consequently is insufficient to avoid secondary health conditions such as obesity and cardiovascular diseases [9]–[11]. In conclusion, sport or physical activity is an important tool for rehabilitation from a physical and psychological point of view. However, if on the one hand sport and physical activity

are important, on the other hand, there are negative consequences related to the overload of the upper extremity. The upper limb is the most commonly affected site in manual wheelchair users. Indeed, different studies have reported that over 70% of manual wheelchair users suffer from shoulder pain [12], [13]. Moreover, the percentage of shoulder pain is higher in wheelchair users who practice wheelchair sports [14]. The repetition of these activities leads to overuse injuries. This was indeed one of the reasons motivating the authors to design an innovative wheelchair propelled through a pulley-cable system [15]–[18].

2 A brief history of wheelchairs

The history of the wheelchair is related to the history of the invention of the wheel. Since the invention of the wheel, the main application was the transport of goods and people. Several paintings, from different ancient cultures, represent the transport of people for several reasons, for example in Fig. 1a is reported Ramesses II at the Battle of Kadesh, 1275 BC [19].

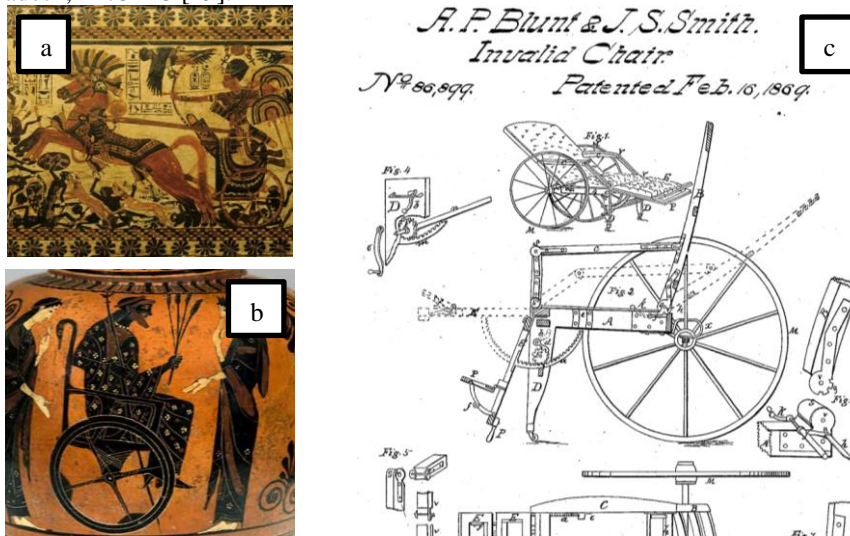


Figure 1: a) Mural painting in ancient Egypt, b) painting on an ancient Greek vase, and c) the first patent of a self-propelled chair named “Invalid chair”

In the beginning, the transport of goods and people was possible using draft animals because the efficiency of the wheels was very low, and they were very heavy. The metal ages were fundamental for the development of the wheel, especially regarding the kinematic pairs. Probably, one of the first wheelchair representations comes from a decoration on a Greek ancient vase [20] Fig. 1b, where a person is pictured while pushing a chair with two rear wheels. A fundamental stage in the evolution of wheelchairs concerns the first patent about the first self-propelled wheelchair “Invalid chair”, 16 February 1869, by Blunt & J.S. Smith [21].

3 Evolution of racing wheelchairs

The history of racing wheelchairs is closely related to the sports activities practiced in the wheelchair. In 1944, the neurologist Ludwing Guttman started to work at the “Stoke Mandeville Hospital” [22], in England, in the first research center for Spinal Cord Injury, SCI. At the Stoke Mandeville Hospital, at that time, most of the patients were injured soldiers of World War II. The soldiers, despite the injuries, were generally in good health, such that Guttman proposed rehabilitation practices based on sports activities. In fact, the paper [23] reports that “...Guttman is credited with the aspiration to improve the dismal prospects of post-war spinal injury patients, and the inspiration of using sports as rehabilitative practices.”, and also that “Guttman is regarded by many as the founder of the modern treatment of spinal injuries.”. On 29 July 1948, at the same time as the opening ceremony of the XIV Olympic Games, the first edition of “Stoke Mandeville Games” was held. In 1952, the “Stoke Mandeville Games” became the “1st International Stoke Mandeville Games”. In 1960, thanks to the collaboration between Guttman and the Italian doctor Antonio Maglio, the “1st Paralympic Games” were held in Rome at the same time as the “XVII Olympic Games” [24].



Figure 2: a) Start of the men's Paralympic race of Tokyo 1964, b) Slalom race, c) wheelchair race at the Paralympic Games in 1976 and in d) 1984

In the Paralympic Games in Tokyo in 1964, the 60 m race for men and women was added and it represents the first wheelchair race at the Paralympic Games. In the next edition in Tel Aviv in 1968, the 100 m race was added and in 1972 in Heidelberg, the slalom race was introduced, Fig. 2b. The wheelchairs employed in these three editions of the Paralympic games were wheelchairs for every-day life. Fig. 2a shows the start of the men's Paralympic race in Tokyo. In this photo there are two types of wheelchairs:

the first type is the wheelchair with two rear wheels with the handrim and two small front pivoting wheels. The second type is instead a wheelchair with 2 front wheels without the handrim and a rear small pivoting wheel. Both were everyday-life wheelchair models used in those years. Until 1975, the racing wheelchairs had many characteristics of the everyday life wheelchairs, as shown the Fig. 2c. At the time of the Paralympics Games in 1976, even the clothes, the training, and the diet were not specialised even if new races were introduced, namely 200 m, 400 m, 800 m, and 1500 m. Only during the Paralympics Games in 1984 in Los Angeles, the racing wheelchair had a considerable development and the differences with conventional wheelchairs were remarkable, as shown in Fig. 2d that is very interesting because it shows two different racing wheelchairs in the same race. The first two wheelchairs in the pictures have the rear wheels with a camber angle and have 2 front pivoting wheels, better visible Fig. 3a. The wheelchair in the third position is a different model, reported in Fig. 3b, in which the two front pivoting wheels were controlled by a steering mechanism. From the mid '70s, the first specialised racing wheelchair began to appear. At the end of the '80s, the racing wheelchair became more efficient, the speed increased, and stability and handling of the wheelchair became a problem to be solved. In this scenario, two solutions were adopted. The first concerned the camber angle of the rear wheels. The second was about the introduction of a steering system and a crown compensation.

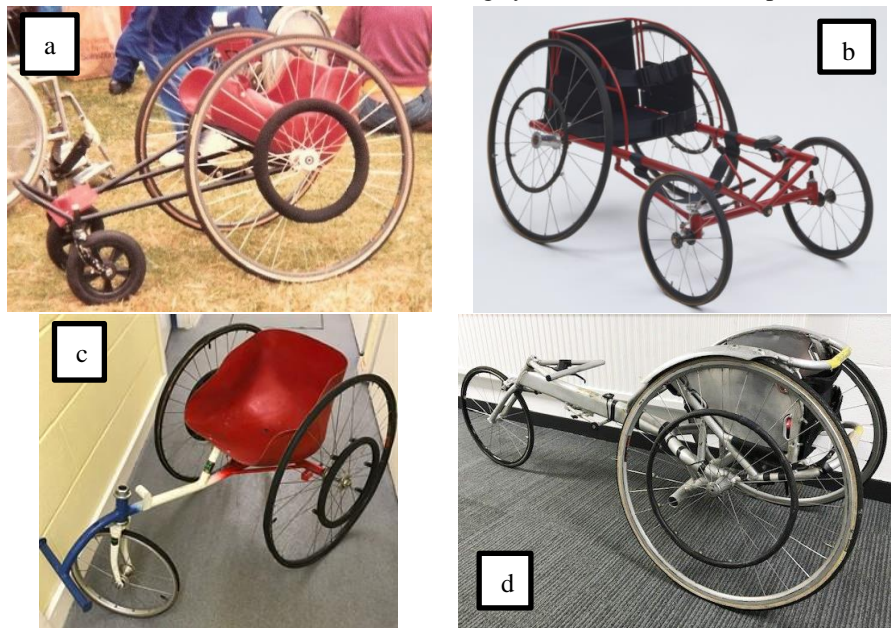


Figure 3: a) and b) different models of racing wheelchairs at the beginning of the '80s and racing wheelchairs with c) front pivoting wheels and d) front steering wheel

About the latter topic, in 1989, Rory A. Cooper wrote a paper about three different systems of crown compensation [25], that employs push or pull springs to compensate the external forces on the front wheel. In the second half of the '80s, Jackson Cycles

designed and prototyped the first three-wheeled racing wheelchair, Fig. 3a, used by Paul Cartwright [26]. The main innovative characteristic concerned the front wheel. The front wheel had a diameter larger than usual front wheel, the pivoting axis was vertical and there was an offset between the axis and the hub, practically a castor front wheel. In the second prototype, Fig. 3b, used by Chris Hallem, the steering axis is oblique [27]. From that time on, wheelchair athletes started to prefer the steering three-wheeled wheelchair. In 1988 there was officially the first edition of the “Paralympic Games”, For this event, the rules and regulations were rewritten less restrictively in order to allow the use of the three wheeled racing wheelchair. Since the Paralympic Games in Barcelona, in 1992, Fig. 4a, the racing wheelchairs had the same functional design of the present racing wheelchair: two rear cambered wheels with the hand rim, a large castor front wheel with a brake, a steering system, and a compensator steering mechanism. In the following years, the main evolution has concerned the material composition and the weight of the chassis, going from steel to titanium and then aluminium to carbon, the efficiency and the material of the components like hubs, roller bearings, wheels, the aerodynamic, Fig. 4b. Further studies focused also on biomechanical analysis, nutrition and training.

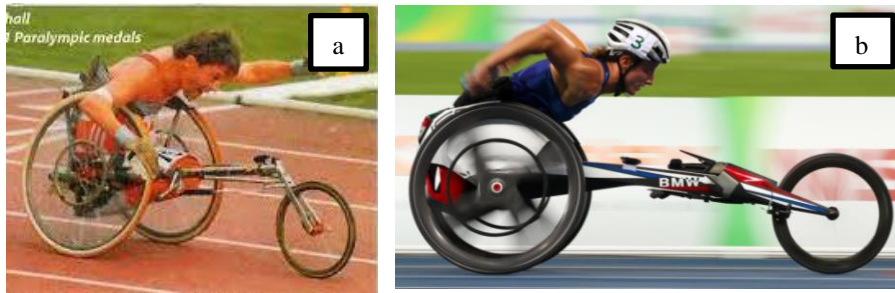


Figure 4: a) Rainer Kuschall at the Paralympic Games in Barcellona, 1992 and b) Tatyana McFadden at the Paralympic Games in Rio de Janeiro, 2016.

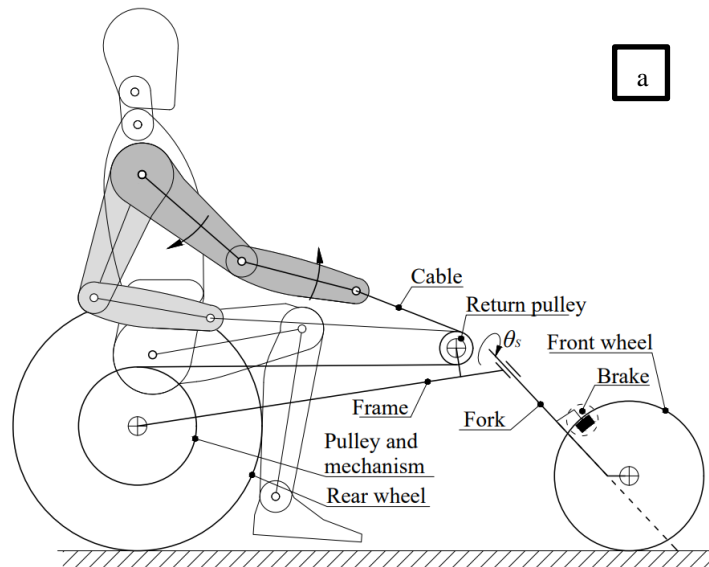
4 Handwheelchair.q racing

The authors conceived a novel device named Handwheelchair.q racing, based on a standard racing wheelchair chassis and using a new propulsion and steering system. The main goal of this prototype is to increase the mobility and maneuverability of the racing wheelchair as well as the reduction of compression loads on the shoulder. The system of propulsion is inspired by a rowing gesture in which the wheelchair is propelled by a system that employs cable and pulley, as described in detail in different papers related to an every-day life wheelchair with the same propulsion system [16], [18], Fig. 5. The gesture from the tab a) to the b) is the active phase in which the user propels the wheelchair, the gesture from the tab b) to the tab c) is the recovery phase. In this phase the cable is rewind by a power spring.



Figure 5: Innovative system of propulsion applied on a standard wheelchair.

In the standard racing wheelchair, the user controls the steering angle by a lever that can be used only in the recovery phase, because in the active phase the hands are in contact with the handrim. In this prototype, Fig. 6, the user holds a handlebar that enables him/her to perform the rowing gesture. By pulling a couple of cables the motion is transmitted to pulleys connected to the wheels by means of reversible freewheel mechanisms. The prototype is provided with three pulleys with different radii to find the right transmission of ratio based on the specific use. In addition, the left and right sides of the handlebar can rotate relatively to each other to control the steering angle by employing Bowden cables connected to a steering pulley engaged with the steering shaft, Fig. 6b. Lastly, a compensator mechanism has been designed to compensate the transversal external forces on the front wheel. The compensator mechanism has been designed with multiple adjustments in order to optimize the mechanism for each specific user for the specific use. In Fig. 5a the top view of the functional design of Handwheelchair.q racing is depicted and in Fig. 5b the prototype of Handwheelchair.q Racing is reported.



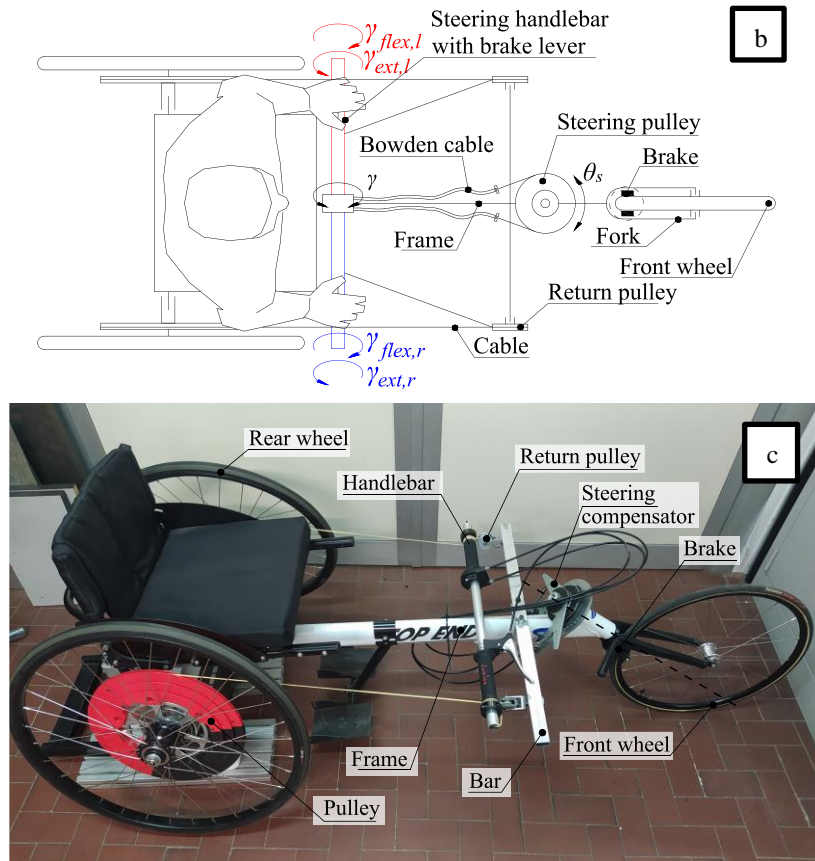


Figure 6: Handwheelchair.q racing a) lateral and b) top view of the functional design and c) prototype.

5 Conclusions

This paper shows the evolution of the racing wheelchair and the innovative racing wheelchair, named Handwheelchair.q racing. In the future, the prototype has to be tested from real user in order to receive feedback about its maneuverability, about the regulation of the compensator steering mechanism and from a biomechanical point of view. In addition, the prototype has to be compared with the standard racing wheelchair in terms of mechanical efficiency. Lastly, in the prototype a mechanism to have a variable transmission ratio can be implemented in order to change the transmission ratio depending on the external factors and the use.

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