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Review Article

Factors related to propulsion efficiency in manual wheelchair users with paraplegia due to spinal cord injury

Fatores relacionados à eficiência da propulsão em cadeira de rodas manual de usuários com paraplegia devido à lesão medular

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Abstract

Introduction: Individuals with paraplegia due to spinal cord injury (SCI) perform manual wheelchair (MWC) propulsion to promote functional mobility to perform daily activities. However, the inefficiency of propulsion caused by inadequate MWC setting, as well as pain and upper limb injury (UL), can result in decreased user mobility. **Objective:** Through the methodology of the integrative review, sought to identify and evaluate factors related to propulsion efficiency in MWC of users with paraplegia due to SCI. **Method:** We selected indexed studies in PubMed, LILACS, and SciELO on the biomechanics of the propulsion of users with paraplegia due to SCI between 2008 and 2018. **Results:** Among the 10 studies included in the review, two studies were classified as level III-2 and eight as level IV evidence. Factors related to propulsion efficiency were identified as: non-propulsive moments; the speed of the UL in the recovery phase; the position of the hand in the release period; the size of the backrest; maintaining body weight; the level of daily activity and shoulder adduction strength; the intensity of the propulsion; the orientation of the UL and the SCI time. **Conclusion:** Evidence regarding the cycle and propulsion patterns, MWC settings, user characteristics, and pain and injury in the UL proved to be factors related to propulsion efficiency in MWC of users with SCI paraplegia.

Keywords: Wheelchair, Paraplegia, Spinal Cord Injuries, Biomechanics.

Resumo

Introdução: Indivíduos com paraplegia devido à lesão medular (LM) realizam propulsão de cadeira de rodas manual (CRM), a fim de promover mobilidade funcional para realização das atividades cotidianas. No entanto, a ineficiência da propulsão causada pela inadequada configuração da CRM, assim como dores e

lesões nos membros superiores (MMSS), pode resultar na diminuição da mobilidade do usuário. **Objetivo:** Por meio da metodologia da revisão integrativa, buscou-se identificar e avaliar fatores relacionados à eficiência da propulsão em CRM de usuários com paraplegia devido à LM. **Método:** Foram selecionados estudos indexados na PubMed, LILACS e SciELO sobre a biomecânica da propulsão de usuários de CRM com paraplegia devido à LM, entre os anos de 2008 e 2018. **Resultados:** Dentre os 10 estudos incluídos na revisão, dois foram classificados como nível III-2 e oito como nível IV de evidência. Foram identificados como fatores relacionados à eficiência da propulsão: os momentos não propulsivos; a velocidade dos MMSS na fase de recuperação; a posição da mão no período de liberação; o tamanho do encosto; a manutenção do peso corporal; o nível de atividade diária e a força de adutores de ombro; a intensidade da propulsão; a orientação dos MMSS; e o tempo de LM. **Conclusão:** As evidências sobre ciclo e padrões de propulsão, configurações de CRM, características do usuário e dores e lesões nos MMSS demonstraram ser fatores relacionados à eficiência da propulsão em CRM de usuários com paraplegia devido à LM.

Palavras-chave: Cadeira de Rodas, Paraplegia, Traumatismos da Medula Espinal, Biomecânica.

1 Introduction

Spinal cord injury (SCI) is characterized by damage to the structures of the spinal canal, bringing physical, psychological, and social complications (Polia & Castro, 2007). According to the World Health Organization (2013), the worldwide incidence of SCI is 40 to 80 cases per million inhabitants. Traffic accidents, falls, violence and sports injuries are the most common causes. In Brazil, the incidence is 71 cases per 1 million inhabitants per year (Masini, 2001). It is estimated that there are more than 180 thousand cases of SCI, with an increase of approximately 10 thousand cases per year (Masini, 2001).

Individuals with paraplegia due to SCI commonly perform manual wheelchair (MWC) propulsion to promote mobility for daily activities (Cooper et al., 1998). However, the inefficiency of the propulsion caused by the inadequate setting of the MWC (Medola et al., 2014) and pain and injuries in the upper limbs (UL) (Requejo et al., 2008) can decrease the mobility of the user.

Several studies have investigated factors related to propulsion efficiency in MWC. These studies describe that ultralight wheelchairs made of carbon fiber and titanium are lighter and more resistant (Cooper et al., 1997) and consequently, require less effort and repetitive movements performed by the user during propulsion, avoiding the risk of pain and injury in upper limbs (Requejo et al., 2008; Chow & Levy, 2011). Like in the MWC structure, the use of rear wheels produced with carbon fiber contributes to preserve the function of the ULs because they are lighter and minimize the transmission of impacts to the user's body (DiGiovine et al., 2006). The front wheels also require attention in the diameter and production material. The use of pneumatic or carbon fiber-type front wheels with a smaller diameter favors to reduce rolling resistance and also minimize the impacts to the ULs (Kwarciak et al., 2009b; Medola et al., 2014).

Literature review studies show that shoulder pain and injury (Requejo et al., 2008; Chow & Levy, 2011) and the setting of wheelchair components (Medola et al., 2014) are factors related to manual propulsion. Understanding these factors is essential to promote increased mobility and user participation, thus improving quality of life (Chow & Levy, 2011). People with paraplegia use the ULs to perform manual propulsion and, consequently, there is an increased demand for these structures (Requejo et al., 2008; Chow & Levy, 2011). This condition can increase the risk of shoulder pain and injury, limiting the user's performance during activities of daily living (Requejo et al., 2008; Chow & Levy, 2011). Studies also show that the inadequate adjustment of the backrest height, the camber, and the horizontal/vertical axis of the rear wheels can affect the range of motion of the UL joints and the stability of the user during manual propulsion. The inadequate setting of these components can affect the efficiency of the propulsion, limiting the user's mobility performance (Medola et al., 2014).

Despite the contribution of the review articles in the scientific literature (Requejo et al., 2008; Chow & Levy, 2011; Medola et al., 2014), recent studies provided new evidence that investigated factors of the propulsion efficiency. Therefore, this review article presents and discusses new scientific evidence, specifically directed at MWC users with paraplegia due to SCI, and also evaluates and classifies studies according to the levels of scientific evidence, using the integrative review as a methodology.

Evidence-Based Practice (EBP) is an approach that seeks to identify and evaluate scientific evidence for the applicability in clinical practice, considering the professional's experience and the client's opinion in the decision-making process (Souza et al., 2010). An integrative review is a method of EBP enabling to include experimental and non-experimental studies; describe concepts; identity, analyze and synthesize the results of a specific theme, providing the health professional with the choice of the best possible evidence in the care of the patient/client/user (Souza et al., 2010).

The occupational therapist is the professional qualified to prescribe assistive mobility devices; develop adaptations and strategies to assist in ADL (activities of daily living) and IADL (instrumental activities of daily living); and guide, train and monitor users and family members on the use of the assistive device (Brasil, 2015). Therefore, this article will also contribute to occupational therapists who work in practice and in giving wheelchair services, using the evidence from the selected studies, professional critical thinking, and considering the opinion of users to promote the propulsion efficiently in MWC. Therefore, using the integrative review methodology, this study aims to identify and evaluate factors related to the propulsion efficiency in MWC of users with paraplegia due to SCI.

2 Method

This study used the methodology of the integrative review aimed at analyzing the knowledge of several studies, classifying them according to the levels of scientific evidence for possible applicability of the results in clinical practice (Souza et al., 2010). The stages of the integrative review are: 1) the elaboration of the guiding question of the research; 2) the search for studies in the databases and establishment of sample inclusion/exclusion criteria; 3) the data collection from selected studies; 4) the critical

analysis of the studies and classification by levels of evidence; 5) the discussion of results; 6) the presentation of the integrative review (Souza et al., 2010).

Therefore, the development of the study was based on the following guiding question: What factors are related to the propulsion efficiency in MWC of users with paraplegia due to SCI? For this purpose, we searched for studies in the PubMed, LILACS and SciELO indexing sources, in English and Portuguese, between 2008 and 2018, using descriptors according to DeCS (Health Sciences Descriptors): wheelchairs (*cadeira de rodas*), spinal cord injuries (*traumatismos da medula espinal*) e paraplegia (*paraplegia*). Other significant terms not found in DeCS were used: propulsion (*propulsão*) e biomechanics (*biomecânica*). Besides searching for studies in the databases, a manual search was performed on the reference list of all articles that were selected for full reading.

The inclusion criteria in the search process were: studies related to the biomechanics of propulsion in MWC; studies involving MWC users (men and women) with paraplegia due to SCI; and journal articles published in Portuguese and English. The exclusion criteria were: studies involving hand-cycling and motorized wheelchairs; editorial articles; simulation studies; pilot studies; narrative reviews; qualitative case studies; case reports; and studies with results from groups consisting of only quadriplegic individuals and/or with other types of diseases/health conditions.

The data collected in the selected studies were systematized in the evidence table and categorized by themes to discuss the results. All studies were carefully evaluated, based on the levels of scientific evidence provided by the National Health and Medical Research Council (1998). The classification of scientific evidence is determined according to the study design used, organized hierarchically into 4 levels: I) evidence obtained based on a systematic review of randomized clinical trials; II) evidence obtained based on a randomized clinical trial; III-1) evidence obtained from pseudo-randomized controlled trials; III-2) evidence obtained from comparative studies with controls and nonrandomized allocation, cohort studies, case-control studies or interrupted time series with a control group; III-3) evidence obtained from comparative studies with historical control, two or more studies from a single group or interrupted time series without a parallel control group; IV) evidence obtained based on case series. The evidence from the articles included in the review was discussed with the other articles in the scientific literature on the theme (Souza et al., 2010).

3 Results

In total, we found 68 studies (PubMed n = 35; LILACS n = 23; SciELO n = 10), in which 10 of them were excluded by duplicate. In the articles that were selected to read the title and abstract (n = 58), we excluded 23 of them. After reading the selected studies in full (n = 35), 27 were excluded. Finally, based on the reference list of articles selected for full reading, we selected two articles (Mulroy et al., 2015; Gil-Agudo et al., 2014) by manual search in the articles of Requejo et al. (2015) and Gil-Agudo et al. (2014), respectively, totaling 10 studies included in the review (Figure 1).
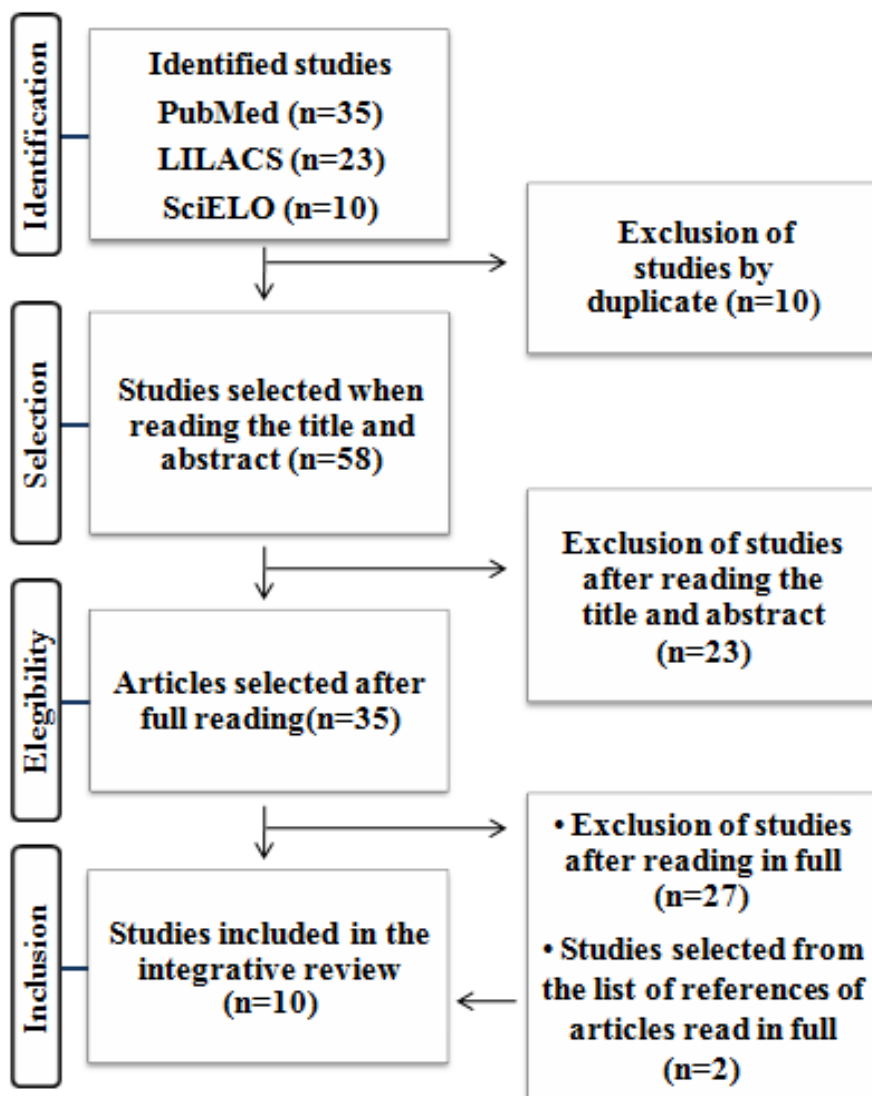
Figure 1. Study selection flowchart. Source: Created by the author.

The selected studies had the following themes: cycle and propulsion patterns, MWC settings, characteristics of the MWC user, and pain and injuries in the upper limbs. Mulroy et al. (2015) and Gil-Agudo et al. (2015) provided evidence classified at a higher level. On the other hand, the other studies were classified as level IV of evidence (Table 1).

Most studies included adults of both genders, except for studies by Gil-Agudo et al. (2014, 2015), who had samples only of men. Only the study by Raina et al. (2012) did not inform the average age of the participants. The studies were from the United States (n = 7), Spain (n = 2) and Taiwan (n = 1).

Table 1. Synthesis of studies classified by levels of evidence.

Author	Level of evidence	Objective	Participants	Data collection	Results
Kwarciak et al. (2009a) /EUA	IV	To create a comprehensive definition of the MWC propulsion cycle and demonstrate its clinical benefit.	n=54 (44 men and 10 women); Mean injury time: 14.4 years (±10.4); Mean age: 40.7 years old (±11.3); Bodyweight: 76.6 kg (±16.4)	Kinetic and kinematic data were collected during MWC propulsion on the dynamometer.	The propulsion cycle was divided into: contact phase (initial contact, propulsion, and release) and recovery phase; The initial contact and release periods were considered as non-propulsive moments of the hand's contact with the rim; The loss of power and the increase in the braking moment occurs as the impulse speed increases during the initial contact and release periods; The use of a propulsion pattern with the hands below the rim during the initial contact period decreasing the braking moment and increasing power.
Raina et al. (2012) /EUA	IV	To determine whether the magnitude of the hand/forearm speed and the reaction force depends on the propulsion technique.	n=34 (31 men and 3 women); Mean injury time: WD; Mean age: WD; Mean body weight: 74.5 kg (±12)	Kinetic and kinematic data were collected during the MWC propulsion on the stationary ergometer.	Participants with paraplegia preferably used the SLOP standard in comparison to other standards (ARCH and SC); The speed of the hand/forearm before contact with the rim was correlated with the effective force during propulsion; There was no correlation between the reaction force and the propulsion patterns.

Table 1. Continued...

Author	Level of evidence	Objective	Participants	Data collection	Results
Requejo et al. (2015) /EUA	IV	To investigate the relationships between the location of the hand in the periods of initial contact and release, and propulsion characteristics, reaction forces, and shoulder kinetics during propulsion.	n=222 (198 men and 24 women); Mean injury time: 9.3 years (± 6.1); Man age: 34.7 years old (± 9.3); Mean body weight: 74.4 kg (±15.9)	Kinetic and kinematic data were collected during MWC propulsion on the stationary ergometer.	PCA and ARA of the hand reduced cadence and greater distance between cycles. Only ARA was associated with increased speed; ARA increased forces in the rim and over the shoulder as well as in the moments of adductors and external rotators; The PCA increased the posterior strength and shoulder flexor moments.
Yang et al. (2012) /Twain	IV	To evaluate the effect of backrest height on kinematics and kinetics during propulsion.	n= (26 men and 10 women); Mean injury time: 11.88 years (±8.4); Man age: 39.1 years old (±10.5); Mean body weight: WD	Kinetic and kinematic data were collected during MWC propulsion on the motorized treadmill in level or inclined condition (3rd), using a low or high backrest.	The use of the low backrest allowed greater shoulder ROM, reduced cadence and increased angle, and impulse time, regardless of the leveling or inclination of the treadmill.
Collinger et al. (2008) /EUA	IV	To show a descriptive and comparative analysis of the kinetics and kinematics of the shoulder during MWC propulsion.	n=61 (49 men and 12 women); Mean injury time: 14.6 years (±10.5); Man age: 43.1 years old (±12); Mean body weight: 75.9 kg (±14)	Kinetic and kinematic data were collected during MWC propulsion on the dynamometer at different speeds (auto-selected; 0.9 m/s, 1.8 m/s).	46% of participants reported experiences of shoulder pain before the study; The weight of the participants was the main factor to increase the forces and moments of the shoulder during the propulsion; Shoulder strengths and moments increased with increasing speed.
Mulroy et al. (2015) /EUA	III-2	To determine predictors of	n= 223 (198 men	Participants were assessed for	Among 201 participants, 39.8%

Table 1. Continued...

Author	Level of evidence	Objective	Participants	Data collection	Results
		shoulder joint pain in people with paraplegia.	and 25 women); Mean injury time: 9.3 years (±6.2); Man age: 34.7 years old (±9.3); Mean body weight: 74.1 kg (±16.3)	shoulder pain for 3 years using WUSPI. Daily activity variables (mean speed and propulsion distance; transfer and sports participation) and shoulder torque variables were measured.	developed shoulder pain. The daily activity variables and the baseline maximum isometric torque were lower in those who developed shoulder pain. The adduction torque of the shoulder was considered a predictor of pain onset. However, none of the factors were considered to be strong predictors of shoulder pain.
Gil-Agudo et al. (2014) /Spain	IV	To assess changes in the shoulder using ultrasound after low and high-intensity propulsion.	n= 14 men; Mean injury time: 7.51 years (± 4.56); Man age: 35.2 years old (± 6.11); Mean body weight: 68.3 kg (± 8.96)	The magnitude of forces and shoulder moments increased during the high-intensity task;	The magnitude of forces and shoulder moments increased during the high-intensity task; increase in reaction forces was correlated with an increase in the thickness of the mm tendon, biceps brachii and with a decrease in subacromial space; There were no changes through ultrasound.
Gil-Agudo et al. (2015) /Spain	III-2	To compare changes in shoulder strengths and moments and ultrasound changes in MWC users and non-MWC users during high-intensity activity.	The WC Group with SCI: n= 22 men; Mean injury time: 8.73 years (±7.08); Man age: 35.5 years old (±7.06); Mean body weight: 68.66 kg (±10.76) The group without SCI: n= 12 men; Man age: 31.3 years old (±7.46); Mean body weight: 73.87 kg (±11.54)	Participants in each group performed high-intensity propulsion on the motorized treadmill.	The strengths and shoulder moments of the MWC users increased when compared to the control group. There were no changes through ultrasound.

Table 1. Continued...

Author	Level of evidence	Objective	Participants	Data collection	Results
Russell et al. (2015) /EUA	IV	To determine how MWC users modify the UL mechanics as the propulsion speed increases.	n=40 (32 men and 8 women); Mean injury time: 8.25 years; Man age: 35 years old; Mean body weight: 74.5 kg (±18)	The UL kinematics and the reaction forces generated in the rim were measured during the propulsion of free and fast speed in the stationary ergometer.	The increase in the propulsion speed reduced the contact time with the rim and increased the magnitude of the reaction forces; The magnitude of the shoulder moment does not necessarily correspond to the increase in speed, but it can be changed according to the UL orientation.
Rice et al. (2009) /EUA	IV	To examine the characteristics of the thrust and changes that may occur during propulsion.	n=21 (19 men and 2 women); Mean injury time: 19.1 (±8.8); Man age: 44.8 years old (±9.6); Mean body weight: 79 kg (±14.96)	Kinetic data were recorded for 10 min. at a speed of 1.4 m/s.	The maximum reaction force decreased as the pulse times and the propulsion cycle increased.

ARA = anterior release angle; ARCH = arch; MWC = manual wheelchair; PCA = posterior contact angle; ROM = range of motion; SC = semicircular; SCI = spinal cord injury; SLOP = single looping; UL = upper limbs; WD = without description; WUSPI = *Wheelchair User's Shoulder Pain Index*. Source: Created by the author.

4 Discussion

This integrative review aimed to identify and evaluate factors related to the propulsion efficiency in MWC of users with paraplegia due to SCI. Therefore, factors related to propulsion efficiency were identified: non-propulsive moments; the speed of ULs in the recovery phase; the position of the hand in the release period; the size of the backrest; maintenance of body weight; the level of daily activity and the strength of shoulder adductors; the intensity of the propulsion; the guidance of ULs; and the SCI time. The findings were categorized as follows: cycle and propulsion patterns, MWC settings, characteristics of the MWC users, and pain and injuries in the upper limbs.

4.1 Propulsion cycle and patterns

During the propulsion cycle, there is an interval in which the hand is in contact with the rim, generating enough force to propel the MWC between two moments when the

hand remains in contact with the rim but does not generate enough force to perform propulsion. (Kwarciak et al., 2009a).

Thus, the propulsion cycle is divided into the contact phase and recovery phase. The contact phase is subdivided into 3 periods which are initial contact, propulsion, and release (Figure 2). The initial contact is understood by the contact of the hand on the rim, but without generating enough force to produce propulsion of the MWC. This period is characterized as the non-propulsive moment of hand contact on the rim. In the propulsion period, the hand remains in contact with the rim but generating enough strength to produce MWC propulsion. This period is defined as the propulsive moment. Like the contact phase, the release phase is defined as the non-propulsive moment of hand contact on the rim. In this period, the hand is being released from the rim and the forces are being completely stopped. At the end of the propulsion cycle, in the recovery phase, opposite to the contact phase, there is an instant when the hand does not come into contact with the rim, that is, no forces are acting to propel the MWC (Kwarciak et al., 2009a).
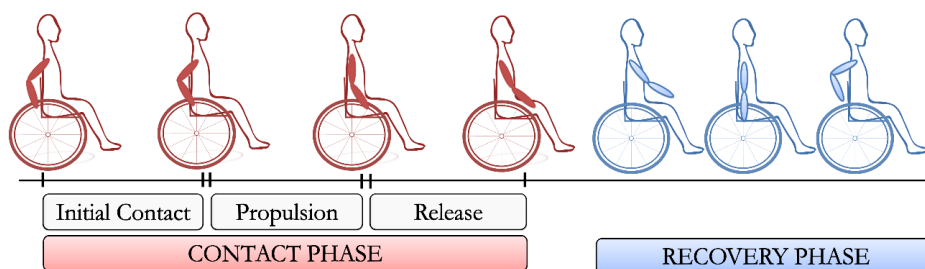

Figure 2. Propulsion cycle. Source: Elaborated by the author.

During the initial contact and release periods, braking times occur due to a non-propulsive moment between the hand and the propulsion rim (Kwarciak et al., 2009a). According to the results of the study, 70% and 88% of all impulses in the initial contact period were identified as braking moments at speeds of 1.08 m/s and 1.74 m/s, respectively (Kwarciak et al., 2009a). At both speeds during the release period, 43% and 63% of all impulses were identified as braking moments, respectively. These data show that the loss of power and the increase in the braking moment occur as the impulse speed increases during the initial contact and release periods. Therefore, when performing propulsion training, the professionals need to consider the magnitude of the speed in the periods of the non-propulsive moment of the hand (Kwarciak et al., 2009a).

The type of propulsion pattern used by the user can change the braking moment and the power loss (Kwarciak et al., 2009a). The propulsion pattern in which the hand is below the rim during the recovery phase has a lower magnitude of the braking moment and loss of power during the initial contact period when compared to the propulsion pattern with the hand positioned above the rim. The application of force during the propulsion cycle can be hindered by the reduction of braking moments and loss of power in the initial contract period (Kwarciak et al., 2009a). Therefore, MWC

users should be encouraged to use the propulsion pattern in which their hands are below the rim during the recovery phase.

Several studies describe four propulsion patterns performed by MWC users: semicircular; single looping (SLOP); double looping (DLOP) and arch. On the one hand, in the semicircular pattern, the hands create a path below the rim during the recovery phase. On the other hand, in the SLOP pattern, the hand path forms a single loop above the rim. In the DLOP pattern, after the contact phase, the hands rise and subsequently fall, forming two loops, ending the propulsion cycle (Shimada et al., 1998). And, finally, in the arch pattern, during the recovery phase, the hand returns to the rim by the same path performed in the contact phase (Boninger et al., 2002) (Figure 3).
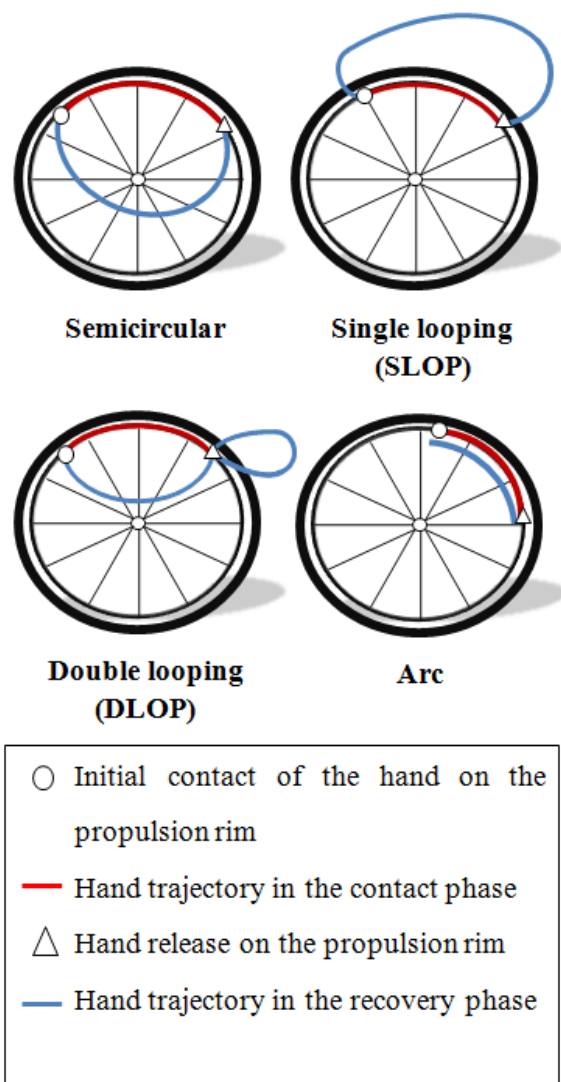

Semicircular

Single looping (SLOP)

Double looping (DLOP)

Arc

○ Initial contact of the hand on the propulsion rim

— Hand trajectory in the contact phase

△ Hand release on the propulsion rim

— Hand trajectory in the recovery phase

Figure 3. Propulsion patterns. Source: Elaborated by the author.

The SLOP standard is used preferentially by MWC users over other propulsion patterns (Raina et al., 2012). These data corroborate the results found by Boninger et al. (2002) since participants with paraplegia also used, preferably, the SLOP pattern. However, the semicircular pattern is the most efficient among the propulsion patterns, since the user performs fewer movements to propel the MWC (Boninger et al., 2002). The instant the user's hand comes into contact with the rim to initiate the contact phase, several reaction forces are generated directed to the ULs. Based on this perspective, the semicircular pattern provides fewer impulses in the rim, and, consequently, fewer forces are directed to the UL. The bow pattern is considered the least efficient since the user will need to push several times to reach the same distance, increasing the risk of pain and injury in the upper limbs due to the excessive movement of upper limbs (Boninger et al., 2002).

During the propulsion, several directional forces are generated as the hand comes into contact with the propulsion rim: Fx (anterior/posterior force), Fy (upper/lower force), and Fz (medial/lateral force) (Cooper, 2009) (Figure 4). The speed of the hand before the contact with the propulsion rim in the recovery phase is correlated with the reaction force in the tangential direction (between the anterior Fx and lateral Fz), also called effective force (Raina et al., 2012). The increase in the magnitude of the Fx (tangential) of users with paraplegia during the contact phase is associated with an increase in the speed of the upper limbs in the recovery phase compared to participants with quadriplegia. However, no correlation was found between the reaction force and the propulsion patterns (Raina et al., 2012).
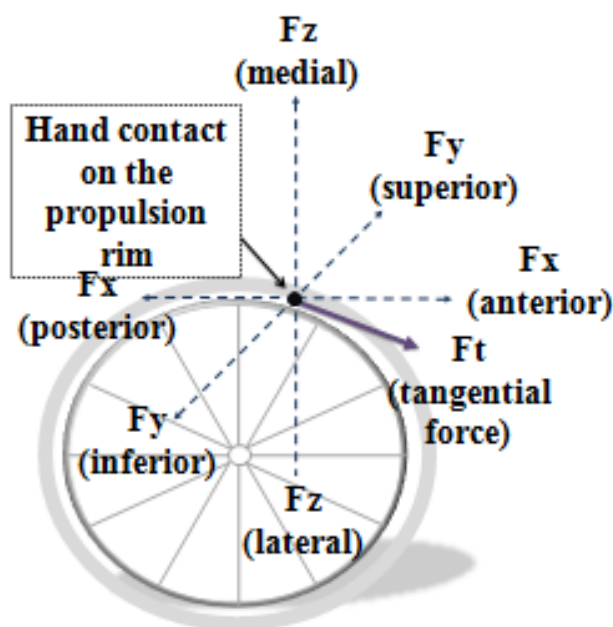

Figure 4. Reaction forces during propulsion in a manual wheelchair. Source: Elaborated by the author.

These data indicate that the speed of the UL is an important factor when the hand comes into contact with the rim again. However, when forces are applied in other directions during propulsion, as in the anterior direction, for example, the reaction forces are generated in the posterior direction, causing an impact on the structures of the upper limbs. Thus, professionals must understand the user's perception of the ULs requirement associated with the magnitude of the speed during the recovery phase.

The increase in the contact angle promotes propulsion with long, smooth movements that maximize the contact time and decrease the reaction forces applied to the rim, minimizing the load and reaction forces on the shoulder (Boninger et al., 2000). However, it is essential to understand where the hand is on the rim during the initial contact and release periods. Both the most posterior initial contact angle (PCA) and the most anterior release angle (ARA) of the hand are associated with a reduced cadence and with an increase in the distance between the beginning of each propulsion cycle (Requejo et al., 2015). Also, the PCA increases the demand for mm. shoulder flexors, while ARA increases the demand for mm. internal adductors and rotators (Requejo et al., 2015).

The increase in joint forces and moments of abduction and internal rotation of the shoulder may favor the appearance of adaptive thickening of the coracoacromial ligament and pain in the shoulder region (Mercer et al., 2006). According to data from Requejo et al. (2015), this condition is associated with ARA. Therefore, to maximize the propulsion angle, it is recommended that users make an initial contact more posterior to the propulsion rim instead of making a hand contact more anteriorly.

According to the Organização Mundial da Saúde (2012), services offering wheelchairs must follow 8 sequential steps: 1) Referral and scheduling; 2) Evaluation; 3) Prescription and selection; 4) Financing and acquisition; 5) Preparation of the product; 6) Adequacy; 7) User training; and 8) Maintenance, repairs, and monitoring. The evidence presented and discussed on cycle and propulsion patterns can be the clinical practice at the user training stage. Thus, based on cycle factors and propulsion patterns, the occupational therapists should give practice and postural adequacy services to conduct propulsion training, maximizing the function of the upper limbs and, consequently, promoting functional mobility in the ADLs.

MWC users commonly report pain in the upper limbs, with the shoulder being the most affected region, followed by the wrist and hand (Cooper et al., 1998). Studies demonstrate that MWC users are at high risk of injury to the coracoacromial arch (Mercer et al., 2006) and the median nerve (Boninger et al., 1999). Propulsion patterns characterized by repetitive movements, such as the SLOP pattern, are one of the main causes. The movements of the SLOP pattern appear to be the most spontaneous way of propelling MWC by users (Boninger et al., 1999). Thus, therapists need to keep in mind that changing the propulsion pattern with appropriate movements is a time-consuming process since certain movements become habits because they are performed repeatedly in the user's daily life.

4.2 Manual wheelchair settings

The use of the low backrest (adjusted to 50% of the trunk length) can provide longer thrust times, reduced cadence, and increased propulsion cycle angles (Yang et al., 2012). A later initial hand contact to the rim and a further recovery of the hand results in greater thrust angles during the propulsion cycle (Yang et al., 2012). A backrest with a 3° of inclination increases the cadence and the displacement of the initial contact and the recovery of the hand forward during the contact phase (Yang et al., 2012). This condition provides a greater range of shoulder flexion/extension movement and increased forces and moments (Yang et al., 2012).

The use of a low backrest proved to be beneficial for reducing the efforts made by the upper limbs during propulsion in the MWC. However, the use of low backrest can cause more instability and discomfort due to the limitation of dorsal support (Medola et al., 2014). Therefore, when selecting the backrest size during the MWC prescription, professionals should also consider the user's perception of posterior comfort and stability.

Previous studies have shown that other components of the MWC and its inadequate setting may intensely demand the Uls, decreasing the mobility and instability of the MWC user (Medola et al., 2014). Seats positioned far above the rear wheels increase the thrust frequency, increasing the risk of injuries in the upper limbs due to repetitive efforts (Boninger et al., 2000). Also, seats positioned at right angles may cause a greater risk of shoulder pain and injuries in users with paraplegia when compared to the use of seats positioned at an acute angle (Giner-Pascual et al., 2011). To promote propulsion efficiency and lower energy expenditure, the recommendation is to put the seat at a height where the angle of the elbow varies from 100° to 120° when the hand touches the propulsion ring (Van Der Woude et al., 1989).

Like the seat, adjusting the position of the wheels influences the efficiency of the propulsion. The smaller vertical distance between the wheel axle and the shoulder and the advance in the horizontal axle position increase the thrust angle while decreasing the frequency of the propulsion cycles and the rolling friction (Boninger et al., 2000). In other words, the rear wheels at a height that provides greater hand contact with the propulsion rim (X-axis) and in a more advanced way (Y-axis) can promote the efficiency of the propulsion biomechanics due to the reduction of frequent impulses and opposite reaction forces that hinder propulsion (Figure 5). Despite these benefits, the position of the rear wheels more forward causes instability, increasing the risk of turning the MWC back more easily. When indicating adjustments to the position of the rear wheels, it is essential to consider the time of injury and the user's perception of stability.
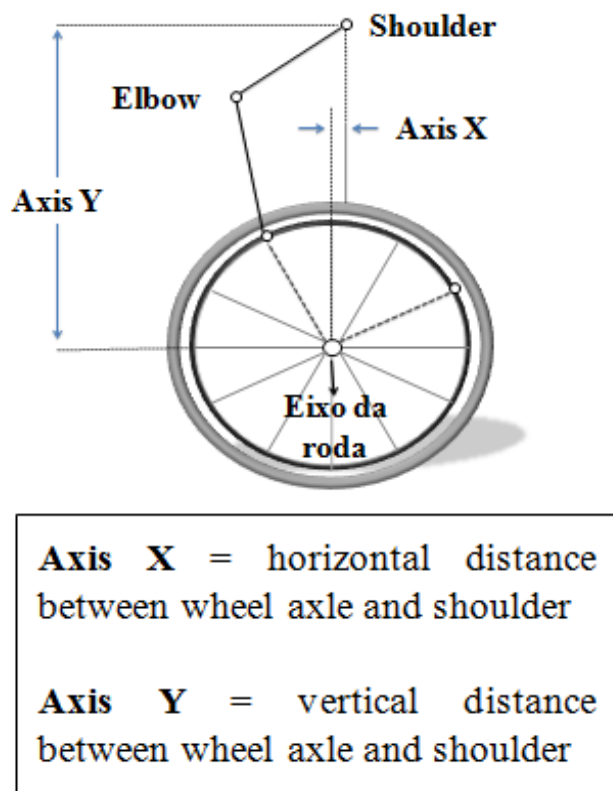
Figure 5. Axis position. Source: Elaborated by the author.

The type of material that of the MWC structure and the type of tire can also affect the efficiency of the propulsion biomechanics (Medola et al., 2014). Studies indicate that users should preferably use an ultralight MWC that has titanium and carbon fiber (Medola et al., 2014). On the one hand, this type of MWC reduces the impacts on the structures of the ULs because they are lighter and more resistant, producing less rolling resistance, that is, decreasing the forces that oppose propelling the MWC (Cooper et al., 1997). On the other hand, MWCs made of aluminum are heavier and, consequently demand more from the ULs during propulsion (Cooper et al., 1997). Pneumatic tires also produce less rolling resistance compared to solid tires (Kwarciak et al., 2009b). Thus, pneumatic tires reduce the risk of pain and injury due to repetitive efforts, due to the reduction in the frequency of impulses and the reaction forces generated to the ULs.

The setting process of the wheelchair also called the adequacy stage, is carried out by the services offering an MWC. This stage is essential to grant users a safe and comfortable propulsion cycle, reducing the risk of falls and pain and injuries in the upper limbs (Organização Mundial da Saúde, 2012). Therefore, the occupational therapist performs the posture adjustment and checks the size, type of material, and adjustments of the MWC components, according to the user's needs.

Studies have shown that backrest size is a factor related to propulsion efficiency. Other factors can also influence propulsion such as the position of the rear wheels

according to the user's shoulder and the selection of the type of material of the MWC. Despite the evidence presented and discussed in the article, it is essential to consider the opinion and needs of users when configuring the wheelchair. When using a low backrest and the rear wheels far ahead, the user may experience discomfort and fatigue due to reduced back support and instability during propulsion, increasing the risk of falls. Furthermore, an ultralight MWC, the strongest and lightest device on the market, is not available to be dispensed by public health services. Therefore, the professionals need to configure the components of the MWC to promote propulsion efficiently, considering the opinion of users and family members/caregivers about it.

4.3 Characteristics of the manual wheelchair user

Bodyweight is a factor that can increase shoulder strength and moments during propulsion (Collinger et al., 2008). Shoulder forces and moments increase with increasing propulsion speed. In the contact phase, the posterior Fx is the largest component of the directional force, while the internal rotation moment is the largest component of the directional moment (Collinger et al., 2008). Maximum joint strength occurs near the beginning of the contact phase, while the shoulder is extended, abducted and internally rotated (Collinger et al., 2008)

Overweight can increase rolling resistance, and it is necessary to generate more force during propulsion. In this way, UL structures are highly demanded due to the constant frequency of impulses and, consequently, users are more susceptible to median nerve injuries and the development of compressions, such as carpal tunnel syndrome (Boninger et al., 1999).

Like body weight, the user's height also influences propulsion efficiency. The vertical distance between the axis of the MWC and the shoulder can decrease or increase according to the height, that is, the higher the user, the farther from the propulsion rim he will be, and therefore, the shorter the propulsive cycle (Boninger et al., 2000). In this way, professionals must adjust the axles (horizontal and vertical) and the MWC seat appropriately with the height and length of the user's arm, bringing it closer to the propulsion rim.

During the physical evaluation, the occupational therapist performs anthropometric measurements to select the wheelchair available on the market according to the user's measurements (Organização Mundial da Saúde, 2012). Thus, one or two trained professionals with knowledge of how and which places of the body should be measured are needed (Organização Mundial da Saúde, 2012). It is also essential for the user to try the MWC not to run the risk of acquiring it with a size that is not following his body measurements. The use of an inadequately sized MWC can not only affect propulsion efficiency but can also increase the risk of pressure ulcers/injuries and even cause the user to abandon the device.

4.4 Pains and injuries in the upper limbs

The level of daily activity was a factor related to shoulder pain. According to the study by Mulroy et al. (2015), participants who developed shoulder pain had a lower daily speed level (2.4 km/h) than participants who remained pain-free (2.8 km/h).

We also found that the moment of shoulder adduction is initially related as a predictor of pain onset. However, it represented only 7.5% of the onset of shoulder pain. Although strong predictors were not found, there was a correlation between shoulder pain and decreased daily activities and the strength of the adductor muscle of the shoulder in paraplegics (Mulroy et al., 2015).

The increase in shoulder forces and moments in all directions is related to delayed propulsion during a task of high intensity (Gil-Agudo et al., 2014). It also can favor an increase in the thickness of the tendon of the long head of the mm. brachial biceps and decreased subacromial space (Gil-Agudo et al., 2014). These results showed that high-speed propulsion requires more effort from the upper limbs, increasing the predisposition to the development of pain and injury (Gil-Agudo et al., 2014).

Impacts on the shoulder can also occur in early propulsion during high-intensity activity (Gil-Agudo et al., 2015). The shoulder moments increase in all directions, except for lateral Fx, as well as the abduction and shoulder extension moments. Also, shoulder pain may be associated with an enlarged tendon of the long head of the mm. brachial biceps (Gil-Agudo et al., 2015).

The positions of the ULs lead to different magnitudes of shoulder moments in the same propulsion condition (Russell et al., 2015). The magnitude of the shoulder moment depends on the forces generated on the mass center (MC) of the forearm and arm (Russell et al., 2015). According to the author, during the propulsion of 1.72 m/s, in which the reaction force (60 N) was previously oriented to the MC of the forearm and arm associated with the elbow extensor moment, there was a reduction in the magnitude of the shoulder moment (13 Nm). In contrast, in the propulsion condition of 1.82 m/s, in which the reaction force (54 N) was oriented posteriorly to the forearm and arm MC associated with the elbow flexor moment, there was an increase in the magnitude of the shoulder moment (27 Nm) (Russell et al., 2015). The two examples indicate that the magnitude of the shoulder moment does not necessarily correspond to the propulsion speed, but can be reduced or increased through moments of flexion or elbow extension associated with the reaction forces in the anterior and posterior direction on the forearm and arm MC.

Gil-Agudo et al. (2014, 2015) showed results similar to previous studies (Mercer et al., 2006; Collinger et al., 2008) with associations that are more prone to the appearance of pain and injuries with increased strength and shoulder moments after the participants performed rapid propulsion. Russell et al. (2015) also demonstrated that the orientation of the reaction forces associated with the elbow moments in the forearm and arm MC is essential to decrease the forces directed at the shoulder. During high-speed propulsion, the reorientation of the reaction forces, generated by the position of the upper limbs concerning the forearm and arm MC has been shown to attenuate the forces directed at the shoulder.

In contrast to previous studies, Rice et al. (2009) showed that the participants who performed a long and high-speed task (1.4 m/s) stayed longer in the contact phase, while the reaction forces decreased during the propulsion and also did not demonstrate the inefficiency of the propulsion. The users' experience (average of 20 years of injury) can be a factor that contributes to adaptations in the biomechanics of the propulsion cycle, which reduces the requirement for intense movements of the upper limbs, favoring the efficiency of the propulsion during the task.

The propulsion in the MWC requires the movement of ULs to promote functional mobility. MWC users with SCI commonly report shoulder pain that affects the function of the upper limb during propulsion (Requejo et al., 2008). A study shows that factors such as intense activities, which require repetitive movements, and certain movement patterns during the propulsion cycle can increase the risk of shoulder pain and injury and also impair propulsion efficiency. Therefore, it is up to occupational therapists to advise on the proper movements during the propulsion cycle, preventing the risk of pain and injury to the shoulders. It is also necessary to emphasize that the user's posture and the setting of the MWC components are also fundamental factors to prevent the UL function. Therefore, all the factors mentioned must be considered together to carry out the propulsion in the MWC with greater efficiency.

5 Conclusion

This integrative literature review provided evidence on factors related to the propulsion efficiency of individuals with paraplegia due to SCI. The results indicated that factors such as cycle and propulsion patterns, MWC settings, user characteristics, and pain and injury in upper limbs are related to the efficiency of propulsion in the MWC of users with paraplegia due to SCI.

Although the studies included in this review were important contributions to clinical practice, most of them used the case series study design, configuring them as level IV of evidence. Therefore, we suggest future investigations with other types of study designs such as longitudinal and comparative studies to produce scientific knowledge with higher levels of evidence.

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