Consistency of the within cycle torque distribution pattern during hand cycling: a pilot study

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Introduction

Hand cycling has become increasingly popular, allowing for a greater mobility and for more sports opportunities for wheelchair users. Demonstrated benefits of hand cycling compared to hand rim wheelchair propulsion include a more efficient use of the trunk and arm muscles, reducing the physical strain on the wrists, elbows and shoulders. In addition, no coupling action of the hands to the propulsion system is required during hand cycling, and therefore the movement pattern is more continuous and less technical (Van der Woude et al., 2000).

Research regarding biomechanical and physiological aspects of hand cycling is limited to studies evaluating the energetic cost. Janssen et al. (2001) evaluated physical capacity and race performance of 16 male wheelchair users and concluded that hand cycling is well suited for aerobic training. Verellen et al. (2004) investigated the influence of different cadence strategies in hand cycling and found that during hand cycling the freely chosen crank rate is not necessarily the optimal one, that producing a given power output (PO) using high crank rates is less efficient and that the freely chosen crank rate has a tendency to increase at higher PO levels. Dallmeijer et al. (2004) showed that gross mechanical efficiency during hand cycling on a treadmill was superior to hand rim wheelchair propulsion at similar PO levels. In agreement, Mukherjee et al. (2001) reported lower physiological responses during hand cycling compared to hand rim wheelchair propulsion in 34 experienced wheelchair users. Other studies have focused on comparing asynchronous and synchronous cranking during hand cycling. Van der Woude et al. (2000) reported higher ME values during synchronous compared to asynchronous hand cycling. As well, Abel et al. (2003) found lower VO2 and heart rate (HR) values at submaximal exercise, and a higher maximal workload during synchronous hand cycling in 35 athletes with spinal cord injury (SCI).

However, several determinants that affect performance during hand cycling have not yet been addressed at present. No data are available with regards to the mechanical and ergonomic optimization of the hand cycle-user interface. As well, to the author’s knowledge no studies have been conducted that measured and analyzed the movement pattern and the force generation strategies during hand cycling. Such data can be important to further optimize hand cycling from a performance as well as a health perspective. The first step in understanding the force generation pattern in hand cycling is to get insight in its consistency. Intra-individual...
consistency is warranted to address causal relationships between force generation strategies and performance (e.g. anaerobic power) or health (e.g. repetitive strain injuries) related aspects. Therefore, the purpose of this exploratory study was to measure the torque applied on the arm cranks during hand cycling and to evaluate the consistency of the within cycle torque distribution (1) in subsequent cycles at a constant PO, (2) between different PO levels, and (3) with respect to time at a submaximal PO level.

Methods

• Participants
Two male participants, age 24 and 29, one able-bodied and one with a complete spinal cord injury (SCI; lesion level Th5-Th6) agreed to participate in this study. Both were active and experienced wheelchair users. The participants were informed and gave their consent prior to testing.

• Equipment
All the tests were performed using a wheelchair (Quickie, Sunrise Medical, Nieuwegein, The Netherlands) to which a hand cycle unit (Stricker, Double Performance, Gouda, The Netherlands) was attached. The hand cycle unit was connected to a computer controlled motor via a system of chains and cog-wheels (Picture 1). This system allowed for precise PO adjustments and recorded at every millisecond the position of the arm cranks with respect to time. Consequently, it was possible to calculate crank rate to the nearest 1 rpm (revolutions per minute) and the torque applied during hand cycling.

• Procedure
Both participants performed a 5 min hand cycling test at 5 Watts (W), and two 4 min tests at 10 and 20 W respectively at a freely chosen crank rate. Exercise tests were separated by a resting period of at least 5 min. Based on heart rate, lactate concentration and ratings of perceived exertion (RPE) that were measured during these tests, a submaximal PO level for both participants was estimated. This PO level was equivalent to an effort of an RPE score of 15 and assured exhaustion within 20 minutes. After a resting period of at least 10 min, participants were instructed to crank at this PO level until exhaustion. Heart rate was monitored with a Polar Accurex Plus (Polar, Finland). Lactate concentration was measured using a blood lactate test meter (Lactate Pro, Arkray, Japan). Perceived exertion was evaluated with a Borg-scale (Borg, 1998). Crank rate, position and torque were recorded every minute during 10 sec by the cycle ergometer system. With respect to the torque values, each of the cycles was divided into 24 segments of 15 degrees. This way, all data were reduced to 24 segmental torque values per cycle.

• Statistical Analysis
To evaluate the consistency of the within cycle torque distribution in subsequent cycles with a constant PO (purpose 1), variation coefficients were calculated from the segmental torque values of the 10 sec measurement. The 24 coefficients were reduced to one average variation coefficient as an indicator of the consistency in subsequent cycles. To evaluate the consistency of the within cycle torque distribution between different PO levels (purpose 2) and over time at submaximal PO level (purpose 3), one averaged propulsion cycle was calculated per 10 sec measurement. Again variation coefficients between PO levels and over time at submaximal PO level were calculated and averaged.

Results

Torque values with respect to the crank position are shown in figures 1-3. The X-axis represents the crank angle counting down from 360 degrees in the cranking direction. The Y-axis displays the torque values.
Figure 2: Within cycle torque generation pattern for subsequent cycles for participant A with SCI (top) and participant B (able-bodied - bottom); cycling direction was clockwise.

Figure 3: Within cycle torque generation pattern at different PO levels for participant A with SCI (left) and participant B (able-bodied - right); cycling direction was clockwise.

Figure 4: Within cycle torque generation pattern over time for participant A with SCI (left) and participant B (able-bodied - right); cycling direction was clockwise.
The variation coefficients that were calculated to evaluate the consistency of the force pattern during hand cycling are shown in table 1. All coefficients range from 3.58% to 9.42% regarding subsequent cycles, from 5.27% to 6.20% between different PO levels, and from 5.06 to 5.45% over time at submaximal PO.

<table>
<thead>
<tr>
<th>VC</th>
<th>A (SCI)</th>
<th>B (AB)</th>
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<tbody>
<tr>
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<tr>
<td>5W</td>
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</tr>
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<td>3.81%</td>
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<td>6.20%</td>
</tr>
<tr>
<td>VC time</td>
<td>5.06%</td>
<td>5.45%</td>
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Table 1: Variation coefficients (VC) for subsequent cycles, for different PO levels and with respect to time for participant A with SCI and participant B (able-bodied: AB)

Discussion

The purpose of this study was to evaluate the consistency of the within torque distribution pattern during hand cycling with respect to subsequent cycles, with respect to different PO levels and over time at submaximal PO. With respect to subsequent cycles, the variation coefficients that were calculated suggest a consistent force generation pattern. The minimal differences that occur are higher at lower PO levels, and are likely to be the result of variables such as postural changes. As well, low PO levels require a low force generation, and the authors assume that at such low intensity levels, a defined pattern is of less importance.

Variation coefficients with respect to different PO levels were low (5.27% and 6.20% for participant A and B respectively), indicating that the force generation pattern is consistent and minimally influenced by the exercise intensity. Moreover, the pattern for subject A, who is more experienced in hand cycling, was more consistent than for subject B. In agreement, Marsh et al. (1993) suggested that cycling cadence in experienced cyclists is more consistent and less likely to be influenced by changes in PO. Future studies with more participants of varying experience levels are needed to support these findings.

The results of this study also indicate that the torque pattern is consistent over time at a constant submaximal PO. Variation coefficients were 5.06% and 5.45%, suggesting that the pattern is minimally affected by fatigue. The graphics however show a tendency that crank rates for both participants increase over time. Although the pattern remains similar, the torque values become smaller indicating faster crank rates (Figure 3). These findings are in line with previous investigations on cycling (Coast et al., 1985), arm crank ergometry (Smith et al., 2001), and hand cycling (Verellen et al, 2004). A sustained effort at a submaximal PO level as conducted in the present study leads to fatigue and finally, to exhaustion. This fatigue has a neuromuscular origin, and can be counteracted by increasing the crank rate, consequently delaying exhaustion.

There remain a number of considerations that need to be taken into account. The materials used in this study only allowed measuring the torque at the crank axis. It can be assumed that during hand cycling several force components are generated at the crank handles, in multiple directions as well as in multiple time phases. Therefore, a more thorough force generation analysis based on a 3 dimensional force registration at the crank handles would provide useful additional information. Moreover, combining force generation analysis and inverse dynamic modeling with EMG measurements, can provide a better insight in the prevalence and the prevention of wheelchair related shoulder, wrist and elbow injuries.

Conclusion

The results of this study suggest that there is a consistent within cycle torque distribution pattern for subsequent cycles during hand cycling, and that this pattern is minimally influenced by factors such as varying PO levels and fatigue. More in-depth studies are now necessary to further investigate these distribution patterns.
patterns, to evaluate inter-individual consistency of the within cycle torque generation pattern, and to interpret the torque applied during hand cycling.

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References


Konsistenz der Entstehungsmuster des Drehmoments per Zyklus beim hand cycling: Eine Pilotstudie

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Abstract

Die Forschung auf dem Gebiet des Hand Cycling (Handradfahren) ist auf Studien beschränkt, die sich mit der Analyse physiologischer Reaktionen, der Auswertung der höheren Effizienz im Vergleich zu anderen Antriebsmechanismen des Arms und dem Vergleich der unterschiedlichen Drehstrategien beschäftigen. Ziel dieser Pilotstudie war es, das Drehmoment zu messen, das auf die Drehbewegungen beim Hand Cycling angewendet wird, und die Konsistenz der Drehmomentverteilung per Zyklus auszuwerten; und zwar (1) in aufeinander folgenden Zyklen mit einer konstanten Leistung, (2) zwischen den unterschiedlichen Leistungsniveaus, und (3) im Hinblick auf Ermüdung bei einem submaximalen Leistungsniveau. Zwei Testpersonen führten eine Reihe von Hand-Cycling-Tests auf unterschiedlichen Leistungsniveaus und einen submaximalen Test bis zur Erschöpfung durch. Variationskoeffizienten wurden berechnet, um die Konsistenz des Kraftverteilungsmusters zu ermitteln; die Werte variierten dabei von 3,58% bis 9,42% bei den aufeinander folgenden Zyklen, von 5,27% bis 6,20% bei den unterschiedlichen Leistungsniveaus und von 5,06% bis 5,45% beim submaximalen Test bis zur Erschöpfung. Diese Ergebnisse weisen daraufhin, dass das Verteilungsmuster des Drehmoments per Zyklus bei aufeinander folgenden Zyklen konsistent ist und dass dieses Muster nur minimal von Faktoren wie variierenden Leistungsniveaus und Erschöpfung beeinflusst wird.
Stabilité du modèle de génération de couple au sein d'un cycle durant le pédalage manuel: une étude pilote

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Abstract

La recherche en matière de pédalage manuel se limite à des études qui analysent les réponses physiologiques, évaluent son efficacité supérieure par rapport à d'autres mécanismes à propulsion manuelle et comparent différentes stratégies de manivelle. L'objectif de cette étude pilote est de mesurer le couple appliqué sur les manivelles durant le pédalage manuel et à évaluer la stabilité de la répartition du couple au sein d'un cycle (1) dans les cycles ultérieurs avec une puissance fournie (PF) constante ; (2) entre différents niveaux de PF et (3) par rapport à la fatigue à un niveau de PF sous-maximal. Deux participants ont été soumis à un certain nombre de tests de pédalage manuel à différents niveaux de PF et à un test sous-maximal jusqu'à épuisement. Les coefficients de variation ont été calculés pour évaluer la stabilité du modèle de répartition de la force. Les résultats ont varié de 3,58% à 9,42% pour les cycles ultérieurs, de 5,27% à 6,20% entre les différents niveaux de PF et de 5,06% à 5,45% dans le test sous-maximal jusqu'à épuisement. Ces résultats révèlent que le modèle de répartition du couple au sein d'un cycle est stable pour les cycles ultérieurs et que ce modèle est minimalement influencé par des facteurs tels que la variation des niveaux de PF et la fatigue.
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Abstract

Research regarding hand cycling is limited to studies analyzing physiological responses, evaluating its higher efficiency compared to other arm propulsion mechanisms, and comparing different crank strategies. The purpose of this pilot study was to measure the torque applied on the cranks during hand cycling and to evaluate the consistency of the within cycle torque distribution (1) in subsequent cycles with a constant power output (PO); (2) between different PO levels; and (3) with respect to fatigue at a submaximal PO level. Two participants performed a number of hand cycling tests at different PO levels, and one submaximal test until exhaustion. Variation coefficients were calculated to evaluate the consistency of the within cycle torque distribution pattern, and ranged from 3.58% to 9.42% regarding subsequent cycles; from 5.27% to 6.20% between different PO levels; and from 5.06 to 5.45% in the submaximal test until exhaustion. These results suggest that the within cycle torque distribution pattern is consistent for subsequent cycles, and that this pattern is minimally influenced by factors such as varying PO levels and fatigue.