Desporto e Atividade Física para Todos – Revista Científica da FPDD, 2015
Vol. 1, N.º 1, ISSN 2183-9603

Handbiking - A Low Metabolic Cost of Locomotion for Spinal Cord Injured People

Handbiking - Um Meio de Locomoção de Baixo Custo Metabólico para Pessoas com Lesões da Medula Espinal

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Abstract

The purpose of this study was to compare aerobic speeds of progression, cardiorespiratory responses and metabolic cost between trained individuals with tetraplegia and paraplegia riding modern handbikes in ecological conditions. Fifteen trained-handbikers, with history of traumatic tetraplegia (n=4) and paraplegia (n=11) rode their handbikes on an athletics track at sub-maximal aerobic speeds under metabolic measurements (K4b2). Independent-sample *t* test showed significant differences between speeds (tetraplegics 4.70±0.72 ms^{-1} *versus* paraplegics 6.41±1.07 ms^{-1}; p=0.012) and cardiorespiratory responses (tetraplegics 15.9±3.6 $mLkg^{-1}min^{-1}$ *versus* paraplegics 23.4±3.5 $mLkg^{-1}min^{-1}$; p=0.003). Submaximal aerobic speeds and cardiorespiratory responses were lower in tetraplegics. However, a low and similar metabolic cost (around 1 $Jkg^{-1}m^{-1}$) was observed in both tetraplegic and paraplegic riding modern handbikes.

Keywords: Handbike, locomotion economy, disabled persons

Resumo

O objetivo do presente estudo foi comparar as velocidades de progressão submáximas, as respostas cardiorrespiratórias e o custo metabólico entre indivíduos treinados com tetraplegia e paraplegia pedalando handbikes modernas em condições ecológicas. Quinze handbikers treinados, com histórico de tetraplegia (n=4) e paraplegia (n=11) pedalaram suas handbikes na pista de atletismo em velocidades submáximas sob o registro de variáveis metabólicas (K4b2). O teste *t* para amostras independentes apontou diferenças significativas entre as velocidades (tetraplégicos 4.70±0.72 ms^{-1} *versus* paraplégicos 6.41±1.07 ms^{-1}; p=0.012) e entre as respostas cardiorrespiratórias (tetraplégicos 15.9±3.6 $mLkg^{-1}min^{-1}$ *versus* paraplégicos 23.4±3.5 $mLkg^{-1}min^{-1}$; p=0.003). As velocidades submáximas e as respostas cardiorrespiratórias foram menores nos tetraplégicos. Contudo, um baixo e similar custo metabólico (em torno de 1 $Jkg^{-1}m^{-1}$) foi observado em ambos tetraplégicos e paraplégicos pedalando handbikes modernas.

Palavras-Chave: Handbike, economica de locomoção, pessoas com deficiência.

Introduction

Handbiking (HB) or Handcycling is a form of adapted cycling, practiced by disabled people using exclusively upper body (Lovel et al., 2012). For people with spinal cord injury, HB is commonly used in rehabilitation programs, recreational activities (Hettinga et al., 2010) and competitions (Fischer et al., 2015). The modern handbikes have been allowing handbikers to travel for longer distances, for an extended duration and at higher speeds than handrim wheelchair riders (Dallmeijer et al., 2004). However, little is presently known about the bioenergetical responses of people with spinal cord injury riding modern handbikes in ecological conditions.

Most people with a spinal cord injury, and especially those with a high lesion, have a very low fitness (Valent et al., 2009). Indeed, upper body power output and oxygen consumption, as well as cardiac output and catecholamine response to exercise are typically reduced compare to individuals with paraplegia (Schmid et al., 1998; Theisen, 2012). In addition, shoulder pain appears to be more common in tetraplegics due to repetitive applied forces during wheelchair handrim propulsion (Curtis et al., 1999). In HB competitions (e.g. Paralympic Games) athletes who present limited function in hands and arms, such as tetraplegics, are classified as H1 and H2, while those presenting poor to good trunk control are included in H3 and H4 classes. H5 class includes those that have excellent trunk balance (UCI, 2015).

It is well established that handbike propulsion (considering also arm crank ergometer) is energetically more efficient and mechanically less straining than wheelchair handrim propulsion (Arnet et al., 2012; Dallmeijer et al., 2004; Mukherjee & Samanta 2001; Tropp et al., 1997; van der Woude et al., 2006). This is explained mainly by the continuous arm motion, power transfer and a more efficient muscle use during handbike propulsion (Dallmeijer et al., 2004; DeCoster et al., 1999; Janssen et al., 2001). Therefore, we suppose that even people with more severe impairments are able to handcycle with a high economy of locomotion. Metabolic cost (C) is considered the key index of the ’economy’ of locomotion (economy=reciprocal of metabolic cost, Minetti, 2004) and allows comparison among different types of locomotion under different conditions (e.g., speed of progression).

Few studies (Maki et al., 1995; Mukherjee & Samanta, 2001) have calculated the metabolic cost of HB in ecological conditions. Despite a more realistic approach of dynamic characteristics, such as stability and maneuverability, these studies were performed with large and heavy old frames handbikes. Furthermore, they did not assess bioenergetics of HB in people with tetraplegia. Therefore, the purpose of this study was to compare aerobic speeds of progression, cardiorespiratory responses and metabolic cost between trained individuals with tetraplegia and paraplegia riding modern handbikes in ecological conditions. It was hypothesized that, tetraplegics would ride the handbikes at lower speeds than paraplegics, but with similar metabolic cost.

Methodology

Participants

Fifteen trained-handbikers, with history of traumatic tetraplegia (n=4; spinal cord injury to the cervical segments C6/C7) and paraplegia (n=11; spinal cord injury between thoracic and lumbar segments T4 – L1), volunteered to participate in this study. Two participants were female (tetraplegia n=1; paraplegia n=1). All participants were wheelchair dependent for their routine ambulation. Participants’ characteristics are showed in Table 1. Selection criteria for participation were: (i) age between 18-58 years, (ii) At least 6 months of experience in HB races (iii) absence of any health problem that contraindicate exercise testing. The study was approved by the University of Verona Ethics Committee and conformed to the standards set by the Declaration of Helsinki. Written informed consent was obtained from all participants.

Handbikes

Each participant used his/her own rigid-frame handbike, with a synchronous crank system, to perform the tests. All handbikes were recumbent models. The tyre pressure was controlled to 8 bars. Handbikes’ mass are showed in Table 1.

Procedures

Participants were asked to ride their handbikes on an athletics track at sub-maximal aerobic speeds under cardiorespiratory monitoring. The target speed was defined based on each participant usual 30-40 km race average speed. Three more speeds, 2, 4 and 6 km h^{-1} lower than the target speed, were further performed randomly. This procedure allowed guaranteeing aerobic and submaximal speeds to each participant. Gear and arm cranking frequency were freely chosen. Each handbike was equipped with a GPS receiver (Edge 305, Garmin, Olathe, USA) allowing participants to control target speed as constant as possible. A rest in-between trials was administered until oxygen consumption returned to the rest value. All tests were performed at the same time of day and in the absence of wind (27±4 °C air temperature and 757±4 mmHg atmospheric pressure).

Cardiorespiratory and bioenergetic measurements Participants were equipped with a portable telemetric gas analysis system unit (Figure 1) (K4b2, Cosmed, Rome, Italy) for measures of heart rate (HR), minute ventilation (VE), oxygen consumption (VO_2) and respiratory exchange ratio (RER) on a breath-by-breath basis After a 5-min rest, participants started the test at a pre-determined constant aerobic speed for at least 4 min to reach an oxygen consumption steady state. Trials with average RER greater than 1.00 were excluded.

Figure 1. Handbiker equipped with a portable telemetric gas analysis system unit

Metabolic cost of HB (C, J $kg^{-1} m^{-1}$) was obtained from the ratio of metabolic power above resting to speed of progression (Di Prampero, 1986). Metabolic power (E) was calculated according to an empirical function of the RER, to obtain the metabolic equivalent of the oxygen (mL O_2) consumption in J divided by time (s):

$$\dot{E} = (VO_2(4.94 \times RER + 16.04)/60)$$

Statistics

The data were checked for normality using the Shapiro-Wilk test. Descriptive statistics (means±SD) was used to characterize the sample. To verify differences in the studied variables between tetraplegia and paraplegia groups, an independent-sample *t* test was performed in SPSS v20. Linear regressions were also performed in SPSS v20. The level of the statistical significance was set at $p<0.05$.

Results

Participants' characteristics did not differ between groups (Table 1). Submaximal aerobic speeds and cardiorespiratory variables (HR, VE; VO_2) were significantly lower in tetraplegics ($p<0.05$) (Table 2). On the contrary, metabolic cost resulted to be similar between groups ($p>0.05$).

Table 1 - Participants and handbikes' characteristics (means±SD)

Variables	Tetraplegia (n=4)	Paraplegia (n=11)	*p-value*
Age (years)	47±5	44±9	0.911
Body mass (kg)	65.3±14.2	70.5±9.1	0.715
Height (cm)	171.5±10.3	174±5	0.530
Lesion duration (years)	14±6	15±9	0.803
HB experience (years)	5±3	6±6	0.661
HB practice (hours $week^{-1}$)	9.5±0.6	7.7±4	0.421
HB mass (kg)	18.6±2.7	16.8±2.9	0.313

Table 2. *Speed, cardiorespiratory variables, and metabolic cost during HB (means±SD)*

Variables	Tetraplegia (n=4)	Paraplegia (n=11)	*p-value*
Speed (m s^{-1})	4.70±0.72	6.41±1.07	0.012
HR (bpm)	102±9	148±17	0.001
VE (L min^{-1})	44±8	63±16	0.043
RER	0.98±0.05	0.95±0.04	0.266
VO_2 (mL kg^{-1} min^{-1})	15.9±3.6	23.4±3.5	0.003
VO_2 (mL min^{-1})	1074±284	1638±275	0.004
C (J kg^{-1} m^{-1})	1.01±0.17	1.09±0.05	0.425

Notes: HR: heart rate; VE: Minute Ventilation; RER: respiratory exchange ratio; VO2: oxygen consumption; C: metabolic cost

Figure 2 shows metabolic cost over speed for one participant with tetraplegia and for one participant with paraplegia who performed the highest speeds. The best curve fits was found to be curvilinear. Then, we plotted metabolic cost as a function of square speed. The regression analysis showed that metabolic cost increased as a linear function of the squared speed in tetraplegic (y = 0.009x + 0.6563; R^2=0.60, p=0.23) and in paraplegic (y = 0.0073x + 0.5118; R^2=0.83, p=0.088) (Figure 2).

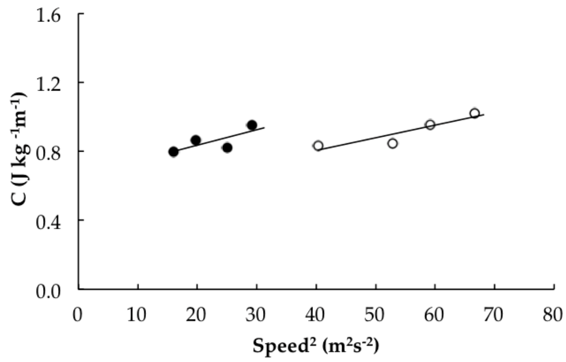

Figure 2. Metabolic cost (C) of HB in one tetraplegic (close circles) and in one paraplegic (open circles) over squared speeds.

Discussion

This study aimed to compare cardiorespiratory responses and metabolic cost between trained individuals with tetraplegia and paraplegia riding modern handbikes in ecological conditions. The main finding was that submaximal aerobic speeds and cardiorespiratory responses were significantly lower in tetraplegics while metabolic cost was similar between groups.

Lower speeds and cardiorespiratory responses were expected in tetraplegics due to less active muscle mass (Figoni, 2003), less strength (Hicks et al., 2003) and impaired sympathetic vascular responses (Mills & Krassioukov, 2011; West et al., 2012). An interrupted sympathetic response might lead to bradycardia and lower ventilation, which could explain our lower values of HR and VE compared to paraplegics during HB. Consequently, VO_2 was also reduced indicating lower tolerance to handcycle at higher speeds. In addition, our results agree with those observed during a 10km HB race performed with attach-unit handbikes. Average race speed and HR were significantly lower in tetraplegics (13.6 kmh^{-1};115 bpm) than in paraplegics (from 19.9 kmh^{-1}; 171bpm) (Janssen et al., 2001). The difference between attach-unit handbikes and rigid-frames handbikes is that the first is more common for recreational and locomotion purposes (Hettinga et al., 2010). In our study, all participants were trained handbikers and performed the tests with a rigid-frame handbike. This suggests that in race condition our subjects probably would attain higher speeds of progression. Indeed, the well-trained athletes who competed in that race with rigid-frames handbikes attained 23.7 kmh^{-1} (tetraplegics) and 34.5 kmh^{-1} (paraplegics) (Janssen et al., 2001).

Despite differences in speed of progression and cardiorespiratory responses, metabolic cost did not differ among groups. Our subjects were able to reach relative high submaximal speeds with metabolic cost values around 1 $Jkg^{-1}m^{-1}$. It also means that HB could be considered a low cost metabolic locomotion even for tetraplegics. For them, HB is easier to perform than handrim wheelchair propulsion. The hands are fixed in pedals with special grips, and forces can be applied continuously over the arm crank improving the economy of movement (Valent et al., 2009). Contrarily, wheelchair propulsion demands more energy to each push (Dallmeijer et al., 2004). Beekman, Miller-Porter and Schoneberger (1999) showed that people with tetraplegia have higher metabolic cost during wheelchair propulsion in ecological conditions than people with paraplegia.

In order to compare our results with those calculated by other studies, we show in Figure 3 the metabolic cost values of different types of locomotion (crutch walking [Thys et al., 1996], wheelchair pushing [Ardigò et al., 2005]), walking and running [Saibene and Minetti, 2003]) as a function of the speed. The two iso-power curves correspond to constant metabolic powers of 5Wkg^{-1} and 11Wkg^{-1}. The diagram shows that for a metabolic power of 5 Wkg^{-1}, for instance, a speed of 2.3ms^{-1} is attained pushing a modern wheelchair, while riding a handbike a speed of about 5.5 ms^{-1} is attained, with the same metabolic demand. This may be because the modern handbikes, differently from wheelchairs, are equipped with gear system (muscle function optimizing tool; Ardigò et al., 2003) and are designed to be lighter and more aerodynamic (van der Woude et al., 2006). Additionally, during HB the arms are in continuous moving and the shoulder muscles activation shows on and off phases (Faupin et al., 2010), while this does not happen when pushing a wheelchair (DeCoster et al., 1999). All these features contribute to increase exercise tolerance and consequently provide additional useful daily metabolic energy expenditure, which could also reduce the risk of cardiovascular diseases in spinal cord injury people (Abel et al., 2003).

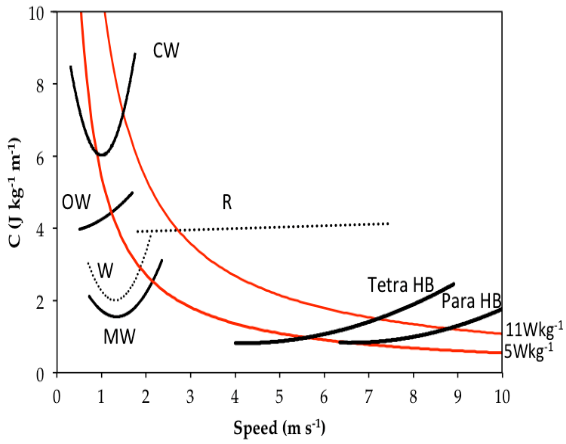

Figure 3. Metabolic cost versus speed curves cross the 2 isopower curves (red) corresponding to constant values metabolic power equal to 5Wkg^{-1} and 11Wkg^{-1} (from bottom to the top). CW: Crutch Walking; OW: Old Wheelchair; W: Walking, R Running, MW Modern Wheelchair; HB Handbike.

Interestingly, the metabolic cost in spinal cord injury people is reduced by half in comparison to the able-bodied walking or by a fourth in comparison to able-bodied running (Saibene and Minetti, 2003). These findings open perspectives for the usage of new technologies with important repercussions on mobility for spinal cord injury people.

Limitations

This study recruited a small sample of trained handbikers, which require caution on results interpretation. Nevertheless, experienced participants and modern handbikes allowed the study to apply ecological methods to assess bioenergetics of HB. Future experiments need to be performed with broader samples considering also disabled athletes of different HB sports classes.

Conclusion

Submaximal aerobic speeds and cardiorespiratory responses were lower in tetraplegics. However, a low and similar metabolic cost was observed in both tetraplegic and paraplegic riding modern handbikes.

References

Abel, T., Kröner, M., Rojas Vega, S., Peters, C., Klose, C., & Platen, P. (2003). Energy expenditure in wheelchair racing and handbiking - a basis for prevention of cardiovascular diseases in those with disabilities. *European Journal of Cardiovascular Prevention and Rehabilitation*, *10*(5), 371–6. http://doi.org/10.1097/01.hjr.0000096542.30533.59

Ardigò, L. P., Saibene, F., & Minetti, A. E. (2003). The optimal locomotion on gradients: walking, running or cycling? *European Journal of Applied Physiology*, *90*(3-4), 365–71. http://doi.org/10.1007/s00421-003-0882-7

Ardigò, L. P., Goosey-Tolfrey, V. L., & Minetti, A. E. (2005). Biomechanics and energetics of basketball wheelchairs evolution. *International Journal of Sports Medicine*, *26*(5), 388–96. http://doi.org/10.1055/s-2004-821316

Arnet, U., van Drongelen, S., Scheel-Sailer, A., Van der Woude, L, & Veeger, D. H. E. J. (2012). Shoulder load during synchronous handcycling and handrim wheelchair propulsion in persons with paraplegia. *Journal of Rehabilitation Medicine : Official Journal of the UEMS European Board of Physical and Rehabilitation Medicine*, *44*(3), 222–8. http://doi.org/10.2340/16501977-0929

Beekman, C. E., Miller-Porter, L., & Schoneberger, M. (1999). Energy cost of propulsion in standard and ultralight wheelchairs in people with spinal cord injuries. *Physical Therapy*, *79*(2), 146–158.

Curtis, K. a., Drysdale, G. a., Lanza, R. D., Kolber, M., Vitolo, R. S., & West, R. (1999). Shoulder pain in wheelchair users with tetraplegia and paraplegia. *Archives of Physical Medicine and Rehabilitation*, *80*(April), 453–457. http://doi.org/10.1016/S0003-9993(99)90285-X

Dallmeijer, a J., Zentgraaff, I. D. B., Zijp, N. I., & van der Woude, L. H. V. (2004). Submaximal physical strain and peak performance in handcycling versus handrim wheelchair propulsion. *Spinal Cord*, *42*(2), 91–8. http://doi.org/10.1038/sj.sc.3101566

DeCoster, A., van Laere, M., & Blondé, W. (1999). Electromyographic activity of shoulder girdle muscles during handbiking. In L. van der Woude, M. Hopman, & C. van Kemenade (Eds.), *Biomedical aspects of manual wheelchair propulsion: The state of the art II.* (pp. 138–40). Amsterdam (the Netherlands): IOS Press.

Di Prampero, P. E. (1986). The energy cost of human locomotion on land and in water. *International Journal of Sports Medicine*, *7*(2), 55–72. http://doi.org/10.1055/s-2008-1025736

Faupin, A., Gorce, P., Watelain, E., Meyer, C., & Thevenon, A. (2010). A biomechanical analysis of handcycling: a case study. *Journal of Applied Biomechanics*, *26*(2), 240–5. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20498497

Figoni, S. F. (2003). Spinal Cord Disabilities: Paraplegia and Tetraplegia. In J. Durstine & G. Moore (Eds.), *ACSM's Exercise Management for Persons with Chronic Diseases and Disabilities* (2° ed., pp. 247–253). Human Kinetics.

Fischer G; Figueiredo P., Ardigò, L.P. (2015). Physiological performance determinants of a 22 km Handbiking time trial. *International Journal of Sports and Physiology Performance*. http://doi.org/http://dx.doi.org/10.1123/ijspp.2014-0429

Hettinga, F. J., Valent, L., Groen, W., van Drongelen, S., de Groot, S., & van der Woude, L. H. V. (2010). Hand-cycling: an active form of wheeled mobility, recreation, and sports. *Physical Medicine and Rehabilitation Clinics of North America*, *21*(1), 127–40. http://doi.org/10.1016/j.pmr.2009.07.010

Hicks, a L., Martin, K. a, Ditor, D. S., Latimer, a E., Craven, C., Bugaresti, J., & McCartney, N. (2003). Long-term exercise training in persons with spinal cord injury: effects on strength, arm ergometry performance and psychological well-being. *Spinal Cord*, *41*, 34–43. http://doi.org/10.1038/sj.sc.3101389

Janssen, T. W., Dallmeijer, A. J., & van der Woude, L. H. (2001). Physical capacity and race performance of handcycle users. *Journal of Rehabilitation Research and Development*, *38*(1), 33–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11322469

Lovell, D., Shields, D., Beck, B., Cuneo, R., & McLellan, C. (2012). The aerobic performance of trained and untrained handcyclists with spinal cord injury. *European Journal of Applied Physiology*, *112*(9), 3431–7. http://doi.org/10.1007/s00421-012-2324-x

Maki, K. C., Langbein, W. E., & Reid-Lokos, C. (1995). Energy cost and locomotive economy of handbike and rowcycle propulsion by persons with spinal cord injury. *Journal of Rehabilitation Research and Development*, *32*(2), 170–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7562657

Mills, P., & Krassioukov, A. (2011). Autonomic function as a missing piece of the classification of paralympic athletes with spinal cord injury. *Spinal Cord*, *49*, 768–776.

Minetti, A. E. (2004). Passive tools for enhancing muscle-driven motion and locomotion. *The Journal of Experimental Biology*, *207*(Pt 8), 1265–72. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15010477

Mukherjee, G., & Samanta, A. (2001). Physiological response to the ambulatory performance of hand-rim and arm-crank propulsion systems. *Journal of Rehabilitation Research and Development*, *38*(4), 391–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11563492

Saibene, F., & Minetti, A. E. (2003). Biomechanical and physiological aspects of legged locomotion in humans. *European Journal of Applied Physiology*, *88*(4-5), 297–316. http://doi.org/10.1007/s00421-002-0654-9

Schmid, A., Huonker, M., Barturen, J. M., Stahl, F., Schmidt-Trucksäss, A., König, D., …..Keul, J. (1998). Catecholamines, heart rate, and oxygen uptake during exercise in persons with spinal cord injury. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *85*(2), 635–41. http://www.ncbi.nlm.nih.gov/pubmed/9688742

Theisen, D. (2012). Cardiovascular determinants of exercise capacity in the Paralympic athlete with spinal cord injury. *Experimental Physiology*, *97*(3), 319–24. http://doi.org/10.1113/expphysiol.2011.063016

Thys, H., Willems, P. A., & Saels, P. (1996). Energy cost, mechanical work and muscular efficiency in swing-through gait with elbow crutches. *Journal of Biomechanics*, *29*(11), 1473–82. http://www.ncbi.nlm.nih.gov/pubmed/8894928

Tropp, H., Samuelsson, K., & Jorfeldt, L. (1997). Power output for wheelchair driving on a treadmill compared with arm crank ergometry. *British Journal of Sports Medicine*, *31*(1), 41–4. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1332474&tool=pmcentrez&rendertype=abstract

UCI Classification Rules and Guide. Retrieved from: http://www.uci.ch/mm/Document/News/NewsGeneral/16/59/20/20140926UCIClassificationRulesandGuide_English.pdf. Accessed in July 2015.

Valent, L. J. M., Dallmeijer, A. J., Houdijk, H., Slootman, H. J., Janssen, T. W., Post, M. W. M., & Woude, L. H. Van Der. (2009). Effects of Hand Cycle Training on Physical Capacity in Individuals With Tetraplegia: A Clinical Trial, *89*(10), 1051–1060.

Van der Woude, L. H. V, de Groot, S., & Janssen, T. W. J. (2006). Manual wheelchairs: Research and innovation in rehabilitation, sports, daily life and health. *Medical Engineering & Physics*, *28*(9), 905–15. http://doi.org/10.1016/j.medengphy.2005.12.001

West, C. R., Mills, P., & Krassioukov, A. V. (2012). Influence of the neurological level of spinal cord injury on cardiovascular outcomes in humans: a meta-analysis. *Spinal Cord*, *50*(7), 484–92. http://doi.org/10.1038/sc.2012.17