Effect of exoskeleton robotic assistance on gait biomechanics among healthy subjects

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1. Introduction

Rehabilitation robots are increasingly developed and used for gait training in neurorehabilitation. Robot-assisted Gait (RAG) follows current guidelines as it increases therapy intensity, trains specific skills and provides assistance-as-needed in function of patients' capabilities. Although RAG shows promising results for gait recovery, little is known about gait biomechanics during the RAG. A previous study, among stroke patients, has analyzed energy consumption during 30 min session with RAG using Lokomat® robot (Lefeber et al. 2018). Oxygen consumption was half as high during RAG compared to 30 min walking without RAG. Authors noted that the intensity of exercise was below exercise recommendations. Some authors have observed less muscle activation during RAG among stroke patients (Androwis et al. 2018), while others showed an increase at higher gait speeds (van Kammen et al. 2020). The aim of this pilot study was to assess the gait of healthy subjects while wearing the exoskeleton robot, to better understand its consequence on mechanic and energetic variables.

2. Methods

2.1. Subjects

Six healthy adults were included in the study. Exclusion criteria were morphological contraindications for the use of Atalante® robot. Subjects were all volunteers and provided written informed consent before freely participating in the study. The study was approved by the ethical board of our faculty of medicine of the Université catholique de Louvain. The trial was registered at ClinicalTrials.gov (NCT05264103).

2.2. Study design

The study took place over two days. The first day, subjects were trained with RAG on firm ground in a hallway designed for gait training. The second day, two quantified gait analysis were performed: first with- and then without RAG.

Figure 1. Illustration of a subject walking with the Atalante® robot on the instrumented treadmill.

2.3. Atalante® robot

The exoskeleton robot Atalante® (Wandercraft) was used in the present study (Figure 1). Atalante® is a self-supporting robot with an adjustable assistance from 0% to 100% (100% corresponding to a maximal

Table 1. Gait variables with- and without RAG.

	Without RAG Median [1st – 3de quartile]	With RAG Median [1st – 3de quartile]	P value
Step length (m)	0.33 [0.31–0.34]	0.16 [0.16–0.16]	<0.001*
Cadence (step min^{-1})	42.2 [40.5–44.01]	84.2 [83.9–85.2]	<0.001*
Wext (J kg^{-1} m^{-1})	0.23 [0.20–0.27]	1.0 [0.87–1.10]	0.031*
Wekf (J kg^{-1} m^{-1})	0.07 [0.07–0.10]	0.16 [0.12–0.18]	0.031*
Wev (J kg^{-1} m^{-1})	0.25 [0.23–0.29]	0.81 [0.73–0.89]	0.031*
Wekl (J kg^{-1} m^{-1})	0.02 [0.01–0.04]	0.17 [0.16–0.19]	0.031*
Recovery (%)	33.8 [26.7–44.7]	14.2 [10.0–15.5]	0.031*
Energy cost (J kg^{-1} m^{-1})	3.60 [2.63–4.04]	3.80 [2.18–4.35]	1.0
Vastus lateralis (μV^2)	19.3 [15.3–21.4]	11.4 [10.3–19.1]	0.44
Biceps femoris (μV^2)	18.4 [17.5–22.9]	10.2 [7.3–17.4]	0.09
Tibialis anterior (μV^2)	32.2 [25.7–48.1]	17.1 [10.2–25.2]	0.16
Triceps surae (μV^2)	26.3 [24.2–35.8]	14.0 [12.1–18.0]	0.06

*P value <0.05.

assistance provided by the robot). 100% of assistance was used throughout this study. The robot was set in a standardized mode called 'small step' with a fixed step length and cadence of 0.17 m and 70 steps min^{-1}, respectively. These settings were chosen because they allow subjects to walk safely with RAG on the treadmill, without therapist support.

2.4. Quantified gait analysis

Quantified gait analysis were performed on an instrumented treadmill (GaitWay 3D, Arsalis). Subjects were equipped with an oro-nasal mask connected to an ergo spirometer in order to assess their energy consumption (VO_2). For both assessments, subjects walked at a constant velocity of 0.22 m s^{-1}. During both conditions, they walked during minimum five minutes in order to reach a steady state level of energy consumption. The electrical activity of lower limb muscles was recorded by surface electrodes (WIFI PICO). Electrodes were placed symmetrically on the *vastus lateralis*, the *biceps femoris*, the *tibialis anterior* and the *triceps surae* muscles. Linear envelope EMG was used to quantify muscular activity, which correspond to the area under the curve of the EMG signal. External mechanical work (W_{ext}, J kg^{-1} m^{-1}) was calculated from ground reaction forces recorded by strain gauges placed under the treadmill. The W_{ext} can be subdivided in three parts: antero-posterior (W_{ekf}), vertical (W_{ev}) and lateral (W_{ekl}). Recovery (%) assessed energy-saving transfers between potential and kinetic energies. Recovery allows to characterize the pendular mechanism of walking. For each condition, data were computed for ten successive gait cycles. The average of ten measurements were then calculated.

2.5. Statistical analysis

Statistical analyses were performed using the SigmaPlot 14.0 (WPCubed GmbH, Munich, Germany). The non-parametric test Wilcoxon was used to compare results obtained with- and without RAG. The significance level was fixed at 0.05.

3. Results and discussion

The RAG modified gait biomechanics of healthy subjects leading to a less physiological gait pattern (Table 1). Step length was reduced by half as cadence was increased by twice compared to without RAG ($p = 0.03$). Future studies should analyze gait biomechanics with a more physiological gait pattern during RAG (which is possible overground with Atalante® robot, but not independently on a treadmill). The external mechanical work was quadrupled during RAG mostly explained by a threefold increase of the W_{ev} ($p = 0.03$) and a tenfold increase of the W_{ekl} ($p = 0.03$). Additionally, the reduction by half of the recovery ($p = 0.03$) showed a disturbance of the pendulum mechanism with RAG. Since the exoskeleton was in a 100% assistance mode, the extra external mechanical work can be compensated by the robot's motors. Indeed, there was no significant change in energy cost ($p = 1.00$).

Concerning muscles activation, EMG showed a trend for lower intensity of activation for all of them. These results are in accordance with the study of Androwis and colleagues among post-stroke patients who showed a decrease of the activation of the *rectus femoris* and the *soleus* during stance phase with RAG compared to without (Androwis et al. 2018). They did not observe any differences for other muscles or during swing phase. Authors underline that patients properly activate their muscles in terms of timing and amplitude. The muscular voluntary contraction during RAG was also relatively preserved in the present study, showing an active participation of subjects even with 100% of assistance provided by the robot. Both studies demonstrate that participants are active and participate with voluntary contraction during RAG, in accordance to rehabilitation guidelines. But, futures studies should assess the influence of the quantity of assistance provided by the robot on gait biomechanics. Indeed, an assistance as needed should optimize patient's engagement and increase potential recovery. Van Kammen and colleagues has analyzed different parameters of RAG in a single session with the Lokomat® robot. Variation of speed was the only parameter that influence stroke patients' gait. Higher speed during RAG increased muscle activity (van Kammen et al. 2020).

4. Conclusions

RAG modified gait biomechanics of healthy subjects by disturbing the cadence, walking pendular mechanism and muscle activation patterns. During rehabilitation, robotic assistance should be optimally adapted in order to keep the subject as active as possible, promoting physiological muscle activation patterns and efficient gait.

Acknowledgements

Authors would like to thank the Wandercraft team for their technical support.

Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Robotic; gait; biomechanics; neurology

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