Effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase

Takuma Inai Corresp., 1 , **Tomoya Takabayashi** 2 , **Mutsuaki Edama** 2 , **Masayoshi Kubo** 2

1 Exercise Motivation and Physical Function Augmentation Research Team, National Institute of Advanced Industrial Science and Technology, Kashiwa City, Japan

2 Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata City, Japan

Corresponding Author: Takuma Inai
Email address: hwd17001@nuhw.ac.jp

Background

An excessive daily cumulative hip moment in the frontal plane (determined as the product of hip moment impulse in the frontal plane during the stance phase and mean number of steps per day) is a risk factor for the progression of hip osteoarthritis. Moreover, walking speed and step length decrease, whereas cadence increases in patients with hip osteoarthritis. However, the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase are not known. Therefore, this study aimed to examine the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase.

Methods

We used a public dataset (kinetic and kinematic data) of over-ground walking and selected 31 participants randomly from the full dataset of 57 participants. The selected participants walked at a self-selected speed and repeated the exercise 15 times. We analyzed the data for all 15 trials for each participant. Multiple regression analysis was performed with the hip moment impulse in the frontal plane during the stance phase as the dependent variable and step length and cadence as independent variables.

Results

The adjusted R^2 in this model was 0.71 ($p<0.001$). The standardized partial regression coefficients of step length and cadence were 0.63 (t=5.24; $p<0.001$) and −0.60 (t=−4.58; $p<0.001$), respectively.

Conclusions

Our results suggest that low cadence, not short step length, increases the hip moment impulse in the frontal plane. Our findings help understand the gait pattern with low hip moment impulse in the frontal plane.

1 **Effects of step length and cadence on hip moment**
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4 Takuma Inai[1], Tomoya Takabayashi[2], Mutsuaki Edama[2], Masayoshi Kubo[2]
5
6 [1] Exercise Motivation and Physical Function Augmentation Research Team, National Institute of
7 Advanced Industrial Science and Technology, Kashiwa City, Chiba, Japan
8 [2] Institute for Human Movement and Medical Sciences, Niigata University of Health and
9 Welfare, Niigata City, Niigata, Japan
10
11 Corresponding Author:
12 Takuma Inai
13 Kashiwa II Campus, University of Tokyo,
14 6-2-3 Kashiwanoha, Kashiwa, Chiba 277-0882, JAPAN
15 Email address: hwd17001@nuhw.ac.jp

Abstract

Background

An excessive daily cumulative hip moment in the frontal plane (determined as the product of hip moment impulse in the frontal plane during the stance phase and mean number of steps per day) is a risk factor for the progression of hip osteoarthritis. Moreover, walking speed and step length decrease, whereas cadence increases in patients with hip osteoarthritis. However, the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase are not known. Therefore, this study aimed to examine the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase.

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Introduction

Degeneration of the hip articular cartilage is noted in patients with hip osteoarthritis, which reduces their physical function ability. Patients with hip osteoarthritis experience hip joint pain (Iidaka et al., 2016, 2020), and decrease in muscle strength (Loureiro, Mills & Barrett, 2013; Zacharias et al., 2016; Loureiro et al., 2018) and range of hip joint motion (Holla et al., 2011, 2012). Such changes decrease the patients' ability to perform activities of daily living (Pisters et al., 2012, 2014) and reduces their quality of life (Salaffi et al., 2005; Boutron et al., 2008). It is, therefore, important to prevent the progression of hip osteoarthritis to avoid these problems.

Tateuchi et al. (2017) proposed a new index in the frontal plane called daily cumulative hip moment (calculated as the product of hip moment impulse in the frontal plane and mean number of steps per day) and examined the relationship between this index and the progression of hip osteoarthritis (i.e., width of the hip joint space). They found that an excessive daily cumulative hip moment in the frontal plane is a risk factor for narrowing of the hip joint space width (Tateuchi et al., 2017). Therefore, it is important to avoid excessive daily cumulative hip moment in the frontal plane to prevent narrowing of the hip joint space width.

Considering that the walking speed is lower in individuals with hip osteoarthritis than in those without hip osteoarthritis (Constantinou et al., 2017; Foucher, 2017; Meyer et al., 2018; Wesseling et al., 2018; Diamond et al., 2018), Inai et al. (Inai et al., 2019a) examined the relationship between walking speed and hip moment impulse in the frontal plane and found that a decrease in the walking speed increases the hip moment impulse in the frontal plane during the stance phase. Therefore, to avoid a high daily cumulative hip moment in the frontal plane, patients with hip osteoarthritis should maintain a normal walking speed (i.e., avoid reducing the walking speed).

Walking speed is calculated as the product of step length and cadence. Constantinou et al. (2017) found that step length decreases for patients with hip osteoarthritis compared to controls. Schmidt et al. (2017) showed that cadence is greater in patients with hip osteoarthritis increases than in controls. However, the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase are not known.

This study aimed to examine the effects of step length and cadence on hip moment impulse in the frontal plane during the stance phase. We hypothesized that (1) a decrease in step length decreases the hip moment impulse in the frontal plane and (2) a decrease in cadence increases the hip moment impulse in the frontal plane. To the best of our knowledge, this is the first study to evaluate the effects of step length and cadence on hip moment impulse in the frontal plane.

Materials & Methods

Participants

Data were collected as previously described in Horst et al. (2019a,b). Specifically, 57 healthy adults (29 women, 28 men; age: 23.1 (2.7) years; height: 1.74 (0.10) m; body mass: 67.9

80   (11.3) kg) participated. Prior to the experiment, each participant read and signed a consent form
81   that had previously been approved by the ethical committee of the Rhineland-Palatinate Medical
82   Association in Mainz, Germany (Horst et al., 2019a,b).
83   **Experimental protocol and data acquisition**
84   The details of the experimental protocol and data acquisition were described previously
85   (Horst et al., 2019a,b). All participants performed 20 walking trials (self-selected speed;
86   barefoot) on a 10-m path. Because some of the trials had technical errors, we used 15 trials for
87   each participant. Ten Oqus 310 infrared cameras (Qualisys AB, Sweden) captured the three-
88   dimensional marker trajectories at a sampling frequency of 250 Hz. Three-dimensional ground
89   reaction forces were recorded by two Kistler force plates (Type 9287CA - Kistler, Switzerland)
90   at a frequency of 1000 Hz. A full-body marker set consisting of 62 reflective markers placed on
91   anatomical landmarks was used. For the static trial, all 62 reflective markers were used. For the
92   dynamic trial (i.e., walking trial), only 54 reflective markers were used. Two experienced
93   assessors attached the markers and conducted the analysis.
94   **Data processing**
95   First, we conducted a statistical power analysis for linear regression analysis using
96   G*Power 3.1 software (effect size $f^2 = 0.35$ [large] based on Cohen (1992), significance level =
97   0.05, power = 0.8, number of predictors = 0.2), which indicated that the required sample size was
98   31 subjects. Therefore, we selected 31 participants randomly (15 women, 16 men; age: 23.0 [2.6]
99   years; height: 1.76 [0.10] m; body mass: 68.8 [10.9] kg) from the 57 participants. For each
100 participant, the data for 15 trials were randomly selected for analysis. We evaluated the stance
101 phase of the right limb (i.e., from right heel contact to right toe-off) for each participant
102 (Tateuchi et al., 2017). The three-dimensional marker trajectories, ground reaction forces, center
103 of pressures, and moments of the force plates were filtered using a fourth-order Butterworth low-
104 pass filter at a cut-off frequency of 6 Hz (Inai et al., 2019b).
105   The external hip adduction moment during the stance phase of the right limb was
106 calculated for each participant using inverse dynamics (Newton-Euler method). Subsequently,
107 the hip joint moment impulse in the frontal plane was calculated by integration of the external
108 hip adduction moment. The hip moment impulse in the frontal plane (Nm s) was normalized by
109 body mass (Nm s/kg). To confirm the quantitative validity of the external hip adduction moment
110 during the stance phase, we also calculated the first peak external hip adduction moment during
111 the first half (0–50%) of the stance phase. The first peak external hip adduction moment (Nm)
112 was normalized with body mass (Nm/kg).
113   Mass, mass position, and inertia parameters of the segments reported previously (de
114 Leva, 1996; Robertson et al., 2013) were used. The hip joint center was derived as a point
115 interpolated at a distance of 18% of the vector norm from each reflective marker of the superior
116 aspect of the greater trochanter along the vector (Kito et al., 2010). The right knee joint center
117 was defined as the midpoint of the medial and lateral epicondyles of the right femur. The right
118 ankle joint center was defined as the midpoint of the right medial and lateral malleoli.

119   The step length from the point of right heel contact was defined as the distance between
120   the right and left heels. The step length was normalized with height (m/HT). Cadence (steps/min)
121   was calculated using the time from right heel contact to left heel contact. Walking speed was
122   calculated using the reflective markers placed on the sacrum and normalized with height (m/HT).
123   Stance time was defined as the time from the time of right heel contact to that of right toe-off.
124   All gait analyses were performed using Scilab (Scilab Enterprises, France).
125   **Statistical analysis**
126   Multiple regression analysis was performed in which the dependent variable was
127   defined as hip moment impulse in the frontal plane during the stance phase, and the independent
128   variables were defined as step length and cadence. To confirm the multicollinearity of this
129   model, the variance inflation factor was calculated. We also confirmed whether the residuals of
130   the model followed a normal distribution, and the correlation coefficient between step length and
131   cadence was also confirmed.
132   The Shapiro–Wilk test was used to determine whether the variables (step length,
133   cadence, walking speed, stance time, and hip moment impulse in the frontal plane) followed a
134   normal distribution. The Pearson's correlation or Spearman's correlation was used, depending
135   upon the results of the normality test. The significance level was set at <0.05.

136

137   # Results
138   Table 1 shows the results of the multiple regression analysis. A positive relationship
139   between step length and hip moment impulse in the frontal plane was observed (i.e., a decrease
140   in step length decreased the hip moment impulse in the frontal plane). An inverse relationship
141   between cadence and hip moment impulse in the frontal plane was also observed (i.e., a decrease
142   in cadence increased the hip moment impulse in the frontal plane). The variance inflation factor
143   in the multiple regression analysis was1.136, and the residuals followed a normal distribution
144   (p=0.905).
145   Figure 1 shows the relationship among step length, cadence, and hip moment impulse in
146   the frontal plane. Long step length and low cadence resulted in an increased hip moment impulse
147   in the frontal plane. In contrast, short step length and high cadence resulted in a decreased hip
148   moment impulse in the frontal plane.
149   Figure 2 shows the waveform of the average external hip adduction moment during the
150   stance phase (Nm/kg). The external hip adduction moment increased from 0% (i.e., right heel
151   contact) to approximately 20% of the stance phase, but it decreased from approximately 80% to
152   100% (i.e., right toe-off) of the stance phase. Bimodal peaks were also observed in this analysis.
153   Table 2 presents the results for the analysis of the gait parameters. The mean and
154   standard deviation (SD), minimum, and maximum values for each variable (hip moment impulse
155   in the frontal plane, first peak external hip adduction moment, step length, cadence, walking
156   speed, and stance time) are shown.
157   Table 3 presents the correlation coefficients between variables (step length, cadence,
158   walking speed, stance time, and hip moment impulse in the frontal plane).

159
160

Discussion

162   This study examined the effects of step length and cadence on hip moment impulse in the
163   frontal plane during the stance phase. Our main findings are as follows: (1) a decrease in step
164   length decreased the hip moment impulse in the frontal plane, and (2) a decrease in cadence
165   increased the hip moment impulse in the frontal plane. Therefore, our hypotheses were
166   confirmed.
167   Patients with hip osteoarthritis exhibit decreased walking speed (Constantinou et al.,
168   2017; Foucher, 2017; Meyer et al., 2018; Wesseling et al., 2018; Diamond et al., 2018) and step
169   length (Constantinou et al., 2017). However, walking speed depends on step length and cadence.
170   Although several factors have been reported to affect hip moment impulse in the frontal plane
171   during the stance phase (Inai et al., 2018, 2019a,b; Tateuchi et al., 2020), the effects of step
172   length and cadence on hip moment impulse in the frontal plane are not known to date. Our
173   results help to understand the gait pattern with low hip moment impulse in the frontal plane.
174   An increase in stride length leads to an increase in the first peak external hip adduction
175   moment during the stance phase (Ardestani et al., 2016). Therefore, we suggest that a decrease in
176   step length may result in a low amplitude of the external hip adduction moment. Furthermore,
177   the hip moment impulse in the frontal plane also decreases because the hip moment impulse in
178   the frontal plane is calculated by the integration of the external hip adduction moment.
179   Tateuchi et al. (2020) examined the effect of gait kinematics of the hip, pelvis, and trunk
180   on external hip adduction moment through hierarchical multiple regression analyses. They
181   reported that the hip moment impulse in the frontal plane deceased with a decrease in stance
182   time, and body mass and stance time accounted for 61% of the variance in hip moment impulse
183   in the frontal plane (Tateuchi et al., 2020). Therefore, the effect of stance time on hip moment
184   impulse in the frontal plane is substantial. Additionally, cadence and stance time were
185   significantly negatively correlated in the present study (Table 3). Although the calculation
186   process clarifies that the moment impulse is associated with cadence, that is, stance time because
187   moment impulse is a time-integrated value, our study is the first to examine the effect of cadence
188   on the hip moment impulse in the frontal plane.
189   In our study (Table 1), the standardized partial regression coefficients of step length and
190   cadence are0.63 (t=5.24) and −0.60 (t=−4.58), respectively. The absolute values of the
191   standardized partial regression coefficients of step length and cadence were the same; therefore,
192   the effects of step length and cadence on hip moment impulse in the frontal plane were similar in
193   the present study. However, the mean walking speed was 1.44 (SD=0.11) m/s in the present
194   study (mean: 0.82 m/(sHT) × 1.76 m, SD=0.06 m/(sHT) × 1.76 m, where HT is height).
195   According to Inai et al. (2019a), the effect of a walking speed of approximately 1.3–1.5 m/s on
196   hip moment impulse in the frontal plane was small. In contrast, the effect of walking speed <1.2
197   m/s on hip moment impulse in the frontal plane is large, and the hip moment impulse in the
198   frontal plane increased exponentially with a decrease in walking speed (Inai et al., 2019a).

199   Therefore, the values of the standardized partial regression coefficients of step length and
200   cadence may change in patients with varying slow walking speeds (e.g., absolute values of the
201   standardized partial regression coefficients of step length and cadence are small and large,
202   respectively).
203   In the present study, the mean hip moment impulse in the frontal plane (not normalized
204   to step length) during walking is 0.50 (SD=0.17) Nm s/kg. Tateuchi et al. (2017) determined that
205   the mean hip moment impulse in the frontal plane during walking at a self-selected speed was
206   0.41 (SD=0.13) Nm/kg (mean: 22.7 Nm s/55.2 kg, SD=7.4 Nm s/55.2 kg). Therefore, the value
207   of the hip moment impulse in the frontal plane in the present study is similar to that reported by
208   Tateuchi et al. (2017). Furthermore, the mean first peak external hip adduction moment during
209   the stance phase in the present study was 1.17 (SD=0.32) Nm/kg (Table 3), which is similar to
210   that reported by Tateuchi et al. [1.05 (SD=0.29) Nm/kg (mean: 57.9 Nm/55.2 kg, SD=16.0
211   Nm/55.2 kg)] (Tateuchi et al., 2017). Therefore, we believe that the values obtained in the
212   present study are quantitatively reasonable.
213   This study has a few limitations. First, we used a public dataset, and the participants in
214   the dataset were young (Horst et al., 2019a,b). Chehab et al. (2017) reported that age does not
215   affect the external hip adduction moment. Therefore, the effect of age on hip moment impulse in
216   the frontal plane may be small. Second, the participants in the present study did not have hip
217   osteoarthritis and were healthy. Diamond et al. (2018) reported that the hip joint moments of
218   patients with hip osteoarthritis were different from those of normal participants during walking.
219   Although the results of this study need to be validated in patients with hip osteoarthritis, our
220   findings may be useful in understanding the gait pattern with low hip moment impulse in the
221   frontal plane. The effects of step length and cadence on hip moment impulse in the frontal plane
222   should be further investigated in patients with hip osteoarthritis.
223

Conclusions

225   Our study revealed that a decrease in step length decreased the hip moment impulse in
226   the frontal plane and a decrease in cadence increased the hip moment impulse in the frontal
227   plane. These findings may be useful for understanding gait patterns when the hip moment
228   impulse in the frontal plane is low (or high).
229

Acknowledgements

231   We would like to thank Editage for English language editing.
232

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332   **Figure 1**. The relationship between step length, cadence, and hip moment impulse in the frontal
333   plane during the stance phase.
334   Red points mean an increased hip moment impulse during the stance phase, and the shade of
335   color indicates the quantitative values of the hip moment impulse in the frontal plane.
336
337   **Figure 2**. The average wave form of the external hip adduction moment during the stance phase.
338   A bimodal peak was observed. Error bars mean the standard deviations.

The results of the multiple regression analysis

Table 1. The results of the multiple regression analysis

Independent variable	Standardized partial regression coefficient	t value	p value
Step length, m/HT	0.63	5.24	< 0.001
Cadence, steps/min	−0.60	−4.58	< 0.001

Adjusted R^2 = 0.71. F (2, 28) = 37.0 (p < 0.001). Dependent variable: hip moment impulse in the frontal plane during the stance phase (Nms/kg). HT: Height.

Results of the gait parameters

Table 2. Results of the gait parameters.

	Mean	SD	Minimum	Maximum
Hip moment impulse in the frontal plane, Nms/kg	0.50	0.17	0.27	0.92
First peak external hip adduction moment, Nm/kg	1.17	0.32	0.67	1.84
Step length, m/HT	0.40	0.03	0.35	0.45
Cadence, steps/min	114.9	7.0	98.4	127.9
Walking speed, m/(sHT)	0.82	0.06	0.73	0.96
Stance time, s	0.61	0.05	0.53	0.73

HT: Height.

The correlation coefficients between step length, cadence, walking speed, and stance time

Table 3. The correlation coefficients between step length, cadence, walking speed, stance time, and hip moment impulse in the frontal pane

	Cadence	Walking speed	Stance time	Hip moment impulse in the frontal plane, Nms/kg
Step length, m/HT	$r = -0.35, p = 0.056$	**$r = 0.76, p < 0.001$**	$r = 0.27, p = 0.132$	**$r = 0.73, p < 0.001$**
Cadence, steps/min	—	$r = 0.30, p = 0.100$	**$r = -0.97, p < 0.001$**	**$r = -0.65, p < 0.001$**
Walking speed, m/(sHT)	—	—	**$r = -0.37, p = 0.040$**	$r = 0.35, p = 0.058$
Stance time, s	—	—	—	**$r = 0.57, p < 0.001$**

HT:Height. Bold letters indicate a significant difference.

Figure 1

The relationship between step length, cadence, and hip moment impulse in the frontal plane during the stance phase.

Red points mean an increased hip moment impulse during the stance phase, and the shade of color indicates the quantitative values of the hip moment impulse in the frontal plane.
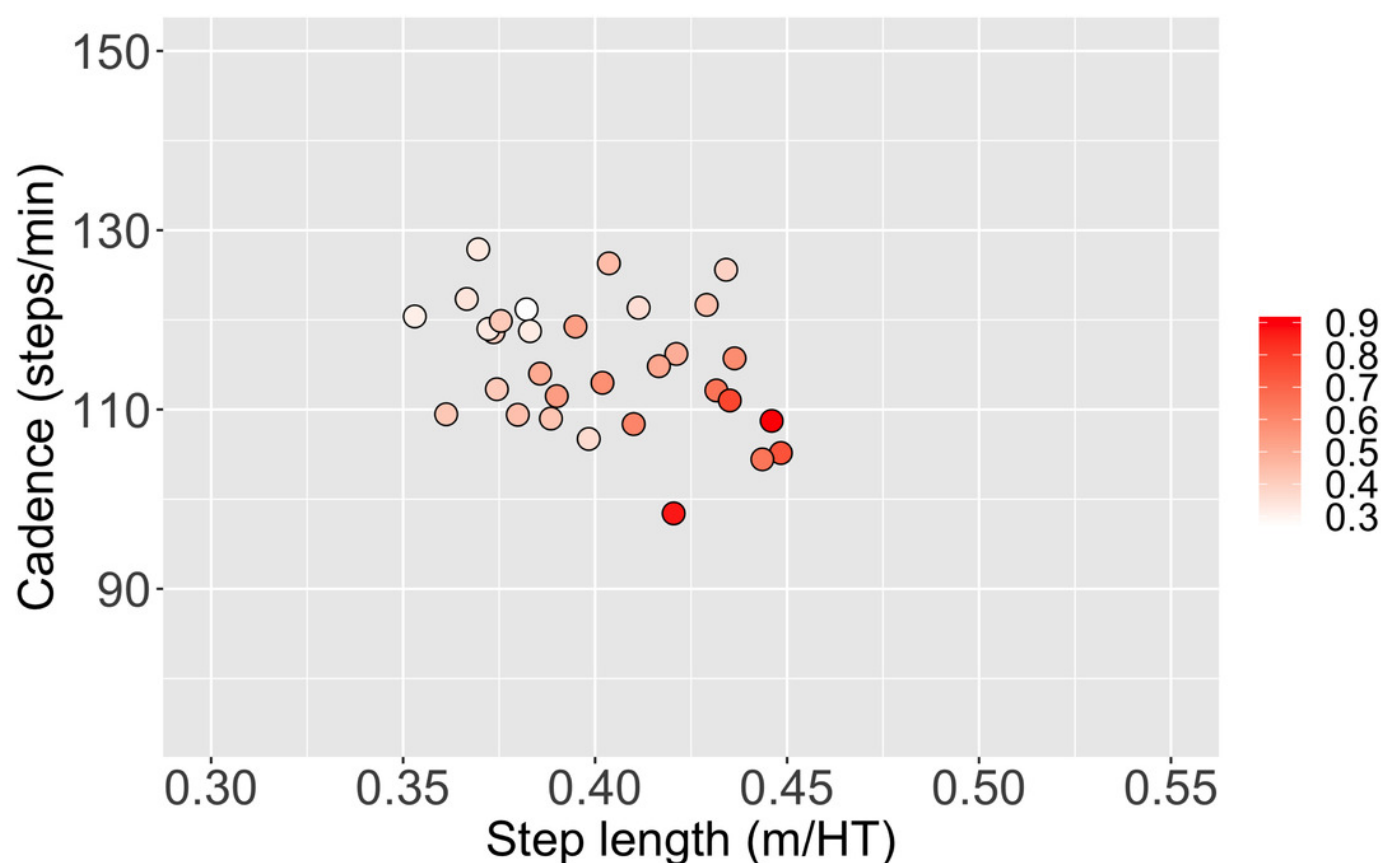
Figure 2

The average wave form of the external hip adduction moment during the stance phase.

A bimodal peak was observed. Error bars mean the standard deviations.