Japanese Journal of Comprehensive Rehabilitation Science (2022)

Editorial

Current perspectives on quantitative gait analysis for patients with hemiparesis

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Hase K. Current perspectives on quantitative gait analysis for patients with hemiparesis. Jpn J Compr Rehabil Sci 2022; 13: 1−3.

Clinical application of quantitative gait analysis

Quantitative gait analysis has been used to evaluate the functional locomotion abilities of patients who have had a stroke. Patients with hemiparesis develop adaptive and compensatory motor strategies represented by an asymmetric performance and thus demonstrate greater gait variability in spatiotemporal, kinematic, and kinetic parameters than neurologically intact controls. Quantitative analyses of these parameters are expected to enable us to make a clinical decision in case of gait dysfunction. Because such analyses generate a large amount of complex data, it is necessary to understand candidates for the underlying contributors to the targeted locomotion disorders and to conduct advanced multivariate analysis and machine learning research.

Contributors to walking dysfunction in patients with hemiparesis

Recent studies on the effects of gait training showed that improvements in paretic propulsive force contributed to changes in self-selected comfortable as well as fastest walking speed [1, 2]. The two critical factors for propulsive force generation are the trailing limb angle (TLA) defined as the angle between the laboratory's vertical axis and the vector from the 5th metatarsal joint to the great trochanter, and the plantar-flexion moment of the ankle joint during the stance phase of the gait cycle. Figure 1 shows the correlations between the walking speed and TLAs as well as plantar-flexion moments of the ankle joint in patients with hemiparesis (N = 30, 62.5±11.8 y/o) and healthy age-matched individuals (N = 62, 63.0±11.6 y/o). In each group, there are significant correlations, in particular, the paretic TLA and plantar-flexion moment strongly contribute to the increase in walking speed in patients with hemiparesis.

Hsiao et al. found that patients with hemiparesis during treadmill walking increase propulsive force mainly by changing TLAs in both the paretic and non-paretic limbs [2]. However, even if the same rehabilitative task is applied to patients with hemiparesis, different mechanisms of response for increasing walking speed are associated with each. Especially, in order to elucidate underlying biomechanical predictors of the behavioral change following rehabilitative treatments, it is important to differentiate the outcomes based on functional recovery in the paretic limb and compensatory motor strategies [3]. Although the latter allow patients with hemiparesis to adaptively implement walking performance, they may have diminished functional improvement of the paretic limb while getting along without the ability to generate the possible force levels of the paretic muscles. The rehabilitative task of creating an opportunity for controlling the body mass on the paretic leg is the definitive treatment required to relieve patients with hemiparesis from a restricted community life [4].

Clinical data-mining to determine gait training strategies

Various types of gait training strategies including robot-assistance have been developed to improve the locomotor functions in patients with hemiparesis. The overall efficacy is often estimated by a change of the mean response to an intervention, but consistent with heterogeneity of clinical and biomechanical features in each patient, there are clear variations in how the patients respond to a given training stimulus. Therefore, recently there has been increasing interest in identifying individual variations in post-training adaptations, differentiating "responders" who respond

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Accepted: December 1, 2021.
Conflict of Interest: The author declares no conflict of interest.

doi.org/10.11336/jjcrs.13.1

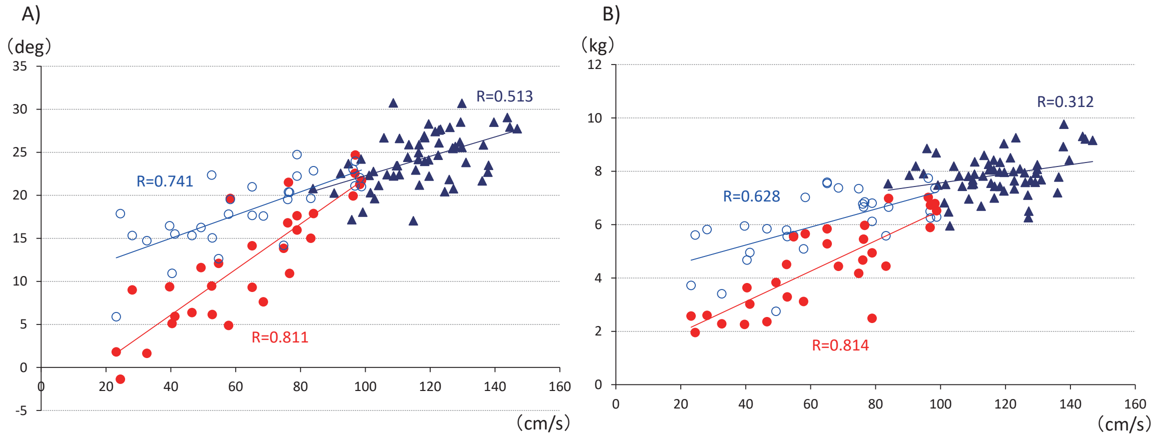

Figure 1. Correlations between walking speed and TLA as well as plantar-flexion moment of ankle joint.
A) Correlations between walking speed and TLA.
B) Correlations between walking speed and plantar-flexion moment of ankle joint.
Solid circles: Paretic limb in patients with hemiparesis ($N = 30$).
Open circles: Non-paretic limb in patients with hemiparesis ($N = 30$).
Triangles: Right limb in healthy subjects ($N = 62$).

well to a given intervention from "non-responders" exhibiting no meaningful improvements [3, 5], and exploring an optimal potential treatment improving the targeted dysfunction in "non-responders" [6, 7]. Indeed, the measurement parameters obtained from a quantitative gait analysis to identify the changes following gait training contain noteworthy features that allow for an understanding of underlying coordination and walking-specific motor control. Feature selection is positioned as a process of clinical data-mining to determine the best subset of the original variables.

The clinical feature selection of baseline variables obtained from a quantitative gait analysis includes two aspects: understanding the biomechanical and pathophysiological mechanisms, and predicting the treatment outcome. Objective and robust data analysis is accomplished by analyzing the entire data set of a gait cycle, and new insights to help improve clinical practice can be derived from the expanded initial features. More likely, the measured multiple gait-related parameters interact with one another, therefore, a statistical analysis system for detecting a set of features representing the gait pattern is required.

Analysis paradigm for feature selection

Multivariate analysis and machine learning methods such as principal component analysis have been used to examine gait variability and identify subgroups based on the biomechanical properties. Figure 2 shows the process of feature selection using Mahalanobis distance (MD) as well as the Markov Chain Monte-Carlo (MCMC) method and clustering for subgrouping. The MD that is commonly applied to problems such as classifying data into groups and determining differences between groups is an effective statistical technique using covariance that can measure how distant a data point is from the center of a multivariate normal distribution (Mahalanobis space). If the objective variable such as walking speed of patients with hemiparesis correlates with the MD value, a set of gait-related parameters forming the Mahalanobis space will be regarded as the clinically meaningful features. For characterizing a distribution by randomly sampling features from the distribution of gait-related parameters, the MCMC method can be used without the need for assuming parameter identifiability or removing non-identifiable parameters [8]. The clustering using a set of features selected by importance sampling may allow for planning more effective treatments with appropriately targeted intervention.

As a result of clustering 25 patients with hemiparesis, two types of subgroups were identified (Fig 2). The walking speeds of patients in cluster 1 improve with increase in the paretic anterior-posterior component of ground reaction force at toe-off as well as with decrease in the bilateral difference of hip flexion angles at heel contact. This means that the increased propulsive force of the paretic limb and improved symmetry of step length contribute to increasing speed, respectively. On the other hand, the walking speeds of patients in cluster 2 are strongly correlated with the paretic hip extension angle at toe-off as well as moderately correlated with the ankle external rotation angle at loading response. In addition to increased propulsion by forming the TLA, the normalized stretch-shortening cycle of the Achilles tendon may contribute to propulsive force generation. Understanding these biomechanical characteristics may enable the creation of a treatment algorithm that can aid clinical decision-making.

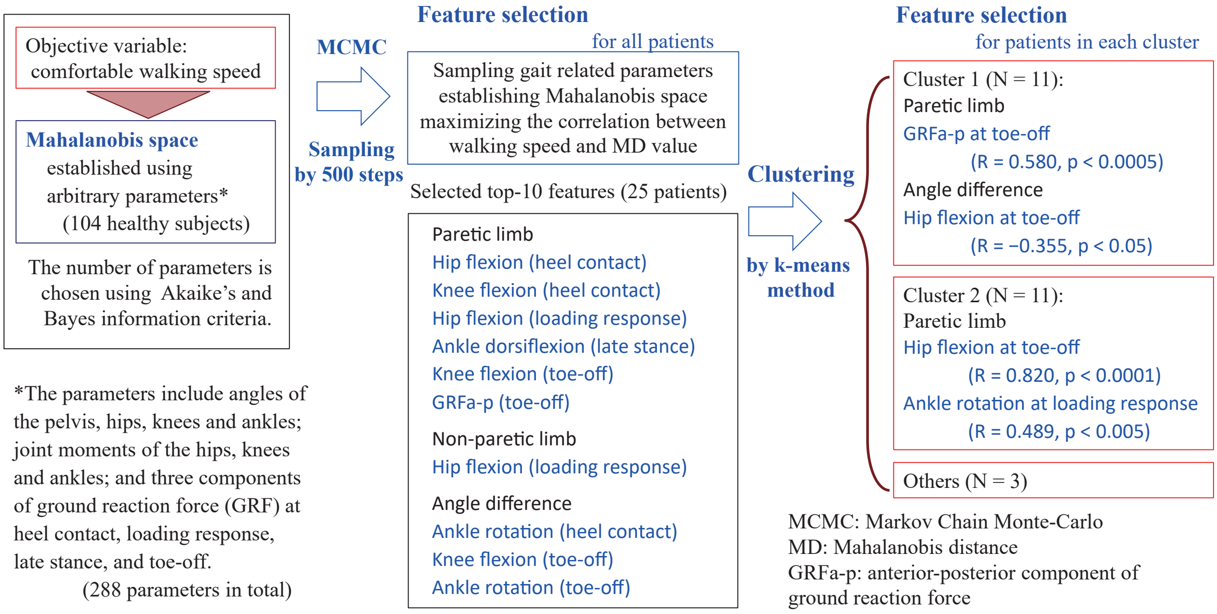

Figure 2. Correlation-based feature selection and clustering algorithm.
Feature selection: Sampling gait-related parameters establishing Mahalanobis space maximizing the correlation coefficient between walking speed and MD values. On a Markov chain according to the probability of transitioning from state i to state j, the gait-related parameter as a random variable is selected when there is a higher correlation between the walking speed and MD values measured in the Mahalanobis space (Monte Carlo method; 500 steps). The top-10 gait-related parameters selected more frequently while sampling 500 times are presented in the filled square.

Conclusions

It is very difficult to discern the underlying factors contributing to performance changes following a rehabilitative treatment. Understanding differences in biomechanical gait profiles corresponding to the treatment outcomes will help us to develop adequate algorithms for determining who should receive what kind of rehabilitative treatments. The use of feature selection of quantitative biomechanical variables should allow us to provide personalized rehabilitative treatment.

This work was partially supported by JSPS KAKENHI grant number 21K21775.

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