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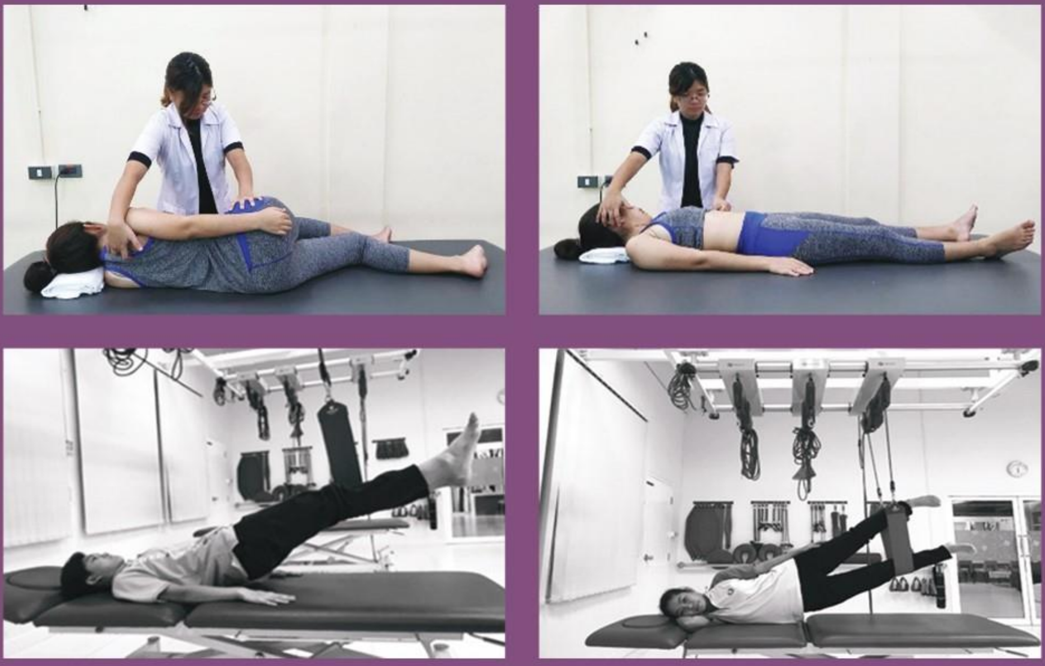

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Production and editorial assistance:
Arpassanan Wiyanad
Pakwipa Chokphukiao
Roongnapa Intaruk

All correspondence concerning manuscripts, editorial issues and subscription should be addressed to:
Editorial Officer: ArchAHS.TH@gmail.com
Faculty of Associated Medical Sciences,
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REVIEW ARTICLE

Arch AHS

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A systematic review of the measurement of infant posture and movement using image or video data analysis

Nisasri Sermpon[1,2], Hirotaka Gima[1*]

[1] Department of Physical Therapy, Graduate School of Human Health Sciences, Tokyo Metropolitan University, Japan.
[2] Faculty of Physical Therapy, Mahidol University, Putthamonthon, Nakhon Pathom, Thailand.

KEYWORDS
Infant movement; Image data analysis; Video data analysis; Movement measurement; Paediatric physical therapy.

ABSTRACT

Gross motor skill development (spontaneous movement and posture) is the most basic assessment domain for infant body control and movement skills. Image or video analysis in early infancy is an alternative quantitative and qualitative method for assessing movement with the advantages of being cost-effective, requiring less set-up time without attaching markers, assessing natural movement, and availability in clinical settings. This study aimed to review novel methods for measuring posture and movement of infants using image or video analysis, focusing on studies that used the markerless technique. PubMed and EBSCO were searched using three main keywords (‘infants’, ‘posture and movement’, and ‘measurement’). Articles from other sources were screened and included, and a manual search was performed. Ultimately, 25 articles published since 2010 were selected. The outcomes of this review primarily focused on study purpose, subject information and position, recording tools, analysis techniques, and study features of interest. Image or video data analysis, primarily using two-dimensional and depth video cameras, was used for clinical investigation and technical evaluation, assuring assessment and treatment methods based on quantitative results. Infants aged 0–6 months were evaluated in the supine position in the studies in this review, with an analysis technique that was primarily computer-based. The parameters included variations regarding program or software; for example, the quantity of motion, the centroid of motion, area, velocity, acceleration, and coordinates. Regarding the advantages of using 2D video data analysis for natural movement assessment, further studies and novel technologies are required for clinical practice.

*__Corresponding author:__ Hirotaka Gima, PT, PhD. Department of Physical Therapy, Graduate School of Human Health Sciences, Tokyo Metropolitan University, 7-2-10 Higashi-Ogu, Arakawa-ku, Tokyo 116-8551, Japan. Email: gima@tmu.ac.jp
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Introduction

Gross motor development is the most basic assessment domain that include infants' skills for controlling or moving their bodies. At an early age, infants learn and improve their supine, prone, sitting, and standing positions as well as the movement of their head and extremities. They also learn to transition from one position to another, such as from supine to prone position, lying down to sitting, and sitting to standing. Finally, they learn to move from one place to another (known as locomotion) by crawling, walking, or running. These motor developments are relevant to neural activity(1). Previous studies which evaluated both typical and high-risk infants have shown the variability and complexity of postural control(2,3) and spontaneous movement(4,5) in early infancy. Poor postural control and abnormality of spontaneous movement may be caused by brain damage(3,6). Therefore, infant posture and movement play an important role in the early detection of neurodevelopmental disorders. Early detection of atypical development allows for prompt and appropriate intervention in a clinical setting(7).

Observation is a tool used for assessment in early infancy; it provides qualitative results. For example, the General Movement Assessment (GMA) developed by Pretlch et al. (2005) can predict cerebral palsy but requires a trained assessor(4,8). Moreover, studies have used video recordings for observation for different purposes including reassessment, result confirmation, elimination of obstacles from observation, and interpretation of information obtained from quantitative data(9). Therefore, using video recordings and image or video data analysis may provide qualitative and more precise data.

Using images or videos for motor development measurement is a more advantageous method of assessing development as it requires less time to set up instruments, does not require attachment of markers to the body, assesses natural movement, and may be more easily available in clinical settings in addition to the laboratory(10). In addition, most of the analysis is performed by a computer system that generates quantitative data, such as the quantity of motion, area, velocity, acceleration, and (x, y) coordination. However, the reliability and validity of this method has yet to be evaluated.

Due to the coronavirus disease 2019 (COVID-19) pandemic, there is a need to maintain a distance between individuals and adhere to safety practice guidelines, especially when dealing with vulnerable and fragile infants. Therefore, movement assessment by observation should be considered. However, as technology continues to advance and evolve, image or video data analysis may be an option for performing a quantified assessment. Considering the various techniques that generate measurable data, this study aimed to review relevant studies in the past decade that obtained measurements for infant posture and movement using image or video analysis, focusing on those that obtained quantitative data with markerless procedures. In addition, this review provides previous objectives, methodologies, and parameters used in image or video data analysis.

Materials and methods

Definition of Keywords

The first keyword, **'infant'**, included babies aged 0–12 months old(11,12), according to the Centers for Disease Control and Prevention stage of child development. The second keyword group **'posture or movement'** focused on infancy milestones, from stages in which infants use entire surfaces as the base of support for their bodies, such as the supine and prone positions, to sitting and standing without base support. Spontaneous movement and attentional activity occur in addition to postural development(13). Finally, the third keyword group **'measurement'** entailed analysis of the image or video data, especially using novel technologies, such as artificial intelligence (AI), machine learning, and deep learning (Table 1).

Table 1 Keywords and literature search strategy in this review

Keyword	Searching formula
Infant	Infant OR Infants OR Baby OR Babies OR Newborn OR Newborns OR Neonate OR Neonates OR Neonatal
AND	
Posture or Movement	Movement OR "Movement analysis" OR Posture OR Position OR Motion OR "Motion analysis" OR "Movement estimation"
AND	
Measurement	Measurement OR Estimation OR Assessment OR Evaluation
AND	
"Image data analysis"	"Image data analysis" OR "Video data analysis" OR "Pose estimation" OR "Automated pose estimation" OR "Computer-based video" OR "Artificial Intelligence" OR "Motiongram"

Literature Search Strategy

This review focused on studies that applied novel techniques in the analysis of image or video data to assess infant posture and movement. The PubMed, Scopus, IEEE Xplore, SpringerLink, and Science Direct databases were searched Manual or Google searches were also applied to obtain as many articles as possible.

Study Selection Process

Two main steps were involved in the selection process. First, the exclusion criteria were defined as follows: 1) Non-use of image or video data analysis in infants; 2) non-use of the terms 'Posture or movement' or 'measurement' in the study; 3) reviews; 4) books or conference proceedings; and 5) research not published in English. Second, the full text of each article that fulfilled the following inclusion criteria were scanned: 1) methodology using video or image data analysis relevant to infant movement; 2) application of novel technologies such as AI, machine learning, deep learning, and computer-based video analysis; and 3) report on 'posture or movement', 'automated pose estimation', 'position', 'motion', or 'movement pattern'.

Screening Process

First, selection was conducted using keywords and strategies for all databases and then the titles and abstracts of articles retrieved were screened based on the exclusion criteria, following which full-text articles that met the inclusion criteria were selected. Finally, all included articles were classified, categorised, analysed, and reviewed.

The entire process of selecting keywords, constructing the search formula, selecting the target papers, and finally deciding which articles to include in the review was performed by S.N. and H.G.

Results

In the past decade, an increasing number of studies have focused on posture and movement assessment using image or video data analysis that provide quantitative parameters. Studies assessed infants moving in their natural habitat using the markerless procedure because attaching markers would have interfered with the performance of infant developmental skills.

Search Results

The selection process was initiated by applying all search terms to PubMed and EBSCO and was limited by year (since 2010), source type (academic journals), and language (English). The results showed 33 PubMed articles and 17,208 EBSCO articles, of which the latter was selected based on the content provider, i.e., MEDLINE, Scorpus, IEEE Xplore, SpringerLink, and Science-Direct. After eliminating duplicate articles, 414 articles were selected from EBSCO; therefore, the final search result contained 447 articles. Subsequently, after first screening titles and abstracts, 385 articles were excluded as they did not follow the inclusion criteria. Next, the researcher rechecked 62 articles and excluded duplicate articles from the two resources (PubMed and EBSCO), leaving 25 articles. The researcher then searched Google again using the keywords, and found 5 more articles; a manual search of the references of these articles yielded 11 more articles. Thus, 41 full-text articles were read, and 16 articles that did not meet the inclusion criteria were excluded. Finally, this study included 25 articles, as shown in Figure 1 and Table 2.

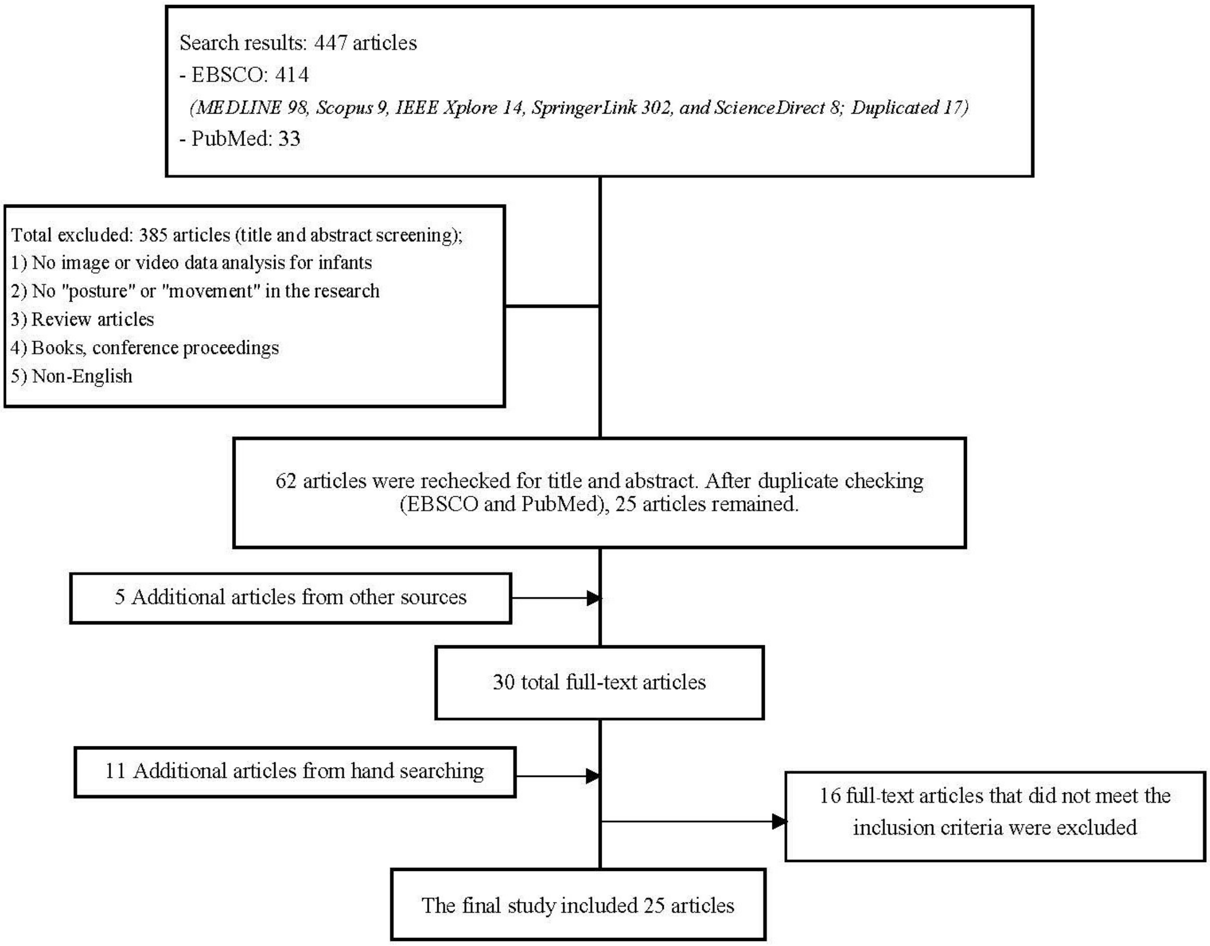

Figure 1 Flowchart of the search process

Table 2 Author, publication year, and title of final recruited articles in the study

Author (Publication Year)	Title
Adde *et al.* (2010)[14]	Early prediction of cerebral palsy by computer-based video analysis of general movements: a feasibility study
Adde *et al.* (2013)[15]	Identification of fidgety movements and prediction of CP by the use of computer-based video analysis is more accurate when based on two video recordings
Adde *et al.* (2016)[16]	Early motor repertoire in very low birth weight infants in India is associated with motor development at one year
Adde *et al.* (2018)[17]	Characteristics of general movements in preterm infants assessed by computer-based video analysis
Baccinelli *et al.* (2020)[18]	Movidea: A software package for automatic video analysis of movements in infants at risk for neurodevelopmental disorders
Caruso *et al.* (2020)[19]	Early motor development predicts clinical outcomes of siblings at high-risk for autism: Insight from an innovative motion-tracking technology
Chambers *et al.* (2020)[20]	Computer vision to automatically assess infant neuromotor risk
Dogra *et al.* (2012)[21]	Toward automating Hammersmith pulled-to-sit examination of infants using feature point based video object tracking
Doroniewicz *et al.* (2020)[7]	Writhing movement detection in newborns on the second and third day of life using pose-based feature machine learning classification
Ihlen *et al.* (2019)[22]	Machine learning of infant spontaneous movements for the early prediction of cerebral palsy: A multi-site cohort study
Kawashima *et al.* (2020)[23]	Video-based evaluation of infant crawling toward quantitative assessment of motor development
Khan *et al.* (2018)[24]	A computer vision-based system for monitoring Vojta therapy
Kinoshita *et al.* (2020)[25]	Longitudinal assessment of U-shaped and inverted U-shaped developmental changes in the spontaneous movements of infants via markerless video analysis
Li *et al.* (2021)[26]	Three-dimensional pose estimation of infants lying supine using data from a Kinect sensor with low training cost
Marchi *et al.* (2019)[27]	Automated pose estimation captures key aspects of General Movements at eight to 17 weeks from conventional videos
McCay *et al.* (2020)[28]	Abnormal infant movements classification with deep learning on pose-based features
Moccia *et al.* (2020)[29]	Preterm infants' pose estimation with spatio-temporal features
Raghuram *et al.* (2019)[30]	Automated movement analysis to predict motor impairment in preterm infants: a retrospective study
Schroeder *et al.* (2020)[31]	General Movement Assessment from videos of computed 3D infant body models is equally effective compared to conventional RGB Video rating

Table 2 Author, publication year, and title of final recruited articles in the study (cont.)

Author (Publication Year)	Title
Stahl *et al.* (2012) [32]	An optical flow-based method to predict infantile cerebral palsy
Støen *et al.* (2017) [33]	Computer-based video analysis identifies infants with absence of fidgety movements
Tacchino *et al.* (2021) [34]	Spontaneous movements in the newborns: a tool of quantitative video analysis of preterm babies
Tsuji *et al.* (2020) [35]	Markerless measurement and evaluation of general movements in infants
Valle *et al.* (2015) [36]	Test-retest reliability of computer-based video analysis of general movements in healthy term-born infants
Wu *et al.* (2021) [37]	RGB-D videos-based early prediction of infant cerebral palsy via general movements complexity

Table 3 Study categorisation based on image or video data analysis

No	Author	Study Purpose	Subjects/age	Subject position	Recording Tool	Analysis Technique	Feature of Interest
1	Adde et al. (2010)[14]	Clinical test/Predict cerebral palsy (CP)	30 high-risk infants/ 10-15 weeks post term age (PTA)	Supine	2D Video Camera	General movement toolbox (motion image, frame differencing, pixel displayed in white represent movement), using computer-based video analysis	- Mean of Quantity of Motion (Q_{mean}) - Standard deviation of Quantity of Motion (Q_{SD}) - Median of Quantity of Motion (Q_{median}) - Standard deviation of the centroid of motion (C_{SD}) - Standard deviation of the velocity (V_{SD}) - Standard deviation of the acceleration (A_{SD}) - Cerebral palsy predictor (CPP)
2	Adde et al. (2013)[15]	Clinical test/Detect fidgety movements (FMs) and Predict cerebral palsy (CP)	26 preterm, 26 term infants/ 9 and 17 weeks post term age (PTA)	Supine	2D Video Camera	General movement toolbox (motion image, frame differencing, pixel displayed in white represent movement), using computer-based video analysis	- Mean of Quantity of Motion (Q_{mean}) - Standard deviation of Quantity of Motion (Q_{SD}) - Median of Quantity of Motion (Q_{median}) - Standard deviation of the centroid of motion (C_{SD}) - Standard deviation of the velocity (V_{SD}) - Standard deviation of the acceleration (A_{SD}) - Cerebral palsy predictor (CPP)
3	Adde et al. (2016)[16]	Clinical test/Detect fidgety movements (FMs)	243 videos of very low birth weight infants/ 9-16 weeks post term age (PTA)	Supine	2D Video Camera	General movement toolbox (motion image, frame differencing, pixel displayed in white represent movement), using computer-based video analysis	- Standard deviation of the velocity (V_{SD}) - Mean of Quantity of Motion (Q_{mean}) - Standard deviation of Quantity of Motion (Q_{SD}) - Standard deviation of the centroid of motion (C_{SD})
4	Adde et al. (2018)[17]	Clinical test/Detect writhing movements (WMs) and fidgety movements (FMs)	27 preterm infants/3-5, 10-15 weeks old	Supine	2D Video Camera	Video analysis software (motion image), Motiongrams	- Mean of Quantity of Motion (Q_{mean}) - Standard deviation of Quantity of Motion (Q_{SD}) - Standard deviation of the centroid of motion (C_{SD})
5	Baccinelli et al. (2020)[18]	Technical experiment, Introduce new novel Movement detection, extract movement features	90 infants; low risk and high risk (300 videos)/10 days, 6, 12, 18, 24 weeks old	Supine	2D Video Camera	Movidea software	- Mean velocity - Mean acceleration - Area form moving average - Cross-correlation coefficient - Intersection mean distance - Total number of intersections - Periodicity
6	Caruso et al. (2020)[19]	Clinical test/Predict Autism Spectrum Disorder (ASD), Neurodevelopmental disorder (NDD)	53 low-risk infants, 50 high-risk infants/10 Days, 6, 12, 18, 24 weeks old	Supine	2D Video Camera	Movidea software	- Quantity of motion (Q_{mean}) - Centroid of motion (C_{xsd}, C_{ysd}, velocity (V_{cmean}), acceleration (A_{cmean})) - Periodicity (H-periodicity, F-perodicity)
7	Chambers *et al.* (2020)[20]	Technical experiment, Clinical test/Predict high risk	85 online videos, 19 high-risk infants/ 3-11 months	Supine	2D Video Camera	Pose estimation algorithm/OpenPose	Naïve Gaussian Bayesian Surprise metric
8	Dogra *et al.* (2012)[21]	Movement detection/using video ensuring pull-to-sit examination (part of Hammersmith Infant Neurological Examination, HINE)	30 babies/ < 12 months	Pull-to-sit	2D Video Camera*2 (top and side view)	Automatic object tracking algorithm	Degree between head and torso then, scoring follow the description of the event
9	Doroniewicz *et al.* (2020)[7]	Movement detection/ Classify general movements (GMs)	31 newborns video recording/ 2-3 days old	Supine	2D Video Camera	OpenPose/Support vector machine (SVM)-Radial basis function (RBF) kernel, Random forests (RF), Linear discriminant analysis (LDA)	16 features characterising spontaneous movement. - Factor of movement's area (FMA) - Factor of movement's shape (FMS) - Centre of movement's area (CMA)

Table 3 Study categorisation based on image or video data analysis (cont.)

No	Author	Study Purpose	Subjects/age	Subject position	Recording Tool	Analysis Technique	Feature of Interest
10	Ihlen *et al.* (2019)[22]	Movement detection Predict cerebral palsy (CP)	377 videos of high-risk infants/ 9-15 weeks post term age (PTA)	Supine	2D Video Camera	Computer-based infant movement assessment (CIMA)	Multivariate empirical mode decomposition (MEMD) - Movement frequencies - Amplitude - Covariation - (x, y) coordinates
11	Kawashima *et al.* (2020)[23]	Movement detection	16 infants/ 10 months old	Crawling	2D Video Camera*2 (top and side view)	Image segmentation, Approximated ellipse and analysis area	- Rhythm of movement - Laterality of movement - Cooperativeness of upper limbs - Number of retrogressions in image centre of gravity (CoG) - Standard deviation of image centre of gravity (CoG) in the medial and lateral directions - Vertical deviation of image centre of gravity (CoG) - Average speed of image centre of gravity (CoG) - Average acceleration of image centre of gravity (CoG)
12	Khan *et al.* (2018)[24]	Technical experiment/ Movement and position detection during Vojta therapy	10 infants/ 2 weeks - 6 months old	Supine, Prone (during treatment)	Microsoft Kinect Camera (RGBD data)	Image segmentation/video tracking	All limbs movement classification
13	Kinoshita *et al.* (2020)[25]	Technical experiment, clinical test/Spontaneous movement detection	9 infants/ -1 to 15 weeks	Supine	2D Video Camera	Image segmentation/video tracking	- Movement magnitude - Movement balance - Movement rhythm - Centre of gravity (COG) Movement
14	Li *et al.* (2021)[26]	Technical experiment, identified joints in RGB image, obtain 3D coordinates	12 sequences from MINI-RGBD dataset	Supine	Microsoft Kinect Camera (RGB image and Depth information)	RGB image (2D) - OpenPose based on PAFs Matching depth information	-Body part length - Percentage of correctly localised Parts (PCP) - Percentage of Correct Keypoint (PCK)
15	Marchi *et al.* (2019)[27]	Clinical test/Detect general movements (GMs) and fidgety movements (FMs)	21 infants/ 8-17 weeks	Supine	2D Video Camera	Pose estimation/OpenPose	Kinematic parameters: velocity, acceleration, jerk, Inter-rater reliability
16	McCay *et al.* (2020)[28]	Classify general movements (GMs)	12 videos from MINI RGBD dataset	Supine	2D Video Camera	Pose estimation/OpenPose	Feature sets: - Histograms of Joint Orientation 2D (HOJO2D) - Histogram of Joint Displacement 2D (HOJD2D) - Fused features-HOJO2D+HOJD2D
17	Moccia *et al.* (2020)[29]	Joint detection in Neonatal Intensive Care Unit, NICUs	babyPose dataset, 16 depth videos of preterm infants/ 24-38 weeks (gestation period)	Supine	RGB-D Video Camera	Pose estimation	Root mean square distance (RMSD); 2D & 3D framework
18	Raghuram *et al.* (2019)[30]	Movement detection; generating a predictive model for motor impairment (MI)	152 videos infants/ 3-5 months corrected age (CA)	Supine	2D Video Camera	Large displacement optical flow (LDOF), Logistic regression	- Minimum velocity (V_{min}) - Mean velocity (V_m) - Mean velocity of the vertical direction (V_{my}) - Receiver-operator-curve (ROC) for predictive model
19	Schroeder *et al.* (2020)[31]	Classify general movements (GMs) in infants with cerebral palsy (CP)	29 high risk infants/ 2-4 months corrected age (CA)	Supine	Kinect (RGB-D) Camera	Shape and Pose estimation Skinned Multi-Infant Linear (SMIL)	Automatic GMA classification

Table 3 Study categorisation based on image or video data analysis (cont.)

No	Author	Study Purpose	Subjects/age	Subject position	Recording Tool	Analysis Technique	Feature of Interest
20	Stahl *et al.* (2012)[32]	Detect fidgety movements (FMs), Predict cerebral palsy (CP)	82 infants (15 cerebral palsy diagnosed), 136 videos/ 10-18 weeks post term age (PTA)	Supine	2D Video Camera	Optical Flow, Computer vision-based infant movement assessment (CIMA), Support vector machine (SVM)	- Motion extraction - Feature extraction - Classification
21	Støen *et al.* (2017)[33]	Clinical test/Detect fidgety movements (FMs)	150 high-risk infants/ 10-15 weeks post term age (PTA)	Supine	2D Video Camera	Video analysis software (motion image, frame differencing, pixel changing)	Mean of Quantity of Motion (Q_{mean}) Standard deviation of the centre of motion (C_{SD})
22	Tacchino *et al.* (2021)[34]	Technical experiment, clinical test/Spontaneous movement detection abnormal vs normal	46 preterm, 21 full term infants/ Birth to 8-12 weeks post term age (PTA)	Supine	2D Video Camera	MIMAS2-Markerless Infant Movement Analysis system	39 components; - Quantitative aspects of the segmental motor activity (10 parameters) - Symmetry aspects of the segmental motor activity (13 parameters) - Rhythmic aspects of the global motor activity (12 parameters) - Geometric aspects of the global motor activity (4 parameters)
23	Tsuji *et al.* (2020)[35]	Clinical test/Detect general movements (GMs)	21 infants (47 videos)/ 25-27 weeks gestation age (GA), 8-15 weeks corrected age(CA), No report for 11 infants	Supine	2D Video Camera	Image segmentation/Approximated ellipse and analysis area	- Movement magnitude - Movement balance - Movement rhythm - Movement of the body centre
24	Valle *et al.* (2015)[36]	Clinical test, Movement detection	75 healthy infants/ 9-18 weeks post term age (PTA)	Supine	2D Video Camera	Image segmentation/Video tracking	- Mean of Quantity of Motion (Q_{mean}) - Standard deviation of Quantity of Motion (Q_{SD}) - Standard deviation of the centroid of motion (C_{SD})
25	Wu *et al.* (2021)[37]	Technique experiment, Detect general movements (GMs)	12 real record infant's movement (a public dataset, MINI-RGBD)	Supine	RGB-D Video Camera	3D Pose estimation; Openpose 2D estimation-Supine 3D estimation	Joint motion complexity, Small-world network reconstruction

Study Purpose

Among the selected studies, 11[14–17,19,27,32–36] used image or video analysis for clinical investigation or evaluation based on quantitative results, 12 studies[7,18,20,22,23,25,26,28–31,37] attempted to develop analysis techniques by applying an algorithm or finding efficiency features to represent infant movement and then planned to use it in a real-life situation, and two[21,24] developed an analysis system that was used to ensure precise assessment and treatment procedures. More than half (56%) of the selected studies[7,14–17,22,26–28,31,33,35–37] used image or video analysis to extract quantitative data relevant to comparing movement with general movement assessment.

Study Recording Tools

The recording tools used in this study can be separated into two main groups: the two-dimensional (2D) and Red Green Blue Depth (RGB-D) or Kinect video cameras. The latter can extract data and provide 3D features. In most studies on young infants, the camera setting is placed above the alert infant lying supine on the mattress and wearing a nappy or bodysuit. Video recording and the general movement assessment takes approximately 3–5 minutes per session. Some studies[21,23] used two cameras, top and side views, to record infants in different planes.

Study Analysis Techniques

The computer system performs most of the analytical process that detects body segments or joint body landmarks. The first step for the study analysis[14–16] was selecting an appropriate recording, then cropping the image or video and using it for 'motion image', which exhibited pixels in black (value 0: no movement), and when there were movements between the frames, the pixel is displayed in white. Other analysis processes included the use of software for motiongrams[17], large displacement optical flow[30,32], and markerless infant movements 2D analysis systems such as Movidea[18,19] and the Markerless Infant Movement Analysis System 2[34]. Some studies used a pose estimation algorithm[7,20,26–29,31,37], which programs and automatically detects joint positions and links them as skeletal images. For the RGB-D[24,26,29,31,37] video camera, the researchers used 2D and 3D pose estimation to generate images (such as skeletal images) or interpret joint or movement detection in three planes using algorithms and systems that were more complex for describing infant movements.

Study Feature of Interest

The features of interest in each study varied along with variations in image or video analysis processes, as shown in Table 3; for example, several studies[14–17,19,33,36] reported on the quantity and centroid of motion. In addition, the review studies showed other parameters; velocity, acceleration, rhythm, area, coordinate, and degree.

Discussion

Research into 2D video data analysis has increased in recent years, likely because of continuous studies using markerless movement, which demonstrates natural movement, or the ability to use the results to generate atypical infant prediction or classification models[10]. Moreover, a video can be recorded in different settings, even in remote areas, and processed using computer systems or software. This may be easily accessible for clients in clinical practice[38].

As shown in Table 3, about 80% of all articles reported that subjects were aged 0 to 5–6 months, including low-high risk, preterm, or full-term infants. Additionally, 22 studies showed that the recording was performed in a supine position. The other recording positions included crawling[23], pull-to-sit[21], and Vojta therapy[24]. These subject details and recording positions were relevant to the infant motor development and study objective. More than half of the review articles were based on general movement assessment (GMA), an observational assessment requiring experienced assessors to observe infants lying on their backs in good condition. Previous studies also recommended GMA for a part of the early assessment to predict or diagnose cerebral palsy in infants aged 3–5 months[4,39]. Therefore, researchers have attempted to use 2D video data analysis to detect movement in the supine position and obtain quantitative parameters; for example, the quantity of motion, the centroid of motion, and velocity in consideration of GMA. Thereafter, the parameters from the studies were used to analyse, predict, or classify neurodevelopmental disorders in early infancy, as shown in six studies[7,14,15,28,31,32]. Many studies evaluated the supine position as an early-age assessment following infant development. However, a combination of movement directions of spontaneous movement or the ability to move upper or lower extremities toward the midline in the supine position should be included in further research.

Herein, a 2D video camera, which provided RGB data, and a depth video camera or RGB-D, were used as recording tools. The cameras were placed based on the planes of movement for the supine position, during crawling, pull-to-sit, and Vojta therapy. The motion capture and quantitative assessment precision for both RGB and RGB-D (Kinect) cameras were acceptable for biomedical research, including gait analysis, but not for surgery, which requires higher precision[40]. Therefore, these tools have recently been used for infant movement assessment. Using a 2D video camera, RGB could be widely applied to low-cost cameras such as those in smartphones, tablets, and laptops, and could be used in different settings[38]. The RGB-D (Kinect) is recommended for evaluation of depth information; this tool requires contrast between the subject and background, which can be calibrated easily[40], and the result may be used for 2D and 3D pose estimation[37]. For example, Schroeder et al. (2020)[31] studied the correlation between computing a 3D infant full-body model using an RGB-D camera with Skinned Multi-Infant Linear (SMIL) motion video and conventional RGB video. The study concluded that the SMIL model would employ low-cost tools and RGB-D recording for automatic GMA detection and CP prediction. In addition, both RGB and RGB-D cameras do not require a large amount of space and are useful when trying to achieve non-contact with the infant, especially in health settings requiring strict infection control measures and to discourage viral transmission. Therefore, 2D video and depth cameras can be used depending on the purpose for interpreting data from a video recording.

The analyses in this review were mainly performed using computer systems. Developed packaged programs were used; for example, the General movement toolbox, Movidea software, Computer-based Infant Movement Assessment, Markerless Infant Movement Analysis system 2, and other programs for optical flow, image segmentation or video tracking, and pose estimation. In addition, a variety of techniques were used to extract video data from the supine position. Studies[7,20,26-29,37] in later years (2019-2021) included pose estimation in the methodology before extracting the features of interest, for example, movement's shape and area, body part length, kinematic parameters and joint motion complexity. Pose estimation could be used for movement detection for various purposes across the human lifespan. This has a low cost, is easy to use, and is markerless; real-time tracking can also be performed in any environment. Interestingly, pose estimation algorithms may be included in analysis techniques for infant movement assessment[38].

The features of interest in these studies were varied. Common reported parameters included quantity of motion, centroid of motion, velocity, acceleration, area, coordinate, degree of body angle, and centre of gravity. These parameters could be used to develop a prediction or classification model based on GMA. For instance, Adde et al. (2010)[14] demonstrated the variability of the centroid of motion with a sensitivity of 85% and specificity of 88% during customized computer-based analysis of the fidgety-movement period identified in those who later developed CP. The study by Stahl et al. (2012)[32], which had a similar objective but a different processing method, applied an optical flow method to extract features with a support vector machine (SVM) for classification. The study reported performance measurement with a relative frequency accuracy of 93.7±2.1%, sensitivity of 85.3±2.8%, and specificity of 95.5±2.5%. Støen et al. (2017)[33] evaluated the centre of motion standard deviation (C_{SD}) for a triage model identifying high-risk infants with a GMA sensitivity of 90% and specificity of 80% during the fidgety period. Doniewicz et al. (2020)[7] studied the automatic detection of writhing movements, focusing on general movements (GMs) presented in the first weeks of life, using three main features: factor of movement area (FMA), factor of movement shape (FMS), and centre of movement area (CMA), to analyse writhing movement or other movements. Subsequently, three classification algorithms were applied: SVM with the radial basis function kernel, random forests, and a classifier based on linear discriminant analysis, which demonstrated an accuracy rate of 80%. This study showed the potential of using human pose estimation algorithms for computer-aided diagnostics of infant movement. Ihlen et al. (2019)[22] constructed the computer-based infant movement assessment (CIMA) model for CP prediction; this model had a sensitivity pf 92.7% and specificity of 81.6%, comparable to observational GMA and neonatal cerebral imaging. This method could be an alternative machine-learning model for predicting CP. Raghuram et al. (2019)[30] conducted an automated movement analysis and built a predictive model for motor impairment; a sensitivity of 79%, specificity of 63%, and accuracy of 66% of was demonstrated for the automated GMA, suggesting the usefulness of a prediction model for screening high-risk infants when clinical GMA could not be performed. Tsuji et al. (2020)[35] performed movement classification using a system that evaluated 25 indices based on the clinical knowledge of GMs, with an accuracy rate of 90.2±0.94% for normal and abnormal GMs, and indicated this method for early infancy, such as for infant movement assessment in the neonatal intensive care unit. Evaluation of the aforementioned parameters could be confirmed through the assessment model; for example, Dogra et al. (2012)[21] applied a video-based method to examine the pull-to-sit movement, which is a part of Hammersmith Infant Neurological Examination. The study reported a sensitivity of 80% and specificity of 89% for the tracking algorithm used to evaluate pull-to-sit scores. This study showed that the tracking algorithm could more easily assess the head movement. To ensure that movements could be assessed via videos, Valle et al. (2015)[36] evaluated the test-retest reliability of computer-based video analysis of GMs, and found that C_{SD}, Q_{mean}, and Q_{SD} had intraclass correlation coefficients (ICCs) of 0.8, 0.86, and 0.9 in the ICC (3.1) model, respectively.

This review showed that movement assessment in early infants could be performed using 2D video camera recordings with computer-based processing and state-of-art technology, leading to the prediction and classification of atypical conditions. In addition to expert observation, this method may help analyse the development of infant movements at a very young age. Early atypical detection may facilitate implementation of an appropriate intervention in the young infant population. Additionally, implementation of this movement assessment methodology in a clinical setting would facilitate improvements in infant healthcare and rehabilitation, particularly in a low-source setting.

There were several limitations to applying pose estimation[38] in 2D video or image data analysis, markerless movement assessment, and quantitative precision, as this requires novel technology and further study. In addition, the prediction or classification model is still in the development process, which may limit the use of 2D video analysis in a clinical setting.

Conclusion

Herein, previous studies focusing on 2D video or image data analysis for evaluating infant posture and movements were reviewed. Most studies applied computer-based 2D video recording and data analysis to achieve quantitative results. Computer programs or algorithm may help evaluate movement detection, construct a prediction or classification model, and ensure movement during assessment or treatment in infants.

Take home messages

Image or video analysis is an alternative movement assessment technique for infants. An increasing number of image or video analysis studies involve early infants. Advantages of this analysis include facilitation of natural movement, reduced set-up time, and portability. Image or video analysis is safe and useful during the COVID-19 pandemic.

Conflicts of interest

The authors declare no conflict of interest.

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Immediate effect of Vojta therapy on walking speed and postural balance of individuals with chronic stroke: a pilot study

Chatwalai Sonthikul[1*], Wanida Kaewmunee[1], Sarocha Bunphruek[2], Kanyanuth Sroisakul[2], Nannapat Thuphom[2], Weeranan Yaemrattanakul[1]

[1] Department of Physical Therapy, Faculty of Medicine, Prince of Songkla University, Songkhla, Thailand.

[2] Undergraduate Student of the Department of Physical Therapy, Faculty of Medicine, Prince of Songkla University, Songkhla, Thailand.

KEYWORDS
Vojta therapy;
Walking speed;
Balance;
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ABSTRACT

The objective of this pilot study was to investigate the immediate effects of Vojta therapy on walking speed, balance, and symmetry of weight bearing in individuals with chronic stroke. Eight individuals (5 males and 3 females) with chronic stroke participated in the pilot study. Each participant received one session of prolonged passive stretching for 15 minutes and Vojta therapy for 30 minutes. All of the outcomes were assessed before and immediately after the intervention. Walking speed (10-meter walk test) was the primary outcome. Dynamic balance (timed up and go test), static balance (sharpened Romberg test), and symmetrical weight bearing (stance symmetry test) were the other outcomes. The statistical analysis compared between before and after the tests using the Wilcoxon test. The level of statistical significance for all measures was set at p-value < 0.05. Walking speed, dynamic balance, and static balance were significantly improved after the intervention, 0.48 m/s to 0.52 m/s (p-value = 0.018), 25.00 s to 22.35 s (p-value = 0.025), and 7.44 s to 14.92 s (p-value = 0.036), respectively. Symmetrical weight bearing also improved, but the change was not statistically significant. This pilot study showed that one session of Vojta therapy can improve walking speed and balance.

*__Corresponding author:__ Chatwalai Sonthikul, M.Sc. Department of Physical Therapy, Faculty of Medicine, Prince of Songkla University, 15 Karnjanavanich Road, Kho Hong, Hat Yai, Songkhla 90110, Thailand. E-mail: chatwalai.s@gmail.com
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Introduction

Stroke, also known as cerebrovascular disease, is the world's second leading cause of death and lifelong disability[1]. The number of individuals suffering a stroke is forecast to more than double by 2050, with elderly persons accounting for the majority of the increase [2]. The rising number of individuals having a stroke each year around the world has resulted in increasing health care expenditures[3].

A stroke is caused by a vascular insult to the brain, resulting in the death of brain cells and the reduction of brain function, which then manifests as weakness, sensory impairment, abnormal muscle tone, and/or perceptual deficits[1]. These deficits lead to decreases in postural control, walking ability, activities of daily living, and quality of life[4-6]. When rehabilitation is undertaken, restoration of walking ability is the primary goal of the patient, caregiver, and rehabilitation team. Walking speed is a key indicator of poststroke gait performance[7], and its improvement is a sign of good stroke rehabilitation progress, indicating reduced disability and improved function at both activity and participation levels[8].

There are several physical therapy (PT) techniques commonly used to improve walking speed in individuals with stroke, including lower extremity strengthening, motor imagery, electrical stimulation, biofeedback, treadmill training, rhythmic auditory stimulation, overground walking with body weight support, and robotic gait training[7,9]. However, none of these techniques has been found to be highly effective alone, and PTs normally use a combination of them over a long period of time before seeing significance.

Vojta therapy, also known as "Reflex Locomotion Therapy", was discovered by Prof. Václav Vojta in the 1960's. His theory was that, based on the assumption that a human has reflex locomotion, repeated stimulation of the central nervous system could trigger specific motor patterns, which could serve as "building blocks" for normal movements and automatic postural control[10]. The reflex locomotion pattern consists of reflex rolling which can start out of a supine position or side-lying position, and reflex creeping which can start out of prone-lying position. The response of stimulation in reflex locomotion can trigger motor, autonomic, and/or sensory responses. The motor responses can appear in a "partial pattern" which consists of only some parts of the full motor response pattern. The "whole pattern" of reflex locomotion responses involves all four limbs, pelvis, trunk, chest, spine, facial, extraocular, and even swallowing muscles. The motor patterns are not static; they are alternating, reciprocating, and show interlimb coordination. The overall appearance of reflex locomotion looks like a primitive fictive whole-body locomotion. Observation of these patterns led Prof. Vojta to believe that the neural coordination centers of reflex locomotion could involve a large network involving the spinal and supraspinal central nervous system. Therefore, He hypothesized that Vojta therapy could stimulate the Central Pattern Generator (CPG), which is the central controller of human walking [11,12].

To successfully activate these reflexive movement patterns, the patient must assume one or another specifically predefined "start positions", which involve exact joint angles within each extremity and precise spatial relationships between the limbs [10]. On each side of the body, there are a total of ten reflex pressure points or "zones". These may be activated independently or in combination, depending on the start position and therapy objectives[10]. Each of these zones well described relationship to palpable anatomical bony landmarks. In order to stimulate any particular zone, mechanical force must be applied with appropriate magnitude and direction to elicit the desired response[10].

In each Vojta therapy session, the therapist not only stimulates the reflex locomotion but also applies manual resistance to one or some parts of the reflexive motor response, leading to summation of reflex response intensity. This could lead to the appearance of a more complete whole body or "global" pattern, which will hopefully lead to long-term potentiation (LTP), or long-term facilitation of the involved neural circuits. Therefore, the repeated stimulation of Vojta therapy will hopefully lead to improved CNS function, and for the purpose of gait and balance rehabilitation, improved co-operation between the brain and spinal cord, and/or activation of the core stabilizing muscles and hip muscles[13-17].

Vojta therapy has widely been used to treat adults and children suffering from neurological or musculoskeletal disorders[17-22]. Khiewcham et al. observed that 20 children with cerebral palsy showed a statistically significant improvement in walking distance and double support time after eight weeks of Vojta therapy[19]. Sonthikul et al. found that 11 cases of chronic complete spinal cord injury immediately improved in dynamic sitting balance and gross motor function following Vojta therapy[22]. In addition, Tayati et al. found that Vojta therapy could enhance dynamic balance in individuals with chronic stroke as measured by timed up and go testing (TUG)[20]. In another study, Epple et al. found that Vojta therapy was statistically superior to traditional physical therapy in postural control in individuals with severe acute stroke[21]. Vojta therapy has been shown to enhance postural control in stroke patients in previous studies[20,21].

However, the impact of Vojta therapy on walking speed is unknown; Thus, as we wished more precise information for our work with Vojta therapy in our institution. We felt that a pilot study was necessary before RCTs could be conducted to provide more concrete evidence of the efficacy of Vojta therapy. Therefore, this pilot study was undertaken before randomized controlled trials can be conducted to establish its efficiency. Therefore, a pilot experimental study was conducted to investigate the effect of Vojta therapy on walking speed, static and dynamic balance, and symmetry of both legs in individuals with chronic stroke.

Materials and methods

Study design

The study was a pilot experimental study which was approved by the Human Research Ethics Committee (HREC) of our institution, Faculty of Medicine, Prince of Songkla University (No. 63-350-30-2).

Participants

The participants of this study were eight interesting community dwelling chronic stroke patients recruited from Songkla province, Southern Thailand from December 2020 to April 2021. Before being admitted to the study, all participants were examined against the inclusion-exclusion criteria after giving written informed consent. The following were the inclusion criteria: (1) over 18 years old, (2) one-sided weakness (hemiparesis), (3) Brunnstrom stage of motor recovery ≥ 3, and (4) able to walk 10 meters on their own with or without the use of a tripod cane. The exclusion criteria were: (1) having received Vojta therapy within the previous month, (2) having problems with perception and understanding as measured by a Thai-Mental State Examination (TMSE) score of less than 23 points, (3) cardiovascular, musculoskeletal, and/or neurological system disorders that are precautions or contraindications for Vojta therapy, and (4) vision problems that could not be corrected with eye glasses.

Intervention

Each participant received one session of therapy which started with a prolonged 15-minute passive stretching and ended with 30 minutes of Vojta therapy. The targets of the stretching exercises were the trunk rotator muscles, hip flexor muscles, hip extensor muscles, hip adductor muscles, and plantar flexor muscles. The participants were stretched and held each position for 15 seconds with 5 repeats. A typical Vojta therapy session consists of reflex stimulation in the supine position, side-lying position, and prone position, in order to trigger the “first phase” and “second phase” response pattern of reflex rolling and reflex creeping, respectively. In each position, the patient received 10 minutes of Vojta therapy in which both left and right-side zones were stimulated, for a total time of 30 minutes. During the first phase of the reflex rolling, the therapist stimulated the chest zone with the patient in the supine position and observed the chest expansion and abdominal contractions as a clue of the reflex response[17]. During reflex rolling, the second phase stimulation was applied to the scapular zone, which is at the junction between the upper 2/3 and inferior 1/3 of the medial scapular border. Reactions such as shoulder support and abdominal contractions[17] were relied on as indicators of successful stimulation. The reflex creeping also stimulated the calcaneus zone when the patient was in the prone posture to induce forward movements and global reactions (Figure 1)[17].

a. Reflex rolling first phase (a) b. Reflex rolling second phase (b) c. Reflex creeping (c)

Figure 1 Process of Vojta therapy (a) Reflex rolling the first phase, (b) Reflex rolling the second phase, (c) Reflex creeping.

Outcome measurements

Each participant was tested both before and immediately after the intervention. All of the tests used video recorder, and the researcher record the times on a video recorder. The assessor monitored the participants during the test to make sure they did not fall, but they did not offer any physical assistance. Between test, the participants were allowed to take as much time as they needed to rest. The 10-Meter Walk Test (10 MWT) was used to assess walking speed as the primary outcome measure. This test has excellent test-retest reliability in the chronic phase of stroke[23]. All participants walked on a flat surface at a comfortable self-selected walking speed for the 10 meters. Each participant did the 10MWT two times, and the average time of the middle 4 meters was used for analysis.

The TUG was used to determine the dynamic balance of each participant. For individuals with stroke, this test has excellent test-retest reliability[24]. When the assessor said, “start,” the participant rose from their chair, walked as quickly and safely as possible for a 3-meter distance, returned to the chair, and sat down with or without a walking device. The best time of three trials was used for analysis.

The Sharpened Romberg Test (SRT) was used to measure static standing balance in stroke[25]. It can assess proprioception in the joints of the lower limb[26]. The participants were requested to stand with their shoes removed, one foot in front of the other, hands crossed, eyes closed, and maintain their stance. The time until a participant moved either foot was recorded. In our study the maximum time of three trials was used for analysis.

The Stance Symmetry Test (SST) was used to determine the weight distribution of both legs. The participants placed their feet on different weighing scales placed 11% of the participant’s height apart, and were instructed to stand still for 30 seconds. The assessors recorded the weight carried by each leg at the 25^{th} second[27]. The results of three trials were averaged using the following formula for a symmetry ratio[28]:

$$\text{Symmetry ratio} = \frac{\text{Average weight bearing through the affected leg}}{\text{Average weight bearing through the non affected leg)}}$$

Statistical analysis

The data were presented as median (interquartile range). To evaluate the effect of the intervention, the outcome measures before and after treatment were compared using Wilcoxon signed rank test. The level of statistical significance for all measures was set at *p*-value < 0.05. SPSS software version 17.0 was used for all statistical analyses.

Results

The study included eight individuals with chronic stroke (average time since stroke: 2.88 years), 5 males and 3 females. Table 1 presents their clinical and baseline characteristics. The median age and body mass index were 55.00 years and 25.66 kg/m^2, respectively. All of the participants had had an ischemic stroke (n = 8). Seven were paralyzed on the left side, while one person was paralyzed on the right side. Two participants had Brunnstrom stages of motor recovery III and IV and four participants had Brunnstrom stage of motor recovery V. The median TMSE score was 28.00. Four participants had hypertension, three had diabetes mellitus, four had dyslipidemia, and one had gout.

As can be seen in Table 2, there was a statistically significant change in 10 MWT, TUG, and SRT according to the Wilcoxon signed rank test before and immediately after the intervention. The walking speed statistically significantly increased from 0.48 m/s to 0.52 m/s when assessed with the 10MWT (*p*-value = 0.018). The time spent on the TUG statistically significantly decreased from 25.00 s to 22.35 s (*p*-value = 0.025). The time spent on the SRT statistically significantly increased from 7.44 s to 14.92 s (*p*-value = 0.036), but there was no statistically significant difference in the SST (*p*-value = 0.161).

Discussion

The aim of this study was to examine the immediate effects of Vojta therapy on walking speed, balance, and symmetry of weight bearing in individuals with chronic stroke. All the participants received reflex rolling and reflex creeping which is a component of reflex locomotion for activate normal movements and postural control[10]. This study found significant difference before and after the training in walking speed, dynamic balance, and static balance. There are three possible mechanisms which could explain the gait and balance changes. First, the Vojta therapy stimulates the transversus abdominis, diaphragm, hip, and rectus femoris muscles which are important in vertical positions such as standing or walking[13,15-17]. Second, Vojta therapy stimulates the propriospinal tract, which connects the brain and spinal cord[13]. The propriospinal tract modulates ascending and descending input to the CPG for locomotion, breathing, and autonomic functions[29]. Third, Vojta therapy stimulates pontomedullary reticular formation and the putamen function[14]. These brain parts control postural control and locomotion before initiating movement by coordinating with the brain stem[30]. This study is consistent with a previous study which found that Vojta therapy improved the kinematics of hip and knee joints during walking in children with spastic diplegia[18]. Khiewcham et al. showed a statistically significant increase in walking distance and walking parameters following Vojta therapy in 20 children with cerebral palsy in a 2016 study[19]. Although the change of walking speed in this study displayed a less than minimal clinically important difference[31], all participants had increased walking speed following the therapy session, and one participant said she noticed that walking was easier with no toe drag. The mechanism for this may have resulted from improved ankle dorsiflexor contraction activation and ankle plantarflexor inhibition following the Vojta therapy, as both muscles are required for walking[32].

Table 1 Demographic and clinical characteristics of the study participants

ID	Gender[a]	Age (years)[b]	BMI (kg/m^2)[b]	Onset (years)[b]	Type[a]	Affected side[a]	Brunnstrom stage[a]	TMSE (Score)[b]	Underlying disease(s)[a]
1	Male	63	28.13	6.3	Ischemic	Left	IV	26	
2	Male	59	23.74	1.1	Ischemic	Right	IV	29	
3	Male	37	26.64	2.1	Ischemic	Left	V	30	HT, DLP
4	Male	64	24.69	3.8	Ischemic	Left	III	27	HT, DM, DLP, Gout
5	Female	48	23.56	1.5	Ischemic	Left	IV	27	DM
6	Male	40	26.99	4.7	Ischemic	Left	V	30	HT, DLP
7	Female	52	20.06	4.8	Ischemic	Left	IV	29	
8	Female	58	26.63	1.1	Ischemic	Left	III	27	HT, DM, DLP
All (n=8)	Male 5 (62.5%) Female 3 (37.5%)	55.00 (42.00, 62.00)	25.66 (23.67, 26.92)	2.88 (1.17, 4.65)	Ischemic 8 (100%)	Left 7 (87.5%) Right 1 (12.5%)	III 2 (25%) IV 4 (50%) V 2 (25%)	28.00 (27.00, 29.75)	HT 4 (50%), DM 3 (37.5%) DLP 4 (50%) Gout 1 (12.5%)

Note: [a] presented with frequency count (percentage), [b] presented with median (Q_1, Q_3)
Abbreviations: BMI, body mass index; TMSE, Thai mental state examination; HT, hypertension; DM, diabetes mellitus; DLP, dyslipidemia.

Table 2 Comparison of outcomes before and after intervention

Variable	Before	After	*p*-value
10-Meter walk test (m/s)	0.48 (0.33, 0.67)	0.52 (0.37, 0.68)	0.018*
Timed up and go test (s)	25.00 (19.01, 32.71)	22.35 (17.45, 29.57)	0.025*
Sharpened Romberg test (s)	7.44 (5.44, 12.90)	14.92 (7.62, 27.37)	0.036*
Stance symmetry test	0.79 (0.64, 0.98)	0.85 (0.78, 1.09)	0.161

Note: Variables are presented as Median (Q1, Q3), *p*-values were analyzed from Wilcoxon signed rank test, * *p*-value < 0.05

Individuals with stroke often have standing balance problems that associate with the ability to support the weight bearing of the affected limb. This causes more problems with the displacement of the center of mass outside of the base of support resulting in unstable walking. There is evidence suggesting that patients with better balance have good walking speed as well[(33)]. This study is consistent with a study by Tayati, which found that Vojta therapy can immediately improve dynamic balance in individuals with chronic stroke[(20)], while Epple at al. also found that Vojta therapy improved postural control in patients with severe acute stroke[(21)].

In this study, even though symmetrical weight bearing was not statistically significantly improved, all participants had improvements in transferring weight to the affected limb. An earlier study reported that improvements in symmetry between affected and unaffected limbs resulted in improved standing balance and walking speed[(33)]. In addition, another study reported that compelled weight bearing exercises can improve weight bearing and walking speed after intensive six weeks of training[(34)] while this study is not consistency because of this study applied only one time of treatment which might not be sufficient for significant improvement.

The intervention was completed by all individuals without any harmful side effects. This study had limitations such as difficulties in generalizing its contents and evaluating the residual or long-term effects because our sample size was very small and had an immediate effect; also, there was inadequate evidence to assess walking function because the study was focused on the walking speed. Future studies should focus on improving total motor and walking functions, including randomized controlled trials to compare with conventional physical therapy.

Conclusion

This study showed that Vojta therapy is promising as a possible effective treatment method for improving walking speed and balance in individuals with chronic stroke. The next step would be to perform randomized clinical trials to compare the efficacy of Vojta therapy with conventional therapies in enhancing walking ability in individuals with chronic stroke, as well as to develop improved treatment techniques for using Vojta therapy.

Clinical implication

• Vojta therapy achieved a significantly improvement in improving walking speed and balance in individuals with chronic stroke.

Conflicts of interest

The authors have no conflicts of interest. There was no financial or instrumental assistance. This project was funded by Research Foundation, Faculty of Medicine, Prince of Songkhla University.

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ORIGINAL ARTICLE

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Effect of sling exercise on running speed, reaction time, and dynamic balance in people with chronic ankle instability

Chairat Phuaklikhit[1], Pimwalun Klamrat[1], Joranin Thaiatwitee[1], Hathai Suepboontawan[1], Suwichcha Noradee[2]

[1] Faculty of Physical Therapy and Sports Medicine, Rangsit University, Thailand.
[2] Football Association of Thailand, Thailand.

KEYWORDS
Chronic ankle instability;
Sling exercise;
Running performance;
Core stability.

ABSTRACT

Chronic ankle instability can affect speed, plantar flexion reaction time and, dynamic balance, all of which are important aspects of running performance. Core muscle activity on both a stable and an unstable exercise can directly enhance performance. However, there remains a paucity of understanding about the effects of different types of exercise on running performance. Thus, the purpose of this research was to compare the effects of sling and floor exercise on running speed, plantar flexion reaction time, and dynamic balance. Twenty-two participants with chronic ankle instability were enrolled in this study. Participants were split into two groups, each receiving core muscle training three times per week for four weeks. Running speed, plantar flexion reaction time, and dynamic balance were assessed using a single beam photocell timer, electromyography, and Y Balance Test™ at baseline and after four weeks of training. As a result, statistical improvements in running speed, plantar flexion reaction time and dynamic balance were shown in the sling group (11.50 vs. 10.95, p-value = 0.016, 369.08 vs. 240.15, p-value = 0.006 and 79.61 vs. 86.27, p-value = 0.036, respectively). However, the floor group showed only dynamic balance (84.98 vs. 96.53, p-value < 0.001) compared to the baseline. Further, there was a statistical difference after exercise in plantar flexion reaction time and dynamic balance (240.15 vs. 334.19, p-value = 0.042 and 86.27 vs. 96.53, p-value = 0.005, respectively). Thus, the results showed that four weeks of a sling and floor-based core muscle training program could increase running performance. To summarize, sling exercise focuses on speed, whereas floor exercise emphasizes balance.

*Corresponding author: Chairat Phuaklikhit, PT, MSc. Faculty of Physical Therapy and Sports Medicine, Rangsit University, Thailand.
E-mail: chairat.p@rsu.ac.th
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Introduction

Running is the most popular type of exercise for people of all ages. Furthermore, running benefits total functional performance, including cardiorespiratory capacity development[1]. On the other hand, it can result in injuries to the body structure due to accidents or the usage of the wrong shoes or field. A simple self-assessment questionnaire found that 45 amateur runners in Thailand had a history of injury (48.9% ankle joints, 28.9% knee joints, 17.8% back, and 4.4% hip joints). Based on statistical data from the amateur runners, ankle sprains were not the injury with the highest prevalence (20.2% of the most common injury sites) and incidence (62.5-111 per 1000 person-year) in runners following knee pain[2]. However, most ankle sprains result in recurrent injuries to the same joint (lateral ankle sprain) and lead to chronic ankle instability (CAI)[3]. The CAI has been linked to a reduction in ankle muscle strength, neuromuscular control, postural control, ankle joint position sense, and kinesthesia[4, 5]. Summarized to a delayed reaction time, it affects the motor time of muscles around the joint[6]. These limitations will have a direct impact on running pace and performance.

The fundamental treatment for an ankle sprain in its early stages is ice compression and anti-inflammatory medication. During the stable period, rehabilitation exercise for strengthening, proprioceptive awareness, strength, flexibility, and balance is employed[7]. Furthermore, a previous study by Dastmanesh and Shinkle (2012) found a relationship between core muscle strength, stability, and improved running performance after an ankle sprain[4]. The exercises for core muscle strength can improve postural control and functional mobility. Additionally, they can reduce the risk of lower-limb injuries when running[4, 8]. The anatomy training approach is used to describe the effectiveness due to the fascia lines system, such as the superficial back line, superficial front line, lateral line, spiral line, functional line, and deep front line. This is explained by the link of body soft tissue as muscle activation transmission[9], which affects running performance. Core muscle training is being used in a variety of ways. The term "floor exercise" refers to a static contraction of the core muscle that is aided by limb movement or external disturbance on a stable surface. This results in a considerable increase in core stability. Sling exercise, on the other hand, is an unstable support exercise that consists of multi-planar and multi-joint motions against gravity with body weight as resistance, which can help with a proprioceptive sense of the spinal joint and core stability muscle strength through neuromuscular control[10, 11]. Furthermore, the unstable support exercise was found to increase muscle activation and proprioceptive sensitivity more than the stable support exercise in a prior study[12, 13]. However, there was a lack of evidence concerning the improvement in ankle proprioceptive sensibility or running performance following a session of sling exercise training. As a result, the purpose of this research is to compare the effects of sling exercise and floor exercise after four weeks of training.

Materials and methods

Participants

A randomized control trial was used in this study. The main outcome is running speed. The sample size was calculated using the G-power program (version 3.0.1) based on assumption with the following parameters: ANOVA: Repeated measures, within-between interaction, effect size of 0.5, significance level (α) of 0.05, desired power (1-β) of 0.95, and 30% dropout rate. Twenty-two participants were assessed. All participants were allocated equally to two groups with sex matched-pairs by sealed envelope randomization, sling group, and floor group. The inclusion criteria were as follows[14]: (1) Age between 18-23 years old, (2) Exercise in running at least 30 minutes per day, three days per week, (3) Normal body build (BMI = 18.5-22.9 kg/m^2), (4) History of an ankle sprain on the "kick-off" side, (5) Cumberland Ankle Instability Tool < 24, (6) Positive for any anterior drawer test or talar tilt test, (7) Level of core stability test 0-2 by pressure biofeedback. The exclusion criteria were as follows: (1) History of lower limb surgery in the six months before participation, (2) Acute injury of a lower limb during the testing period, (3) Diagnosed with heart disease, (4) Taking any medication causing drowsiness during the testing period, (5) Hearing impairment or deafness. The study was approved by the ethics review board of Rangsit University (Approval number RSUERB2020-0077).

Protocols

Before the group's allocation, all participants who satisfied the inclusion and exclusion criteria were put through a single 60-meter sprint race trial. Participants were told to run as quickly as they could following the start sound, and the highest running speed was recorded by a single beam photocell timer (Dashr, USA) from the starting point to the endpoint(15, 16). All participants were allowed one round of practice, but they had to rest for at least five minutes before data collection. The plantarflexion reaction time was measured using surface electromyography (DELSYS, Delsys Incorporated, USA) located at the sprained leg on the middle part of the medial gastrocnemius. Participants were allowed to set in the block as starting position with a sprained leg on the back. When the starting sound was heard, the participants began to run as fast as possible. The delay of the graph from the initial signal to the first muscle activation was recorded as plantarflexion reaction time, and the average of two testing times was employed in this study(17). Measurement of dynamic balance with a Y Balance Test™ (modified Star Excursion Balance Test; mSEBT) was reported to be reliable with the standardized equipment and methods(18). The instruction was to execute a single-leg stand in the middle of the Y-balance kit platform (FMS Y-BALANCE) on the injured ankle. Both hands were placed on the hips during the test, and one leg was used to push a box as far as possible with the big toe and return to the initial two-foot standing position, three times for practice and three times for the test in each direction(19). Each subject was allowed to bend the knee and hip of the fixed leg to reach as far as possible while reaching for the leg. However, the task resulted in failure and would have to be redone if the subject 1) could not stand on one leg, 2) moved the fixed leg from the marked point, 3) could not hold both hands on the hips, 4) could not return to the initial two-foot standing position, 5) showed obvious swaying during the test, 6) the big toe on the reached leg touched the ground before returning to the center, or 7) the reached leg showed pushing force onto the box. The greatest distance in each direction was used to calculate by the formula for composite reach distance, which is the total of three directions of reach distance divided by three times the leg length and multiplied by 100(20). All of the data collection was recorded by the researcher (A), an experienced physiotherapist, and a researcher on the sports field.

Exercise protocols

Participants were given five models of sling exercises (Redcord®) or floor exercises, as indicated in Table 1, under the supervision of the researcher (B), an experienced sports physiotherapist, and rehabilitation exercise. The experimental group was given the sling exercise, which was recommended by the Redcord® fitness program for running and theory Redcord active introduction handbook (Figure 1). The control group, on the other hand, received the floor exercise, which was devised similarly to the experimental group (Figure 2). All participants began with the basic protocol and gradually increased the level of difficulty based on their performance each week by adjusting the lever arm and the height of the strap, as judged by exercise effort and participant feedback. After 12 sessions during the four weeks of training, the procedures were complete.

Table 1 Exercise protocols

Group	Exercise	Intensity
Sling	Supine bridging - one leg	Hold 6 sec./rep 6 rep/ set 6 set
	Supine knee flexion - straight hips	Hold 6 sec./rep 6 rep/ set 6 set
	Side-lying - hips abduction	Hold 6 sec./rep 6 rep/ set 6 set
	Prone plank with cycling	20 rep/ set 3 set
	Backward lunge + hip pull and raise	20 rep/ set 3 set
Floor	Supine bridging	Hold 6 sec./rep 6 rep/ set 6 set
	Bridging with step	Hold 6 sec./rep 6 rep/ set 6 set
	Side plank with hip abduction	Hold 6 sec./rep 6 rep/ set 6 set
	Mountain climber	20 rep/ set 3 set
	Backward lunge with heel raise	20 rep/ set 3 set

Figure 1 Models for sling exercise (a) Supine bridging - one leg, (b) Supine knee flexion - straight hips, (c) Side-lying - hip abduction, (d) Prone plank with cycling, (e) Backward lunge - hip pull and raise.

Figure 2 Models for floor exercise (a) Supine bridging – one leg, (b) Bridging with step, (c) Side plank with hip abduction, (d) Mountain climber, (e) Backward lunge with heel rise

Statistical analysis

In this study, IBM SPSS Statistics Version 22 was utilized for data analysis. The Shapiro-Wilk test was used to determine the normality of data. Descriptive statistic was used to test the general characteristics. The differences in running speed, plantar flexion reaction time, and dynamic balance across times and groups were compared using a two-way mixed repeated ANOVA. The differences between those times and groups were analyzed using the Bonferroni post hoc test. A statistically significant difference was defined as a p-value < 0.05.

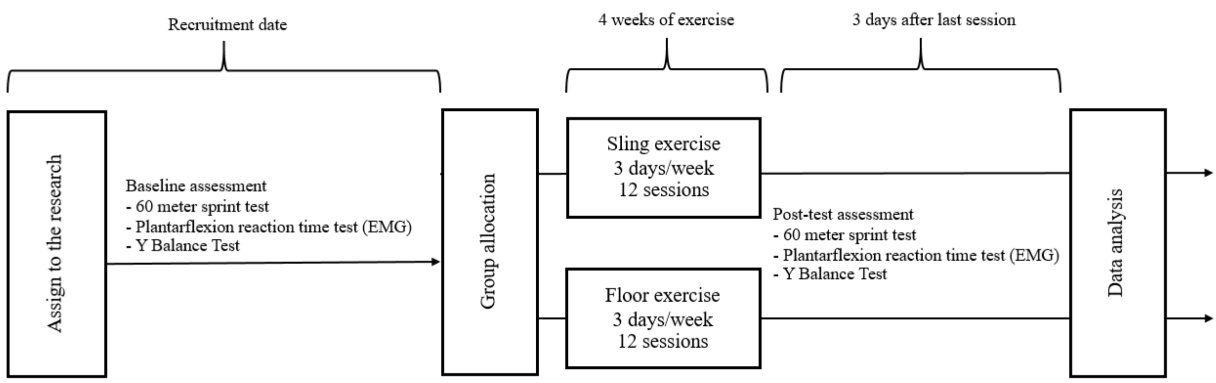

Figure 3 Flow chart diagram

Results

During the study, participants did not report any adverse side effects, and all subjects completed the study. The characteristics of the 22 subjects are shown in Table 2.

Table 2 Demographic and clinical characteristics

Variable	Sling exercise (n = 11)	Floor exercise (n = 11)	*p*-value
Age (years)	19.73 ± 1.27	19.73 ± 0.9	1.00
Gender [Female; n (%)]	7 (63.64%)	7 (63.64%)	
BMI (kg/m^2)	20.30 ± 1.75	20.68 ± 2.09	0.651
Core stability (grade)	1.09 ± 0.7	1.18 ± 0.6	0.748
CAIT (points)	19.27 ± 4.23	18.82 ± 4.35	0.806

Note: Values are shown as means ± SD; BMI, Body mass index; CAIT, Cumberland Ankle Instability Tools

For the results, the changes in running performance in both groups are shown in Table 3. Sling exercise showed a significant change in running speed, plantar flexion reaction time, and dynamic balance compared to baseline (*p*-value = 0.016, 0.006, and 0.036, respectively). However, the floor group only showed a significant change in dynamic balance compared to baseline (*p*-value < 0.001). In addition, there was a significant difference between the groups at weeks 4 for plantar flexion reaction time and dynamic balance (*p*-value = 0.042 and 0.005, respectively) (Figure 4).

Table 3 Comparison of running speed, plantarflexion reaction time, and dynamic balance between groups and within groups

Variable		Sling exercise (n = 11)	Floor exercise (n = 11)	*p*-value
Running speed (seconds)	Pretest	11.50 ± 1.87	11.58 ± 1.64	0.908
	Posttest	10.95 ± 1.72	11.38 ± 1.62	0.402
	p-value	0.016*	0.405	
Plantarflexion reaction time [milliseconds]	Pretest	369.08 ± 101.17	391.08 ± 144.25	0.642
	Posttest	240.15 ± 72.93	334.19 ± 91.28	0.042*
	p-value	0.006*	0.266	
Composite reach distance (%)	Pretest	79.61 ± 6.32	84.98 ± 3.71	0.055
	Posttest	86.27 ± 6.55	96.53 ± 3.10	0.005*
	p-value	0.036*	< 0.001**	

Note: Values are given as means ± SD; *significant difference (*p*-value < 0.05); **significant difference (*p*-value < 0.001)

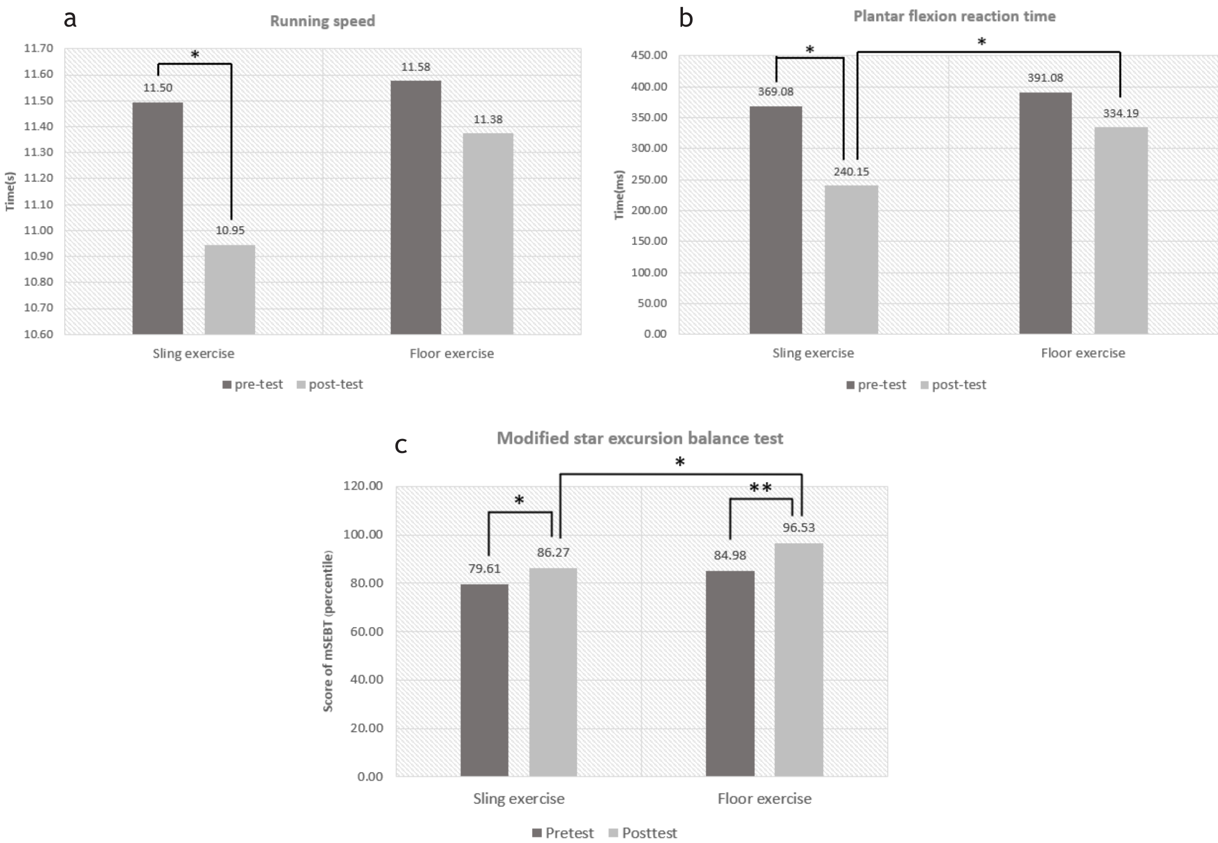

Figure 4 Comparison of (a) the running speed, (b) plantar flexion reaction time, and (c) composite reach distance within and between groups

Note: *significant difference (*p*-value < 0.05); **significant difference (*p*-value < 0.001)

Discussion

The main finding of the present study was that the four weeks of core stability training by sling exercise resulted in significant improvement in running speed, plantar flexion reaction time, and dynamic balance.

The impact of the training program on sling exercise can increase running speed and plantarflexion reaction time. Concentration was on activating the key muscle groups involved in running, such as the core, gluteus, thigh, and ankle plantar muscles. In this study, the protocol included a closed-chain isometric exercise with a single-limb component, which enhances target muscle activation the most. Co-contraction of the core body and surrounding the joint muscle should also be encouraged[21]. As a consequence, the exercise program used in this study can help to stabilize the core and joint muscles.

The core muscles will be the first to operate as a central component, transferring power along the fascia line to the limb. The relationship between the core muscle and the limb muscle was described using the anatomical line including the superficial front line, superficial back line, and spiral line[9]. Consequently, the limb muscle will react faster to the movement[22]. Furthermore, core muscle activation involves anticipatory postural adjustment (APAs), which occurs before voluntary functional movements, and are essential aspects of postural control[23]. The feed-forward postural response can be used to explain this phenomenon. In addition, the APAs operate to maintain lumbopelvic stability during predicted postural perturbations, just as those turned up during limb-oriented movements[24]. Conversely, the reaction force will send feedback to the core muscle when the action has occurred at the limb. Afterward, the core has to respond to work and achieve proper functioning in accordance and continuity with the movement[25]. In summary, the core muscle will influence all other segments in the chain to react and perform with proper timing and control.

Running is a unilateral hip flexion and extension activity that puts significant destabilizing torque on the trunk. Stronger core muscles allow for better control of the torque created when running, resulting in less energy wasted in unnecessary movement and improved performance[8]. Due to CAI problems, there is a proprioception deficit, a decrease in muscle activation around the ankle joint, a change in neuromuscular control, and leading to a decrease in running performance. The core-based exercise will help to generate muscular activity from the proximal to distal regions, as well as relearning of muscle activation patterns and improving proprioception. Same as previous studies, the specialized core stability and balance exercise can enhance core muscle strength, resulting in improved core stability, balance, and overall running performance[26].

The sling exercise has also proven to be considerably superior to the floor exercise because lowering the base of support with an unstable platform results in higher instability. In addition, the sling exercise involves higher activation of the core and gluteal muscles, which helps to improve stability levels[13, 27]. Furthermore, sling exercises increase the lever arm length, playing a significant role in producing an optimal amount of muscle activation[28].

Proprioceptive kinesthesia activation also occurred in instability training, which was one factor for the improvement of running performance. Proprioceptive kinesthesia is a mechanism of sensation that acts as the judgment of movement[5], which is related to the speed of the movement time due to strongly promoted by activation of the muscle spindle and Golgi organelles in cells of the joint tendons, and muscle spindles. In this study, increases in reaction time and running speed were shown to be superior in the sling exercise. Similar to previous studies of the sling exercise, the improvement of proprioceptive position sense and kinesthesia after training was shown better than the conventional group[29].

The composite reach distance improved substantially more in the floor exercise than in the sling exercise. Since floor exercises are included in active movement and balance exercises, it shows the higher change of balance outcome compared to the sling exercise that factor in the somatosensory stimulation with balance exercise[30]. Particularly, the floor exercise in this study focused mainly on ankle stability. Nonetheless, the somatosensory stimulation with balance exercise demonstrated the greatest improvement in the total clinical rating scale, as a metric mentioned above[30].

This research had a few limitations. First, this study did not follow up on long-term improvement in running performance after four weeks of exercise. Second, the whole-body functional balance assessment while jogging or running must be adequate for evaluating the effect of sling exercise and accurately detecting balance changes. Therefore, functional balance must be used to determine the change in core stability-related balance study due to the running skill movement. In addition, this technique should be used to study professional sprinters in future research.

Conclusion

Both core stability exercises can improve the running performance, such as running speed, plantar flexion reaction time, and dynamic balance. Particularly in sling exercise, a significant improvement of all parameters was shown after four weeks of exercise. On the other hand, floor exercise was improved significantly only in dynamic balance and was superior to the sling group.

Take home messages

Four weeks of sling exercise can increase running ability by enhancing the core muscles and proprioceptive awareness, particularly in terms of maximal sprint speed and muscular responsiveness to signaling.

Conflicts of interest

The authors declare no conflicts of interest.

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ORIGINAL ARTICLE

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The prevalence of glucose-6-phosphate dehydrogenase deficiency in Trat province, eastern Thailand

Nattaphol Prakobkaew[1*], Surachat Buddhisa[1]

[1] Faculty of Allied Health Sciences, Burapha University, Thailand.

KEYWORDS
G6PD deficiency;
Fluorescent spot test;
G6PD enzyme activity.

ABSTRACT

The most prevalent X-linked enzymopathy in Thailand is glucose-6-phosphate dehydrogenase (G6PD) deficiency. The eastern Thailand border region is at risk of developing drug-resistant malaria and the frequency of G6PD deficiency and the characterization of G6PD variants are unclear. A fluorescent spot test (FST), quantitative G6PD activity assay, and polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) to identify common G6PD variants were used to evaluate the prevalence of G6PD deficiency. G6PD deficiency was found in 12.06% of the population. Females with an FST of 6.43% were intermediate, whereas females with an FST of 1.61% were deficient, and men with an FST of 4.02% were deficient. G6PD Viangchan was the most common variant, followed by G6PD Mahidol, according to PCR-RFLP results. G6PD activity in the heterozygotes females were more than 60% of normal activity. In G6PD deficient samples, there is a strong negative correlation between G6PD activity and hemoglobin, hematocrit. The frequency of G6PD deficiency in the region is important for G6PD diagnosis and potentially useful for implementing appropriate anti-malarial drug treatment.

*Corresponding author: Nattaphol Prakobkaew, MT, PhD. Faculty of Allied Health Sciences, Burapha University, 169 Long-Hard Bangsaen Rd., Chonburi 20131, Thailand. E-mail: nattaphol@go.buu.ac.th
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Introduction

Glucose-6-phosphate dehydrogenase (G6PD) is the first step in the pentose phosphate pathway, which is the synthesis of NADPH. NADPH is required to produce reduced glutathione, which is essential for the avoidance of oxidative damage and the reduction of red blood cell sensitivity to hemolysis. The G6PD gene is found on chromosome X (Xq28) and has a high level of polymorphism, with around 190 mutations coding for 400 biochemical or allelic enzyme variations(1,2). The mutations cause enzyme deficits and are passed down through the generations as X-linked characteristics. Due to X-chromosome inactivation, hemizygous men and homozygous females have G6PD deficiency, but heterozygous females may have normal or deficient G6PD activity(2). Many G6PD defective variants have been found in diverse groups in Southeast Asia. Thailand has the highest prevalence of G6PD Viangchan and G6PD Mahidol. The prevalent mutation in the Burmese population has been identified as G6PD Mahidol. In the Laotian, Cambodian, and Vietnamese populations, G6PD Viangchan has been shown to be the most frequent variant(3-5).

Anti-malarial drug-resistant parasites and insecticide-resistant mosquitoes are increasing rapidly. Artemisinin resistance (ART-R) and multi-drug resistant falciparum malaria pose additional significant problems for Cambodia, resulting in substantial treatment failure(6). Cambodia has a porous border with Thailand and a highly mobile population which increases the risk of drug resistance developing in Thailand. The prevalence of G6PD deficiency and related variations in the Thai population has been reported in several studies, with prevalence rates ranging from 5% to 18%(7-11). A few investigations into the prevalence of G6PD deficiency have been performed along the Thai-Cambodian border. Furthermore, whereas normal and heterozygous females have similar enzyme activity, enzyme assay accuracy in detecting female heterozygotes with normal G6PD activity is limited. The frequency of G6PD deficiency and enzyme activity in Trat province's subregions were investigated. To avoid life-threatening consequences, a patient's G6PD status must be determined prior to the administration of anti-malarial drugs. The aim of this study was to determine to find out how common G6PD deficiency is in Trat. It is hoped that the outcomes of this study will be helpful to healthcare practitioners in Trat province to make better decisions about prescriptions in the future.

Materials and methods

Blood sample

This study was approved by the Burapha University Ethics Committee for Human Research (11/2560). Volunteers aged at least 18 years old from Trat Hospital were enrolled in the study, from which at least one leftover EDTA blood sample from routine blood test was collected. The red blood cell (RBC) count, white blood cell (WBC) count, hemoglobin concentration (Hb), hematocrit (Hct), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were all determined using an automated hematology analyzer (Mindray BC-5800, Shenzhen, China). A total of 373 blood sample from the Thais who had 9-18.5 g/dL hemoglobin concentration and 4-10 x10^9/L WBC count were enrolled in this study. A total of 373 G6PD fluorescent spot tests, G6PD enzyme activity, and G6PD mutation were tested.

Fluorescent spot test

The fluorescent spot test (FST) was used to screen for G6PD deficiency using a commercial kit (Trinity Biotech USA, Jamestown, NY, USA) within 24 hours after blood collection. According to the manufacturer's protocol, 10 µL of whole blood sample was added to 200 µL reagent and set a spot on the filter paper as the zero-time point, then incubated at 37.0°C. A sample mixture was dropped on the filter paper and then further sample mixtures dropped on the filter paper after additional incubating for 5 and 10 minutes. The fluorescence intensity of dried spots was observed under UV illumination and divided into three groups: normal (strong fluorescence at 5 and 10 minute); intermediate (poor fluorescence at 5 minutes and moderate fluorescence at 10 minutes); and deficiency (no fluorescence at 5 and 10 minutes). The fluorescence intensity of the sample was compared to that of a G6PD deficient blood sample and a G6PD normal blood sample.

G6PD enzyme activity quantitative test

Enzyme activity was measured using the G6PD Assay Kit (Trinity Biotech USA, Jamestown, NY, USA) according to the manufacturer's instructions. Briefly, ten microliters of whole blood was combined with 1 mL of G6PDH solution. After 10-minute incubation at room temperature, 2 mL of G6PDH substrate reagent was added and incubated at 30.0°C for 5 minutes. Absorbance of the kinetic reaction was measured at 340 nm, G6PD enzyme activity was estimated as U/gHb using the manufacturer's formula and standardized by hemoglobin concentration. Then, the cut-off value for G6PD deficiency in study population was calculated from adjusting the median G6PD activity of men[12]. Each sample was run in duplicate and the measurement values differed by more than 10%, the experiment was repeated analysis. The accuracy of the G6PD activity results was evaluated using a normal G6PD level control. Sample testing was done if the control value was within the range.

Detection of G6PD gene mutations

Genomic DNA from all peripheral blood samples was extracted using the phenol-chloroform method. RFLP-PCR assays were used to screen for two frequent G6PD variants in Thailand; the Viangchan variant (871 G>A) and the Mahidol variant (487 G>A), as previously described[13]. PCR was performed under conditions as follows: 95°C for 5 minutes; 35 cycles of 95°C for 60 seconds, 58-62°C (depending on Tm of the primer pair) for 45 seconds and 72°C for 45 seconds; and 72°C for 5 minutes. The PCR amplicons were then digested in a 10 µL reaction volume with suitable restriction endonuclease (Thermo Fisher Scientific, USA) at 37°C. After 5 hours, 5 µL aliquot from each of the digested mixture was mixed with DNA staining dye (Genedirex Inc, Taiwan), then analyzed on 3% agarose gel-electrophoresis and visualized under UV light.

Statistical analysis

Hematological parameters and G6PD activity are all reported as mean ± SD. Statistical analysis was performed using tests appropriate to the dataset, as specified in the figure legends, using GraphPad Prism 9 software (GraphPad, San Diego, CA). The *p*-value < 0.05 was considered statistically significant.

Results

G6PD fluorescent spot test (FST) and G6PD enzyme activity

The semi-quantitative fluorescent spot test detected 45 G6PD defective samples based on 373 samples screened for G6PD deficiency, including 15 (4.02%) deficient males, 6 (1.61%) deficient females, and 24 (6.43%) intermediated females (Table 1). There were no significant differences in the hematological parameters between FST normal and G6PD deficient or intermediate individuals (Table 1).

Next, G6PD enzyme activity was measured in 45 samples of FST positive and 46 samples of men with normal FST. The results of male samples were used to determine the normal activity for this population. Three male samples showed enzyme activity levels that were less than 10% of the median and were excluded from the analysis. The adjusted male median (AMM) G6PD enzyme activity was 7.5 U/gHb and set 100% G6PD activity of this population. The cut-off value for G6PD deficiency (activity below 60% of the AMM) in this population was < 4.47 U/gHb. Based on these cut off and WHO classifications, 21 of 26 cases (80.7%) with FST deficiency result had less than 60% G6PD activity. Moreover, the result demonstrated that 20% (3/15) of FST deficient males were considered as having severe enzyme deficiency (activity below 10% of normal) and 79.2% (19/24) of FST intermediate females had very mild or no enzyme deficiency (more than 60% of AMM activity) (Figure 1) (Table 2).

In addition, the correlations of G6PD enzyme activity and hematological parameters were investigated. We observed a statistically significant negative correlation of G6PD enzyme activity with Hb (r^2 = 0.151, *p*-value = 0.009), and with Hct (r^2 = 0.141, *p*-value = 0.011) in FST deficient and FST intermediate individuals (Figure 2).

G6PD mutation variants determination

The prevalence of G6PD mutation variants identified in the Thai population, including the Viangchan variant and Mahidol variant, were investigated by PCR-RFLP in all samples. The prevalence of G6PD mutation variants in Trat province was 12.07% (45/373), with G6PD Viangchan accounting for 97.78% of this. Based on WHO classifications and commonly used ranges; 10%, 20%, 30%, and 60% of the AMM, the enzyme activity of 15 male subjects with Viangchan hemizygote ranged from 1% to 30% of normal G6PD activity. Viangchan heterozygote was found in 24 females with intermediate and deficient FST results; 19 of the 24 Viangchan heterozygote females had normal enzyme activity (>60% normal activity), and 5 of 24 had moderate enzyme deficiency (10-60% normal activity). Viangchan homozygote was found in 5 females with deficient FST results and moderate enzyme deficiency (10-60% normal activity). Intriguingly, Mahidol heterozygote was only found in a single female with deficient FST and enzyme activity which was 23% of normal. The G6PD activities of male hemizygotes and female homozygotes were not significantly different, while moderate G6PD deficiency among female heterozygous is found to be significantly greater than the other three groups (Figure 3).

Table 1 Characterization of hematologic data, fluorescent spot test and quantitative G6PD activity among 373 subjects

Parameters	FST- Normal		FST-Deficiency		FST-Intermediate
	Male	Female	Male	Female	Female
Number of samples	141	187	15	6	24
Age (years)	55.8 ± 15.9	55.9 ± 17.3	50.0 ± 14.1	49.0 ± 14.7	48.3 ± 20.7
WBC ($x10^9$/L)	7.5 ± 3.2	7.7 ± 3.4	8.9 ± 4.4	6.5 ± 1.2	6.5 ± 2.4
RBC ($x10^{12}$/L)	4.8 ± 0.8	4.5 ± 0.3	4.6 ± 0.6	4.5 ± 0.4	4.4 ± 0.6
Hb (g/dL)	13.3 ± 2.1	12.1 ± 1.6	13.6 ± 2.1	13.3 ± 0.9	12.3 ± 1.3
Hct (%)	38.8 ± 5.9	35.7 ± 4.3	39.8 ± 5.9	39.5 ± 3.0	36.2 ± 4.2
MCV (fL)	82.9 ± 5.7	80.3 ± 8.7	84.2 ± 4.4	81.5 ± 8.7	80.5 ± 3.5
MCH (pg)	28.3 ± 3.1	27.5 ± 2.1	28.6 ± 1.4	27.3 ± 1.0	27.8 ± 1.8
MCHC (g/dL)	34.0 ± 1.2	33.5 ± 0.8	33.2 ± 0.9	32.5 ± 0.9	32.7 ± 1.3
G6PD activity (U/gHb)	8.2 ± 2.1[a]	-	1.4 ± 0.7	2.3 ± 0.5	6.3 ± 2.3

Note: [a] Calculated from 46 randomly selected males.

Table 2 Phenotypic and genotypic classification of G6PD status in 45 G6PD FST positive subjects

G6PD enzyme activity		Fluorescent spot test		Genotypic test		
% Normal activity	Number	Intermediate	Deficiency	Hemizygous	Heterozygous	Homozygous
		Number	Number	Number	Number	Number
> 60%	19	19	0	0	19	0
10 – 60%	23	5	18	12	6	5
< 10%	3	0	3	3	0	0
Total	45	24	21	15	25	5

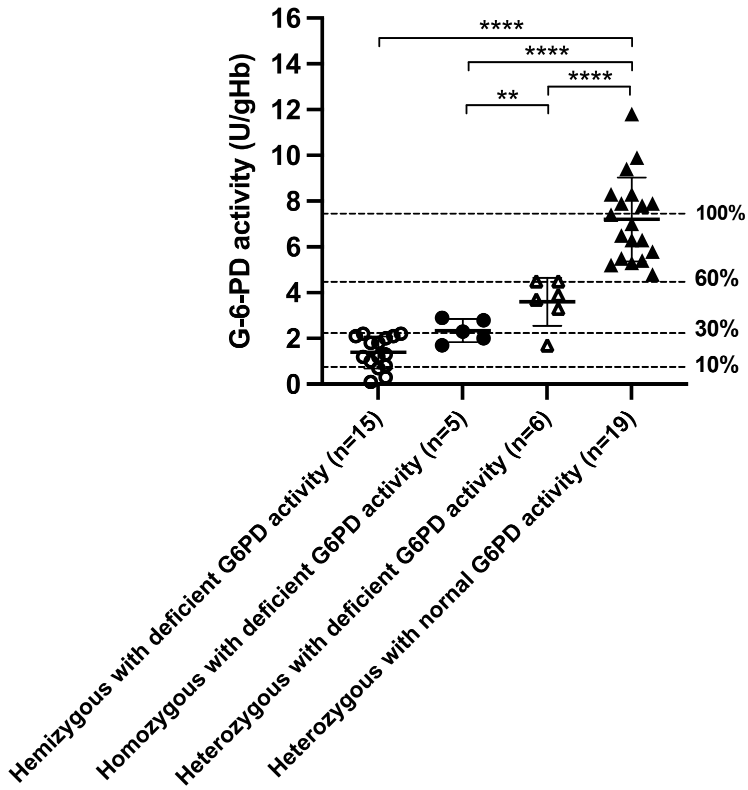

Figure 1 Distribution of G6PD activity classified using a fluorescent spot test

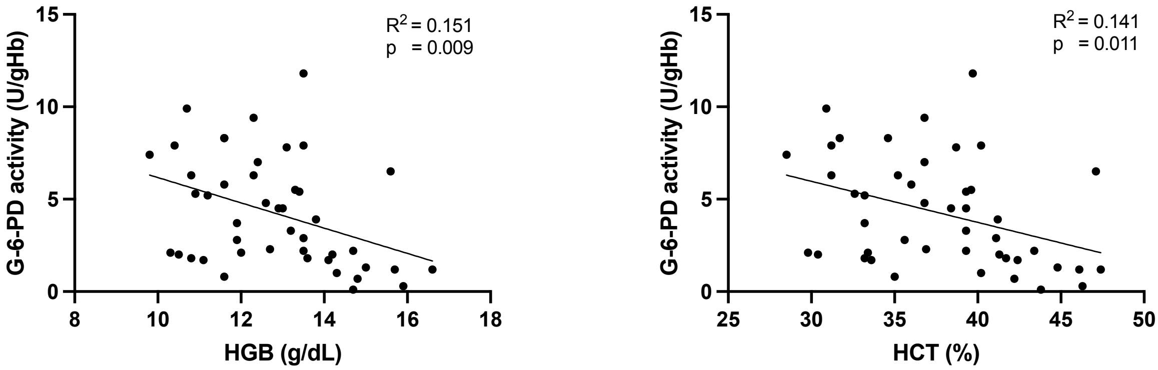

Figure 2 Correlation between G6PD activity and hemoglobin and hematocrit levels in G6PD deficient samples

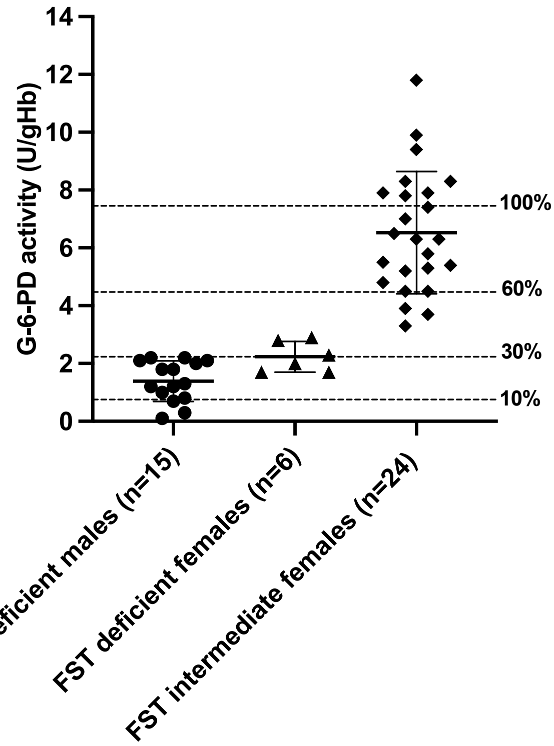

Figure 3 Distribution of G6PD activity classified using PCR-RFLP. A normal level of G6PD activity is characterized as greater than 60% activity. Statistical significance was determined using One-way ANOVA ($^{**}p$-value = 0.01, $^{****}p$-value < 0.0001)

Discussion

G6PD deficiency is very common in Thailand. The Viangchan variant was found in 44 of the 373 blood samples, indicating a significant occurrence. This conclusion is consistent with earlier research which revealed G6PD Viangchan being the most common variant among the Thai population[7,11,14]. In this study, 79.2% (19 of 24) of heterozygote females with > 60% normal enzyme activity were discovered. In female heterozygote, random X-chromosome inactivation results in a variety of phenotypes ranging from normal to deficient enzyme[2]. FST screening may be affected by G6PD variants with near normal activity, resulting in a false negative result. FST is widely used for screening and properly identified all male G6PD deficient patients as well as female severe deficient patients[4]. However, FST identified female heterozygote with near normal G6PD activity as intermediate fluorescent intensity and the sensitivity was above 80% in G6PD > 70% normal enzyme activity[4]. In this study, the FST resulted in moderate fluorescence intensity (6.4%), which is lower than the reported prevalence of G6PD deficiency in 353 Thai female adults (14.6%)[14]. In this study, FST was performed to assess the male and female prevalence in Trat province. The varied populations investigated may explain this conflicting finding.

In the present study, only one incidence of a heterozygote Mahidol variant with a G6PD defective phenotype was discovered. G6PD mutations are very common in Thailand, with the Viangchan variant predominating in the east and the Mahidol variant predominating in the west[10,11,15]. The incidence and distribution of G6PD gene variants vary in the Thai population. Because of the diversity in frequency due to different locations and people, subregion prevalence is critical for optimal approaches for mutation detection, treatment, and prevention. According to WHO criteria, the Viangchan variant is classified as class II (Activity <10% of normal), while class III involves enzyme activity 10-60% normal[16]. All male Viangchan hemizygotes had enzyme levels < 30% normal, while 20% (3/15) had enzyme levels < 10%, and 80% (12/15) had enzyme levels between 10 and 30%. The G6PD enzyme was shown to vary in RBCs. In addition, the age of RBCs had an influence on G6PD activity and rates of enzyme degradation with RBC aging varying significantly across different G6PD variants[17]. Furthermore, the negative relationship discovered between G6PD activity and Hb, Hct is consistent with earlier findings[18]. Other early reports have shown that G6PD activity was increased in anemic people with Hb variants and mutations on the G6PD gene[19]. The increasing of reticulocyte numbers might explain these findings; anemic patients were compensated by a higher number of reticulocytes, which have much greater G6PD activity than mature red cells[19]. In this study population, 31.1% (14 of 45 FST positive) of anemic subjects had mild anemia. However, the current analysis was not designed to prove this hypothesis. In recent years, malaria has been substantially less common due to early detection and the delivery of anti-malaria drugs. Dihydroartemisinin-piperazine in combination with primaquine is the first-line medication for *P. falciparum*, while chloroquine in combination with primaquine is the first-line therapy for *P. vivax*[20,21]. Low enzymatic activity in RBCs has been linked to the Mahidol and Viangchan variants, which are associated with a high hemolytic risk. These people are also at risk of anti-malaria drug induced hemolysis, since 56.8% (26/45) in this study had enzymes that were less than 60% normal. An oxidative stress trigger might hemolyze moderate enzyme activity in heterozygotes. Laboratories should screen for G6PD deficiency before patients take an antimalarial drugs. For heterozygote diagnosis, the FST test is insufficient. The optimal method to find G6PD deficient heterozygotes is to use a combination of FST and enzyme activity.

A limitation in this study is that it only investigated Viangchan and G6PD Mahidol variants. The G6PD prevalence in this study did not include FST positive samples that were negative for G6PD Viangchan and G6PD Mahidol variants. However, molecular genotyping for other Thai variants, such as Canton variants, Kaiping variants, Chinese variants, and Union variants, should be carried out in other FST positive samples.

Conclusion

According to the findings of this study, G6PD deficiency was found in 12.06% of the population. Females with an FST of 6.43% were intermediate, whereas females with an FST of 1.61% and men with an FST of 4.02% were deficient. The G6PD Viangchan variant appears to be the most common among these populations. The frequency of G6PD mutations varies due to regional differences. Our findings provide baseline information that can be used to implement appropriate diagnosis, as well as gain a better understanding of G6PD in this population.

Take home messages

G6PD deficiency was highly prevalent in Trat province, with a prevalence of 56.8% (26/45) and enzyme activity below 60% of normal. These people are also susceptible to anti-malaria drug-induced hemolysis. For accurate diagnosis and increased awareness of drug management, a combination of FST and enzyme activity should be used.

Conflicts of interest

The authors declare no conflict of interest.

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Relationships between quality of life, fear of falling, and functional performance in community-dwelling older women with fall risks

Supansa Srikong[1,2], Uraiwan Chatchawan[2], Punnee Peungsuwan[2*]

[1] Mahasarakham Municipality, Mahasarakham Province, Thailand.

[2] Research Center in Back, Neck, Other Joint Pain and Human Performance (BNOJPH), School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University, Thailand.

KEYWORDS
Short-form health survey-36 (SF-36);
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Physical performance;
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Fall risk.

ABSTRACT

The aim of this study is to examine the correlations between quality of life (QOL), fear of falling (FOF), and functional performance, as well as to compare the differences in those variables between two older adult women groups (faller and non-faller). Sixty five community-dwelling older women with fall risks were recruited from a public health service centre in Mahasarakham Municipality, Thailand. The Short Form-36 Health Survey (SF-36), Falls Efficacy Scale-International (FES-I), Timed Up and Go Test (TUG), 10-Meter Walk Test (10MWT), Five-Times Sit-to-Stand Test (FTSST), and One-Leg Stand Test (OLST) were outcomes. Spearman's correlation coefficient, independent t-test, and Mann–Whitney U test were used for data analysis. The results showed that seven in eight SF-36 domains were significantly correlated with FES-I (p-value < 0.01), and only the physical function domain was related to TUG, 10MWT, FTSST, and OLST (p-value < 0.05). The participants with a low concern of falling had better SF36 and TUG scores than those with a high concern of falling. There was a relationship between some SF-36 domains, FOF, and physical function tests in both the faller and non-faller groups, and a significant difference in only the TUG between the groups. Conclusion, older adult women who have low QOL and previous fall experiences have high FOF and low physical performance. This relationship supports healthcare providers in planning fall prevention programmes for community-dwelling older adult women.

*Corresponding author: Punnee Peungsuwan, PT, PhD. School of Physical Therapy, Faculty of Associated Medical Sciences, Khon Kaen University 123, Mitraphab Highway, Muang, Khon Kaen 40002, Thailand. E-mail: ppunne@kku.ac.th

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Introduction

Falling is the most common cause of injuries in older adults, and one-third of individuals over the age of 65 falls every year[1]. A fall or the fear of falling (FOF) can impact both physical and mental health, leading to the restriction of daily living activities and deterioration in physical functions[2-4]. FOF is common among the older adult population, and its consequences have been identified as important factors that influence health-related quality of life (HRQOL)[3, 5-6]. Older adults who have not experienced falls but have FOF are at a significant risk of falling and having worse health than those without FOF.

Falls increase with age and are more common among women over the age of 65[8]. Moreover, women have a higher FOF than men among community-dwelling older adults[2, 9]. Falls and their consequences have an impact on people's quality of life (QOL), particularly the older adults. Several previous studies have demonstrated a relationship between HRQOL, FOF, physical performance and independent variables associated with the older adult population of many countries[3, 7, 10]. However, there have been few studies on the relationship between the QOL, fall awareness, and falls of the older Thai population. Previous studies on these relationships were focused on older adults in the rural ethnic minority areas in the upper northern[11] and semi-rural[12] dwellings of Thailand. Meanwhile, it is important to continuously investigate the effects of these relationships on the physical performance of the older adults in Thailand, particularly women because they have a higher fall risk than men[13-14]. A subjective rating of his/her health perception may change throughout his/her lifetime, and it can be affected by age, gender, education, socio economic status, sociocultural status, heredity, and lifestyle[15].

Therefore, it is necessary to confirm the cross-cultural relationships between the QOL, FOF, and physical performance of the older population in the northeast region of Thailand. In this study, correlations between QOL, FOF, and functional performance were examined, and the differences in those variables between two groups of older adult women (faller and non-faller groups) were also compared.

Materials and methods

This cross-sectional study was conducted between January and August 2021 at the community area of Mahasarakham Municipality, Mahasarakham Province, Thailand. The proposal was approved by the Ethics Committee for Human Research at Khon Kaen University, Thailand (HE632255).

Participants

Sixty-five adults aged 65 years or above who can ambulate by themselves were recruited through the registration lists of older adults receiving primary healthcare services. A sample size was calculated using G*Power at 10% two-sided significance level and 80% power. The effect size was calculated from the correlation of QOL, FOF, and physical performance obtained from a previous study[7, 16], and its average was 0.34 ($n > 63$). The inclusion criteria comprised ability to complete over 12 s of the Timed Up and Go Test (TUG) (which is used to determine the fall risk)[17] and ability to communicate. Participants with hearing and vision impairments, movement disability, cognitive problems based on the Mini-Mental State Examination-Thai version (MMSE-Thai) with a score less than 17 (0–17 scores indicate cognitions equivalent to the elementary education level)[18], including those who use medicines such as anti-depressants, sedatives, and anti-psychotics, were excluded from the study.

Data collection

Age, sex, marital status, educational level, cigarette smoking status, alcohol consumption, health and medical history, and fall history in the past year (to divide the faller and non-faller groups) were recorded. All the participants completed the Short Form-36 (SF-36) Health Survey and Falls Efficacy Scale–International (FES-I), as well as the TUG, One-Leg Stand Test (OLST), Five-Times Sit-to-Stand Test (FTSST) and 10-Meter Walk Test (10MWT), which were monitored by two physiotherapists. One physiotherapist conducted face-to-face interviews with all the participants using the SF-36 and FES-I questionnaires, while the other physiotherapist took the measurements of all the physical performance tests.

Outcome measures

The Short-Form Health Survey-36 (SF-36)

SF-36 is designed to assess the patients' perceptions of their physical health and mental well-being[19]. An individual's perceived level of physical and mental health can be measured by the SF-36. The SF-36 Thai version was translated and validated by Leurmarnkul and Meetam, in Thai people[20]. Cronbach's alpha of the new version exceeds the 0.7 level in all dimensions. The SF-36 is a multiitem scale questionnaire that evaluates points of several clinical components consist of physical functioning (PF), role physical (RP), body pain (BP), general health (GH), vitality (VT), role emotion (RE), social function (SF) and mental health (MT). The result of the scales is presented as a final score ranging from 0 to 100, where 0 is the worst and 100 is the best state of health[19].

The Falls Efficacy Scale-International (FES-I)

FES-I is an ideal questionnaire for measuring FOF because it has excellent psychometric properties and measures concerns relating to basic and more intense physical and social activities. The FES-I showed excellent internal and test-retest reliability (Cronbach's alpha = 0.96, ICC = 0.96)[21]. The Thai version of FES-I was measured in this study based on Thiamwong et al.(2011) study (validity and internal consistency; Cronbach's alpha=0.95 in 433 older adults)[22]. All 16 items of the FES-I can be rated from 1 to 4 (total 64 scores). Moreover, Delbaere et al. (2010) suggested the FES-I scale was divided to 16 to 22 (a low concern FOF) and 23 to 64 (a high concern FOF)[4].

After the completion of the two questionnaires, the participants performed functional performance tests, and the fall parameters were measured by a physiotherapist. Based on the participants' perceptions, the test sequence started from light to more intense in this order: OLST, TUG, 10MWT, and FTSST. The physiotherapist tested the intra-reliability of the physical performance tests, which showed good intraclass correlation coefficient (ICC) scores of 0.98, 0.96, 0.85, and 0.95 for the OLST, TUG, 10MWT, and FTSST, respectively.

The one-leg stand test (OLST)

OLST is a simple and effective method for screening balance impairments in the older adult population. It has been widely used as a static balance assessment tool in community-dwelling older adults[23]. This test previously showed the inter-rater reliability (ICC = 0.99 for eyes open and eyes closed)[23]. A participant was instructed to stand on one leg with opening the eyes, and without the support of the upper extremities or bracing of the unweighted leg against the stance leg, and they had to fixed gaze straight ahead. Both legs were tested, and an assessor recorded the time to start from raising the leg until they lost balance with a touched leg on the ground [23].

The timed up and go test (TUG)

TUG is commonly used to check the dynamic balance ability for functional mobility examination. This test was a sensitive (87%) and specific (87%) measure for identifying community-dwelling adults who are at risk for falls[24]. The participants started by a seat on an armchair, and they walked independently with their regular footwear. An examiner asked the participant to stand up using a verbal command and walk a 3-meters walkway from the chair, arrive at the endpoint, turn around back to the chair and sit down. The start timing was recorded from their stood up until seated again in the correct position[24].

The 10-meter walk test (10MWT)

10MWT is a performance measure used to assess walking speed. The 10MWT had high test-retest reliability (ICC = 0.93-0.91) in adults aged 20-79 years[25]. The participant was asked to walk a 10-meter walkway. They performed at their preferred walking speed independently with their regular footwear. The time was measured for the intermediate six meters to approve for acceleration and deceleration. An assessor started time recording when the participant's toes of a foot cross the 2-meter mark and stopped the timing when their toes of the foot cross the 8-meter mark. The time was converted as a walking speed[25].

The five times sit-to-stand test (FTSST)

FTSST is an acceptable tool for assessing lower extremity strength and predicting an individual's risk of fall. It has been widely used among the community-dwelling older adult population and had moderate to excellent test-retest reliability (ICC = 0.64-0.96)[26]. An examiner asked the participants to perform as quickly as from sitting to standing up five times without a break, while they had to keep their arms folded across the chest. The rater then demonstrated the correct technique to perform the test, including coming to a completed stand, defined as an upright trunk with hips and knees extended. Timing began when the rater spoke the word "go" and stopped when the participant's buttocks reached the seat following the fifth stand[26].

All the participants performed three trials of each physical function test, and an average value was calculated. The participants were asked to rest seated on a chair for 1-2 mins between trials and for 5 mins after each test.

Statistical analysis

Statistical analyses were performed by SPSS version 23. The conformity of the results to the normal distribution was tested using the Shapiro–Wilk test. The correlations between SF-36 and other variables were tested using the Spearman's correlation coefficient. The correlation coefficient levels were indicated as strong (0.9-1.0), high (0.7-0.9), moderate (0.5-0.7), low (0.3-0.5), and little (0.0-0.3)[27]. An independent t-test and the Mann-Whitney U test were used in comparisons between two groups of a low and the high concern FOF, and the faller and non-faller. A *p*-value < 0.05 was considered statistically significant.

Results

Sixty-five adult women aged 65 years or above (average: 75.46, standard deviation: 5.85, range: 65-85 years) years were recruited in this study. The demographics of the participants and the average values of their cognitive function, FOF, health status, and physical performance are presented in table 1. Forty percent of the participants had an average fall of 2.42±2.6 times, whereas 60% were in the non-faller category. The most of participants' education was early elementary level (67.8%).

The correlations between SF-36 and age, FES-I, and physical performance are presented in table 2. Most of the SF-36 domains, including PF, RP, BP, GH, VT, SF, and RE, were significantly negatively correlated with FES-I, except the MT domain. Additionally, the PF domain of SF-36 was significantly correlated with TUG, FTSST, 10MWT and Rt. OLST. Meanwhile, the BP and GH domains showed a significant correlation with Lt. OLST and FTSST, respectively, whereas no correlation occurred between SF-36 and age and number of falls.

Table 1 Characteristics of participants

Characteristics		%, mean (SD)
Age (years)		75.46 (5.85)
Education status	Early elementary (n = 44)	67.8%
	Late elementary school (n = 19)	29.2%
	Junior high school (n = 1)	1.5%
	High school (n = 1)	1.5%
History of falls (n)	Faller (n = 26)	40%
	non-faller (n = 39)	60%
Cognitive function	MMSE-Thai	23.51 (3.8)
Fear of falling	FES-I	35.97 (12.58)
Health status	SF-36	65.56 (14.61)
Physical performance test	TUG (sec)	16.07 (2.4)
	FTSST (sec)	19.71 (5.8)
	10MWT (m/s)	0.8 (0.16)
	Rt. OLST (sec)	4.4 (5.65)
	Lt. OLST (sec)	4.53 (5.63)

Note: The data were presented in the mean (SD) and percent. MMSE-Thai, Mini-Mental State Examination- Thai version; SF-36, Short-Form Health Survey-36; FES-I, Fall Efficacy Scale-International; TUG, timed up and go test; FTSST, five times sit-to-stand test; 10MWT, 10-meter walk test; OLST, one leg standing test.

Table 2 Correlation between SF-36 and age, fear of falling and physical performance

SF-36	Age	Number of falls	FES-I	TUG (sec)	10MWT (m/s)	FTSST (sec)	Rt. OLST (sec)	Lt. OLST (sec)
Total PH	0.035	-0.124	-0.55	-0.12	0.16	-0.24	0.23	-0.12
	(0.78)	(0.32)	(<0.001#)	(0.35)	(0.22)	(0.05)	(0.07)	(0.35)
PF	-0.01	-0.06	-0.50	-0.34	0.29	-0.31	0.29	-0.13
	(0.95)	(0.65)	(<0.001#)	(0.005**)	(0.02*)	(0.01*)	(0.02*)	(0.31)
RP	-0.02	-0.11	-0.34	0.15	0.02	-0.01	0.15	0.04
	(0.88)	(0.37)	(0.006**)	(0.23)	(0.88)	(0.92)	(0.23)	(0.74)
BP	0.12	-0.12	-0.45	-0.04	0.07	-0.12	-0.01	-0.27
	(0.35)	(0.33)	(<0.001#)	(0.78)	(0.57)	(0.36)	(0.97)	(0.03*)
GH	0.02	-0.02	-0.38	-0.18	0.17	-0.32	0.03	0-.07
	(0.89)	(0.85)	(0.002**)	(0.16)	(0.17)	(0.01*)	(0.85)	(0.57)
Total MH	-0.18	0.01	-0.32	-0.10	0.06	-0.08	0.10	0.17
	(0.14)	(0.93)	(0.009**)	(0.43)	(0.63)	(0.51)	(0.43)	(0.17)
VT	-0.12	-0.01	-0.33	-0.15	0.04	-0.23	-0.01	0.17
	(0.36)	(0.97)	(0.006**)	(0.25)	(0.77)	(0.07)	(0.97)	(0.18)
SF	-0.12	-0.11	-0.31	-0.12	0.01	-0.08	0.10	0.02
	(0.34)	(0.37)	(0.01*)	(0.34)	(0.96)	(0.51)	(0.43)	(0.90)
RE	-0.17	-0.04	-0.33	0.01	0.11	0.04	0.23	0.17
	(0.17)	(0.75)	(0.007**)	(0.94)	(0.40)	(0.74)	(0.07)	(0.19)
MT	-0.19	0.16	-0.12	-0.10	0.03	-0.10	-0.11	0.11
	(0.12)	(0.22)	(0.34)	(0.42)	(0.84)	(0.45)	(0.38)	(0.37)

Note: Data present the values of correlation (p-value). SF-36, Short-Form Health Survey-36; FES-I, Fall Efficacy Scale-International; TUG, timed up and go test; 10MWT, 10-meter walk test; FTSST, five times sit-to-stand test; OLST, one leg standing test; total PH, total physical health; total MH, total mental health; PF, physical functioning; RP, role physical; BP, body pain; GH, general health; VT, vitality; RE, role emotion; SF, social function; MT, mental health.*, ** and # present *p*-values of < 0.05, < 0.01 and < 0.001, respectively. The data were analyzed using the Spearman correlation coefficient.

Table 3 reveals that the total physical health (total PH), PF, BP, and GH were significantly different between the groups of participants with low and high concerns of falling. Meanwhile, TUG (mean difference = 1.51 s, 95% CI = 0.10–2.91 s, *p*-value = 0.04) was significantly different between the groups.

Table 3 Comparisons of the SF-36 and other variables between the low concern and high concern of falling

Variable	High concern FOF (n = 51)		Low concern FOF (n = 14)		*p*-value
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	
Age	75.25 ± 5.82		76.21 ± 6.13		0.59
Number of falls		0 (1)		0 (0)	0.16
SF-36:					
Total PH		67.25 (31.50)		84.63 (11.81)	0.001**
- PF		55 (40)		85 (16.25)	<0.001**
- RP		100 (100)		12.50) 100)	0.06
- BP		74 (29)		90 (4.50)	0.006**
- G^H		62 (20)		75 (17)	0.008*
Total MH		82.75 (19.50)		87.83 (8.46)	0.16
- VT		65 (30)		72.50 (16.25)	0.12
- SF		100 (12.50)		0) 100)	0.24
- RE		100 (33.33)		100 (0)	0.15
- MT		80 (24)		82 (8)	0.99
TUG, sec	16.40 ± 2.46		14.89 ± 1.75		0.04*
10MWT, m/sec	0.78 ± 0.16		0.87 ± 0.12		0.06
FTSST, sec		19.20 (6.70)		17.33 (5.35)	0.09
Rt. OLST, sec		2.19 (5.49)		3.35 (7.50)	0.21
Lt. OLST, sec		2.79 (7.22)		1.96 (4.98)	0.34

Note: The data were presented in mean±SD using an independent t-test for parametric data, and median (IQR) using the Mann-Whitney U test for non-parametric data. SF-36, Short-Form Health Survey-36; total PH, total physical health; total MH, total mental health; PF, physical functioning; RP, role physical; BP, body pain; GH, general health; VT, vitality; RE, role emotion; SF, social function; MT, mental health; TUG, timed up and go test; 10MWT, 10-meter walk test; FTSST, five times sit-to-stand test; OLST, one leg standing test. * and ** present ***p***-values at < 0.05 and < 0.01, respectively.

Table 4 presents the correlation between SF-36 and age, fear of falling and physical performance of older adults in the faller (n = 26) and non-faller (n = 39) groups. There was a significant negative correlation between FES-I and total PH, PF, RP, total mental health (total MH), VT, and RE in the faller group. Similar result was obtained between FES-I and total PH, PF, BP, GH, and SF in the non-faller group. Additionally, the findings showed a significant negative correlation between TUG and PF, as well as FTSST and VT in the faller group. Furthermore, a significant positive correlation was observed between Lt. OLST and total MH, RP, VT, SF, and RE in the faller group, whereas a significant negative correlation was observed between Lt. OLST and total PH, BP, and GH in the non-faller group.

Table 4 Correlation between the SF-36 and variables of age, fear of falling and physical performance in older women with faller (n = 26) and non-faller (n = 39)

SF-36	Age		FES-I		TUG (sec)		10MWT (m/s)		FTSST (sec)		Rt. OLST (sec)		Lt. OLST (sec)	
	Faller	Non-faller	Faller	Non-faller	Faller	Non-faller	Faller	Non-faller	Faller	Non-faller	Faller	Non-faller	Faller	Non-faller
Total PH	-0.22	0.32	-0.57	-0.48	-0.11	-0.11	0.28	0.06	-0.27	-0.17	0.31	0.18	0.26	-0.33
	(0.28)	(0.048)	(<0.001#)	(<0.001#)	(0.58)	(0.50)	(0.17)	(0.72)	(0.18)	(0.30)	(0.12)	(0.27)	(0.21)	(0.04*)
PF	-0.26	0.24	-0.54	-0.46	-0.45	-0.29	0.36	0.22	-0.31	-0.26	0.31	0.30	-0.01	-0.18
	(0.21)	(0.14)	(<0.001#)	(<0.001#)	(0.02*)	(0.07)	(0.07)	(0.17)	(0.12)	(0.12)	(0.13)	(0.07)	(0.95)	(0.27)
RP	-0.09	0.07	-0.40	-0.24	0.07	0.24	0.20	-0.20	-0.14	0.10	0.37	-0.01	0.41	-0.22
	(0.67)	(0.66)	(0.04*)	(0.14)	(0.73)	(0.15)	(0.32)	(0.23)	(0.51)	(0.55)	(0.06)	(0.96)	(0.04*)	(0.17)
BP	-0.18	0.38	-0.33	-0.55	0.11	-0.13	0.12	0.01	0.05	-0.20	-0.10	0.07	-0.06	-0.34
	(0.38)	(0.02*)	(0.10)	(<0.001#)	(0.61)	(0.45)	(0.57)	(0.98)	(0.82)	(0.23)	(0.62)	(0.67)	(0.76)	(0.04*)
GH	-0.21	0.31	-0.28	-0.37	-0.17	-0.13	0.15	0.17	-0.39	-0.23	0.13	-0.05	0.31	-0.38
	(0.31)	(0.06)	(0.16)	(0.02*)	(0.41)	(0.44)	(0.46)	(0.31)	(0.05)	(0.17)	(0.52)	(0.79)	(0.12)	(0.02*)
Total MH	-0.31	-0.06	-0.53	-0.22	-0.26	0.04	0.19	-0.01	-0.27	0.05	0.08	0.15	0.56	-0.08
	(0.12)	(0.72)	(0.01*)	(0.17)	(0.20)	(0.81)	(0.36)	(0.94)	(0.18)	(0.77)	(0.69)	(0.38)	(<0.001#)	(0.61)
VT	-0.23	0.03	-0.45	-0.26	-0.19	-0.06	0.08	-0.00	-0.43	-0.08	0.01	-0.02	0.56	-0.12
	(0.26)	(0.87)	(0.02*)	(0.10)	(0.35)	(0.71)	(0.68)	(0.99)	(0.03*)	(0.64)	(0.95)	(0.92)	(<0.001#)	(0.48)
SF	-0.20	-0.01	-0.22	-0.35	-0.12	-0.10	-0.06	0.03	0.03	-0.17	0.22	-0.01	0.43	-0.30
	(0.32)	(0.95)	(0.28)	(0.03*)	(0.56)	(0.53)	(0.77)	(0.84)	(0.87)	(0.31)	(0.28)	(0.97)	(0.03*)	(0.06)
RE	-0.30	-0.06	-0.59	-0.17	-0.22	0.19	0.33	-0.05	-0.23	0.23	0.15	0.31	0.54	-0.04
	(0.14)	(0.71)	(<0.001#)	(0.29)	(0.28)	(0.26)	(0.09)	(0.75)	(0.26)	(0.17)	(0.46)	(0.06)	(0.01*)	(0.80)
MT	-0.23	-0.16	-0.27	-0.08	-0.13	-0.04	0.00	0.03	-0.15	-0.03	-0.21	0.01	0.21	0.11
	(0.26)	(0.34)	(0.19)	(0.65)	(0.52)	(0.81)	(0.99)	(0.88)	(0.47)	(0.84)	(0.29)	(0.98)	(0.30)	(0.52)

Note: Data present the values of correlation, ρ and p-value. SF-36, Short-Form Health Survey-36; FES-I, Fall Efficacy Scale-International; TUG, timed up and go test; 10MWT, 10-meter walk test; FTSST, five times sit-to-stand test; OLST, one leg standing test; total PH, total physical health; total MH, total mental health; PF, physical functioning; RP, role physical; BP, body pain; GH, general health; VT, vitality; RE, role emotion; SF, social function; MT, mental health. *, ** and $^{\#}$ present p-values of < 0.05, < 0.01 and < 0.001, respectively.

Table 5 shows that the faller group had significantly greater the FES-I than the non-faller. (mean difference = 7.23, 95% CI = 1.08–13.38, *p*-value = 0.02), and no significant difference in other variables.

Table 5 Comparisons of the SF-36 and physical function tests between faller and non-faller for older women

Fall experience	Faller (n = 26)		Non-faller (n = 39)		*p*-value
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	
Age	76.35 ± 6.21		74.87 ±6.5		0.32
FES-I	40.31 ± 12.59		33.08 ± 11.87		0.02*
SF-36:					
Total PH		67.63 (34.5)		76 (22.5)	0.11
- PF		62.5 (55)		65 (35)	0.24
- RP		87.5 (100)		100 (50)	0.23
- BP		73 (39)		84 (28)	0.21
- GH		60 (33.75)		67 (12)	0.34
Total MH		87.25 (19.28)		87.67 (18.08)	0.88
- VT		70 (36.25)		65 (25)	0.93
- SF		100 (25)		100 (0)	0.18
- RE		100 (33.33)		100 (33.33)	0.95
- MT		84 (31)		80 (8)	0.28
TUG, sec	2.35 ± 16.09		16.06 ± 2.46		0.96
10MWT, m/s	0.79 ± 018.		0.81 ± 014.		0.65
FTSST, sec		18.99 (5.57)		18.92 (7.02)	0.68
Rt. OLST, sec		2.1 (5.6)		2.46 (7.19)	0.47
Lt. OLST, sec		1.88 (5.17)		2.79 (7.21)	0.37

Note: The data were presented in the mean±SD for parametric data using an independent t-test, and median (IQR) for non-parametric data using the Mann-Whitney U test. Short-Form Health Survey-36; FES-I, Fall Efficacy Scale-International; total PH, total physical health; total MH, total mental health; PF, physical functioning; RP, role physical; BP, body pain; GH, general health; VT, vitality; RE, role emotion; SF, social function; MT, mental health; TUG, timed up and go test; 10MWT, 10-meter walk test; FTSST, five times sit-to-stand test; OLST, one leg standing test. * and ** present *p*-values at < 0.05 and < 0.01, respectively.

Discussion

In this study, correlations between QOL, FOF, and functional performance were examined, and differences in those variables between two older women groups with fall risks (faller and non-faller, low and high concerns of falling) were compared. The results revealed that the correlations of all SF-36 subscales, except MT, with FOF were low and negative. Additionally, the correlation of PF with all the physical performance measures was low. Therefore, older adults with high FOF seemed to have a lower physical component than individuals with low FOF, except for RP. FOF was higher in the faller group than in the non-faller group, and there was no significant difference between all SF-36 subscales and physical ability. Meanwhile, the total PH and total MH scales of SF-36 were correlated with FOF and TUG, FTSST, and OLST in the faller group.

The findings of several previous studies on the relationship between FOF and QOL in community-dwelling older adults are consistent with our results[3, 5, 28-29]. A systematic review study[30] reported that several studies showed moderate to strong correlations between FOF and QOL ($r = -0.47$ to -0.80). The relationship between FOF and the physical components of QOL was stronger than that with the mental components[5, 29]. In the previously mentioned studies, FOF was associated with almost all the SF-36 scores, confirming that it is an important predictor of HRQOL in the faller group[2, 7, 30-31]. The results of this study are consistent with previous studies, which showed a lower correlation between SF-36, FOF, and physical performance tests such as TUG, FSST, 10MWT, and OLST. However, the sample size may have been too small. FOF is recognised as an important psychological factor among older adults, who often develop paranoia, experience reduced activity, experience loss of confidence in daily activities, as well as impaired physical, cognitive, and mental health functions, which impede their QOL[32]

The results also indicate that older women with low concern about FOF had significantly better SF-36 scales and TUG than those with high concerns about FOF. Park et al. (2014) reported that TUG time was well correlated with the degree of FOF[7]. Previous studies reported that women participants had the highest FOF[31], and low SF-36 scores in both men and women[5]. Our study found a rather high FOF in women participants (78.46%).

Generally, people are divided into very fearful, somewhat fearful, and not fearful, although in individuals with no FOF. A report stated that more than 50% of the people with no prior fall experience had FOF[33]. This study included both older adults in the faller and non-faller groups, which had similar SF-36 subscales and physical ability. However, the FOF of the faller group was higher than that of the non-faller group. Additionally, some subscales of SF-36 were correlated with FOF and physical ability in both groups. Meanwhile those in the faller group was significant difference in SF-36 scores compared to those in the non-faller group[34-35].

Although the sample used in this study was divided into low and high FOF and faller and non-faller groups, there was indeed a significant negative relationship between some SF-36 domains and FOF in the faller group, and the PF and VT domains correlated with TUG and FTSST, respectively. Meanwhile, older people with a history of falling showed greater prevalence of FOF. Hence, they need to be more careful as they perform physical functions in their daily living activities, which restrict their social and environmental activities and negatively impact their mental health[32]. In severe cases, falling is one of the leading causes of morbidity and mortality[36]. Additionally, the study was indeed a positive relationship between Lt. OLST and RP, total MH, VT, SF, and RE in the faller group, whereas a negative significant relationship was accidentally found between Lt. OLST and BP and GH in the non-faller group. The negative and positive linear relationships revealed by the OLST measure may be the responses of different dominant legs in each individual. Thus, future research should record the participant's dominant leg. A previous study reported no correlation between the static and dynamic balance measures[37], which may be due to the differences between the components of dynamic and static balance. Falling is associated with various impairments in the neuromuscular system[38], including vestibular, visual, and somatosensory information; in this study is possible that the information afferent input that is unequal on each leg side may impact the outcomes.

This study has several limitations. First, the sample used in this study was small; hence discrepancies can occur in the results such that it cannot be used to generalise the older population in other countries. Although there were differences between the participants in the faller and non-faller groups, which may influence the interpretation of the findings, the results are consistent with those of previous studies. Second, only older adult women in the municipalities and rural areas were recruited, which is not representative of the general older Thai women population. Moreover, this study was cross-sectional and presented only the associations between QOL and FOF and QOL and physical performance but not the causal relationships. The strength of our study is that it provides knowledge about the significant relationship between QOL, FOF, and physical performance in the older Thai women population, and these outcomes were also the difference between faller and non-faller groups, including those with low and high concerns of falling. We suggest that a large representative sample would be advantageous in health planning for further studies.

Conclusion

The results of this study support our understanding that low QOL is associated with FOF and low physical performance in older adult women with fall risks and fall experience. The relationship can support the planning of fall prevention programmes for community-dwelling women and older adults.

Clinical implication

- This study found that QOL was sigs nificantly associated with FOF and physical performance in community-dwelling women older with fall risks.
- Elderly women with a high concern of falling and those with fall experience showed low QOL and physical functions.
- To ensure that the TUG test is a used screening tool to assist health care providers to identify older people at risk of falling.

Conflicts of interest

The authors declare no conflict of interest.

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