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Microsoft Kinect-based differences in lower limb kinematics and temporal characteristics of sit to walking phase of modified TUG test between men with and without Parkinson's disease

Microsoft Kinectiga hinnatavad posturaalsed ja ajalised erinevused istest kõndima minekul modifitseeritud Tõuse-ja-Mine testi sooritusel Parkinsoni tõvega ja tõveta meestel

Master`s thesis
Physiotherapy

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ABBREVIATIONS

CG - Control group

EPG - European Physiotherapy Guideline

GS - Gait Speed

H&Y - Hoehn ja Yahr

iTUG - instrumented Timed Up and Go

Kinect for Microsoft - Kinect

Max - maximum

MDS-UPDRS - Movement Disorder Society-Sponsored Revision of the Unified Parkinson´s Disease Rating Scale

Min - minimum

modTUG - modified Timed Up and Go

PAS - Parkinson's Assessment Scale

PD - Parkinson's disease

ROM - Range of Motion

UPDRS - Unified Parkinson's disease Rating Scale

STS - Sit to Stand

TUG - Timed Up and Go

3D- three-dimensional

ABSTRACT

Aim: The aim of the study is to analyse the differences detectable by Microsoft Kinect in lower limb kinematics and spatiotemporal characteristics during sub-phases of modified Timed Up and Go test in male individuals with PD compared to healthy male counterparts.

Methods: Sixteen elderly men, eight with mild-to-moderate PD (average age 67.5±4.5 and disease stage 2.2±0.7 according to H&Y) and eight healthy age-matched males (average age 69.8±8.0) participated. Microsoft Kinect along with KinectPsyManager (v1.0) software was used. Matlab2016b software enabled calculation of postural (knee and hip joint position in sagittal plane, distance between knees) and temporal characteristics of sit-to-walking motion (phases of modTUG), further divided to sitting, sit-to-stand and walking. Goniometric measurement of hip and knee joint while sitting was used in comparison. Gait speed from sit-to-walking and step length on number of steps performed during modTUG were calculated.

Results: Men with mild to moderate PD did not differ from healthy counterparts in aspects of postural characteristics of sit-to-walking-performance, with the only exception being the smaller distance between knees in sitting. Additionally, Kinect sensor was found to overestimate static postural characteristics of sitting when compared to goniometry. It is likely that Kinect underestimates dynamic postural characteristics during sit-to-walking motion. In temporal characteristics PD participants were found to be slower during walking phase of sit-to-walking-motion, but did not differ in sit-to-stand. Gait speed was found to be slower and step length shorter in men with PD.

Conclusions: According to Kinect, men with mild-to-moderate PD do not differ in static or dynamic lower limb postural characteristics while performing sit-to-walking, except distance between knees while sitting compared to healthy elderly. People with PD perform slower in walking task of sit-to-walking and do not differ in sit-to-stand transfer and have slower gait speed together with reduced step length compared to healthy elderly.

Keywords: Microsoft Kinect, Parkinson's disease, modified TUG test, sub-phases, sit to walking

LÜHIÜLEVAADE

Eesmärk: Käesoleva magistritöö eesmärk on analüüsida Microsoft Kinectiga tuvastatavaid erinevusi Parkinsoni tõvega meeste ning tervete samaealiste meeste alajäsemete posturaalsetes ning ajalis-ruumilistes parameetrites modifitseeritud Tõuse-ja-Mine testi ja selle alafaaside sooritusel.

Metoodika: Kuusteist meest, kaheksa kerge kuni mõõduka Parkinsoni tõvega (keskmine vanus 67.5±4.5 ning haiguse aste 2.2±0.7 Hoehn&Yahr skaalal) ning kaheksa tervet samaealist meest (keskmine vanus 69.8±8.0, kes moodustasid kontrollgrupi) osalesid. Posturaalsed näitajad (puusa- ning põlveliigestes) ning ajalised näitajad salvestati programmi KinectPsyManager (v1.0) abil Kinecti sensoriga istumast kõndima siirdumisel Tõuse-ja-Mine testi alafaasidena. Programmi Matlab2016b abil konverteeriti registreeritu analüüsitavateks andmeteks. Staatilises istumisasendis registreeritud nurki võrreldi goniomeetriliste mõõtmistega puusa-ja põlveliigestes. Ajalis-ruumilistest näitajatest mõõdeti sammude arv ning arvutati sammupikkus koos kõnnikiirusega.

Tulemused: Kinectiga hinnatuna puudusid erinevused Parkinsoni tõvega haigete ning tervete samaealiste vahel nii staatilistes kui dünaamilistes posturaalsetes näitajates. Ainsa erinevusena ilmnes Parkinsoni tõvega haigetel oluliselt väiksem põlveliigeste vaheline kaugus istuvas asendis, seevastu kõndimisel erinevust ei tuvastatud. Leiti, et Kinecti sensor ülehindab nurki staatilises istumisasendis võrrelduna goniomeetriaga ning tõenäoliselt alahindab dünaamilisi posturaalseid näitajaid istest kõndima minekul. Parkinsoni tõvega uuritavate istest püsti tõusmise kiirus oli sarnane tervetega, seevastu kõndimine aeglasem. Parkinsoni tõve haigete sammupikkus oli lühem ning kõnnikiirus aeglasem.

Kokkuvõte: Kerge ja mõõduka haigusväljendusega Parkinsoni tõve haigetel meestel staatilistes ja dünaamilistes posturaalsetes näitajates puuduvad Microsoft Kinecti kohaselt erinevused võrrelduna samaealiste tervete meestega. Erandiks on põlveliigeste vaheline kaugus istudes, mis on Parkinsoni tõve haigetel meestel väiksem. Parkinsoni tõvega meeste istumast kõndima siirdumine on aeglasem, sealjuures on tervetega võrreldes aeglasem soorituse kõndimise faas. Lisaks on neil aeglasem kõnnikiirus ning lühemad sammud võrreldes tervete samaealiste meestega.

Märksõnad: *Microsoft Kinect*, Parkinsoni tõbi, modifitseeritud Tõuse-ja-Mine test, alafaasid, istest kõndima minek

1. LITERATURE REVIEW

1.1. Overview on Parkinson´s disease

Parkinson's disease (PD) is one of the most common neurodegenerative diseases among elderly. The occurrence of PD rises with age, with 425 per 100,000 between the age of 65-74 and 1903 per 100,000 individuals over 80 suffering from it (Pringsheim et al., 2014). In Estonia, the prevalence of PD is 152 per 100,000 (Taba & Asser, 2003). Due to the aging of the population the demand on health care resources connected to PD are expected to increase (Pringsheim et al., 2014).

The cause of the disease is still unknown and is often classified as idiopathic or sporadic Parkinson's disease (Falup-Pecurariu et al.,2017; Kalia & Lang, 2015). However, latest epidemiological studies have shown that the possible cause is a complicated interaction of genetic and environmental factors that affect several fundamental cellular processes leading to degeneration of neurons (Kalia & Lang, 2015; Pringsheim et al., 2014).

The pathophysiology of PD is complex. The main pathological marker for PD is considered to be the degeneration of the cells in basal ganglia, more specifically in -*substantia nigra pars compacta* and presence of Lewy pathology. The cells degeneration leads to insufficient levels of dopamine, resulting in characteristic symptoms (Kalia & Lang, 2015).

The main symptoms of PD include resting tremor, rigidity, bradykinesia and postural instability (Kalia & Lang, 2015). Postural instability usually occurs in the later stages of the disease. A characteristic stoop posture commonly includes flexed neck, trunk, hips and knees showing the dominance of flexor tone over the tone of extensor muscles. Rigidity is found to be more pronounced in lower and upper limbs comparing to neck (Falup-Pecurariu et al., 2017). Patients can also present with other clinical features such as freezing of gait or festination (Delval et al., 2016). PD is usually classified as a movement disorder, but also includes many non-motor disorders including autonomic and cognitive dysfunction (Falup-Pecurariu et al., 2017).

The onset of PD is usually stealthy and progression slow (Kalia & Lang, 2015). The symptoms can vary in the day and day to day and are vary substantially among patients. In early stages of the disease the clinical features can be intermittent (Falup-Pecurariu et al., 2017). Often, the onset of PD is non-specific: patient might present with symptoms such as changes in mood or fatigue. Another early sign of PD can be difficulties in everyday tasks, especially task with repetitive nature like brushing teeth or buttoning shirt (Falup-Pecurariu et al., 2017).

Upper and lower limb freezing and festination are found to be prevalent early after the diagnosis of PD and also an early indicator of disease progression (Delval et al., 2016). The most common presenting sign is resting tremor (4-6 Hz) in one hand or leg (Falup-Pecurariu et al., 2017).

Diagnosing PD is complex as there is no specific test for definitive diagnosis in early stages of the disease. The diagnosis is based on clinical symptomatology and is usually made when the patient has main PD symptoms of bradykinesia, rigidity and resting tremor and secondary parkinsonism is excluded. (Kalia & Lang, 2015).

Levodopa is a medication widely used in management of PD (Rascol, 2016; Connolly & Large, 2014). It is an amino-acid precursor for dopamine and works by replacing the levels of dopamine lacking in the body, resulting in reductions of symptoms. Unfortunately, there are many side-effects to long term use of Levodopa – eg involuntary and abnormal movements (choreoathetoid movements) and fluctuations in motor performance, so called on-off periods (Rascol, 2016; Connolly & Large, 2014). Often a combination of drugs is needed for management of PD symptoms (Connolly & Large, 2014). At present, there are no available neuroprotective therapies with clinical evidence (Espay et al., 2017).

The widely used system for assessing the current stage and progression of the disease is the scale developed by Hoehn and Yahr (H&Y) (Appendix 1). The scale divides the disease into 5 different stages where stage 1 marks the beginning of the disease and stage 5 is the most progressed stage of PD (typically the patient is bedridden). There is also an addition to the scale with stages 1.5 and 2.5 (Goetz et al., 2004).

Another measure, looking at the disease severity on a more complex, holistic level, is Unified Parkinson's disease Rating Scale (UPDRS) and its revised version Movement Disorder Society-Sponsored Revision of the Unified Parkinson´s Disease Rating Scale (MDS-UPDRS). MDS-UPDRS has 4 different assessment areas: non-motor experiences of daily living (13 items); motor experiences of daily living (13 items); motor examination (18 items) and motor complications (6 items). Each item subscale will be rated from 0-4 where 0 is normal and 4 severe (Goetz et al., 2008). The assessment is usually made by a clinical specialist of PD-neurologist, specialist nurse or specialist physiotherapist.

Once the disease is more progressed, usually a multidisciplinary team management is needed, including input from physiotherapists, speech and language therapist, occupational therapists among others for a holistic management of the patient (Rochester & Espay, 2015)

The physiotherapist role in management of PD addresses the physical and social aspects of living with the disease. Appropriate assessment of functionality is the key to proper management. When symptoms like tremor usually submit well to medical treatment, then

problems with gait and posture are found to be persistent despite pharmacological treatments (Rochester & Espay, 2015). This further highlights the importance of non-pharmacological management (Bloem et al., 2015).

As PD is a neurodegenerative disease, the condition of the patient will continue to progresses over time. It is crucial to continue monitoring the progression of the disease and functionality of the patient in order to offer the best possible support and care for people living with PD.

1.2. Assessment of mobility and functionality in patients with Parkinson's disease

Functionality is a capability of a person to cope with daily activities of life. An important part of functionality is mobility - the ability to move and to perform tasks needed for coping. Activities of daily living such as getting up from a bed or a chair and walking are the basic movements that enable a person to preserve independence.

It is found that gait impairment has a distinct association with reduced mobility and independence (Rochester & Espay, 2015). Everyday tasks that involve transfers, gait and gait-related activities are limited among patients with PD (Keus et al., 2014). For a person diagnosed with PD the fear of losing walking ability or ability to maintain upright posture while sitting or walking is found to be the first concern (Giladi et al., 2013).

Assessment of gait gives the health care specialist a lot of information about patient`s motor control deficits and insight about the efficiency of therapeutic interventions (Morris et al., 2001). Assessing functionality among patients with PD is important as changes in disability will trigger clinical management changes like modification of medications. Additionally, it is important to detect changes to maintain patient safety, prevent caregiver stress and detect the need for further referrals to social services for disability management (Shulman et al., 2016).

There are several widely used assessment measures of the functionality and mobility that can be applied in PD population (Shulman et al., 2016). Medijainen et al (2015) found that men with PD perform better in functional assessment tests comparing to women with PD regardless of the disease severity, highlighting the need of gender specific functional testing. Further, as the anthropometrical parameters of men and women differ (Perissinotto et al., 2002), it was decided in present study to set the focus on the assessment of male individuals.

A tool for functional assessment including gait assessment in PD is the Modified Parkinson's Assessment Scale (PAS) that consists of 14 parts, sub-grouped into 3 different groups: Chair Transfers, Gait Akinesia and Bed Mobility. Modified PAS has good correlation with previously mentioned UPDRS (Keus et al., 2009). One item of the Modified PAS, more

exactly the part of “Gait Akinesia”, is the assessment of rising from a chair. An independent test similar to that is called Timed Up and Go test (TUG).

TUG test is widely used in the community to assess and predict falls, health declines and difficulties with ADLs in elderly (Viccaro et al, 2011). Additionally, TUG is used to assess patients with moderate to severe PD (Zampieri et al., 2011) and is found to predict 75% of PD participants accurately as fallers or non-fallers (Nocera et al., 2013).

TUG test assesses the patient’s ability to perform sequential locomotors tasks of standing up, walking 3m turning and walking back to sit down. The standard procedure of TUG test measures the duration (in seconds) of the aforementioned performance (Herman et al., 2011). However, it is found that in assessing patients with early to mild stage of PD, the classical TUG test is not sensitive enough to detect abnormalities (Zampieri et al. 2011).

In recent years there have been increasing number of studies using different type of motion sensors in addition to classical TUG. Studies show that instrumented TUG (iTUG) can provide more information comparing to measures taken by a classical TUG (Mellone et al., 2012; Zampieri et al. 2011; Van Uem et al. 2016). In addition, iTUG is found to be sensitive to pathologies (Zampieri et al., 2010). In previous studies measurements of time and range of movements (ROM) of specific sub-phases of iTUG in has been gathered in healthy subjects (Mellone et al., 2012) and participants with PD compared to healthy subjects (Van Uem et al., 2016). Phases like sit to stand (STS), walking, turning 180 degrees turn, walking back and turning to stand and sit are often analysed while using instrumented versions of TUG test (Van Uem et al, 2016).

In addition to instrumented versions, also modified version of TUG (modTUG) has been occasionally used in research. For example, walking 7m compared to conventional 3m walking distance was used by Zampieri et al (2011). The instruments used to complement the results of standard TUG test are often inertial sensors like gyroscopes (Zampieri et al. 2011) or even smart phone based accelerometers (Mellone et al., 2012). In addition to inertial sensors, a major part of motion assessment is using different types of camera based assessment tools (Eltoukhy et al., 2017; Galna et al., 2014).

Conventional video-based assessment tools like 3D gait analysis systems (eg Vicon) are the gold standard for analysis of gait and other motions. The drawback of Vicon-like systems are the need for spacious (laboratory) setting, usage of reflective markers and many cameras, as well the experts who know the system well. Altogether, this makes this method of assessment very resources-dependant (Galna et al., 2014).

A rather new, simple and low cost motion sensor is found to be Kinect for Microsoft

(henceforward Kinect). Kinect is a camera-based sensor most known as an accessory for a gaming console known as Xbox. Kinect recognises movement of the body without additional body markers or force platforms, and has proven to be reliable in measuring temporal characteristics of people with PD (Galna et al., 2014). Although being a rather new method, Kinect as already found usage in research. For example, it has been used for assessment of respiratory function (Xia & Siochi, 2012) and human gestures (Lun& Zhao, 2015) Few papers have also been published, using Kinect in studies on participants with PD (Eltoukhy et al., 2017; Galna et al., 2014).

Combining a classical outcome measure like TUG test with Kinect could give more information about spatiotemporal characteristics and allow the physiotherapists to review different phases of the performance in addition to classical measurements of total test time. Recording different phases of a functional activity like getting up from a chair or walking might potentially provide information in which part of the task people with PD struggle more, making it possible to develop specific and targeted interventions to address these difficulties, and thereby increase or maintain the functionality of a person living with PD.

2. AIM AND OBJECTIVES

Aim of present study is to analyse the differences of lower limb kinematics and temporal characteristics detectable by Microsoft Kinect during sub-phases of modified Timed Up and Go test in male individuals with PD compared to healthy male counterparts.

Objectives

1. To analyse the differences between goniometric and Kinect-based measurements in static lower limb sagittal plane angle while sitting in men with and without PD
2. To analyse the differences between men with and without Parkinson in sagittal plane lower limb angles during sit-to-walking phase of modTUG
3. To analyse the differences in the distance between knees in men with and without Parkinson in during sit-to-walking (and sub-phases) of modTUG test
4. To analyse the differences between men with and without PD in spatiotemporal characteristics of sit-to-walking phase (and sub-phases) of modTUG test
5. To analyse the associations between disease severity and spatiotemporal characteristics during modTUG test in men with PD

3. METHODS

Current master thesis was conducted as a part of a larger project "Changes of functional capacity among patients with Parkinson's disease" and has been approved by the ethics committee of University of Tartu (certificate nr 245/M-25, dated 16.02.2015). The data was gathered in Tartu University Hospital and University of Tallinn during one year (February 2015-February 2016).

Four people participated in the data collection process and at least two assessors were always present to ensure the safety of the participants. The data collection process included collection of demographic characteristics, neurological assessment and assessment of five-times-sit-to-stand-test, gait initiation and modTUG test recorded with Kinect, which will be further explained below. In addition, all the participants with PD participated once in a physiotherapy session designed to introduce the patients with strategies to improve the before mention motions. The author of present thesis carried out these physiotherapy sessions.

Additionally, the author of the present thesis participated in following aspects of the study: participant recruitment and interviews, including assessment of patient`s cognitive status using Mini Mental Status Exam (MMSE), goniometric measurements and ensuring the safety of the participants. As the guidelines for writing the Master thesis limit the content of the thesis, only data enabling the answer to raised study questions was included in data analysis of this paper.

3.1 Participants

The Parkinson's Disease Association of Tartu and Tallinn were contacted for participant recruitment. As these associations unite both people with PD (members) and without (supporting members, eg spouse, caregiver of the member etc), the control group could also be formed. Altogether, sixteen men were divided into two equal sized and age-matched groups – PD-group and Control group (CG) were recruited as they met the inclusion criteria. The person was excluded in case of previous cardio-vascular incident, concurrent neurological condition, presence of any other untreated medical condition that might affect mobility; acute lower limb traumas during last two years. In addition, participants with moderate to severe cognitive impairment on MMSE and persons who used walking aids were excluded from the study. All the patients had confirmed PD diagnosis (according to the Queen Square Brain Bank (QSBB) criteria) by an expert neurologist and were on on-period of their medication cycle during testing. Demographic parameters, including age, height and weight were measured. Additionally, body mass index was calculated. The demographic characteristics of participants did not have a statistically significant differences, and are illustrated in Table 1

Table 1. Participants demographic characteristics (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
Age (years)	67.5±4.5	69.8±8.0
Height (m)	1.8±0.1	1.7±0.1
Weight (kg)	91.3±10.5	90.0±18.8
BMI (kg)	29.4±3.0	30.7±6.0

PD - Parkinson's disease, CG - Control, n - number of participants in the group, BMI - Body Mass Index

3.2 Analysis of differences between goniometric and Kinect-based measurements of static postural characteristics while sitting in men with and without PD

In order to measure static lower limb postural characteristics, the participant was seated on standard chair (height 44 cm, without armrests) with backrest. The chair was placed facing Kinect device located 3.35m away from the chair at a height of 90cm.

Kinect is a camera based gadget that uses infra-red sensors and colour sensors to track the movements of people. Kinect has a built-in software that allows to detect 20 points of the body (large body joints) thereby constructing a digital image of the body (henceforward Kinect model, Appendix 2). The use of additional body markers is not needed (Lissenko, 2015).

Kinect was used for this study in order to track and save the movements of participants of the study while performing modTUG test. The software KinectPsyManager v1.0 was developed in the Tallinn University of Technology for this purpose. The software allows to record the movements of previously explained Kinect model while performing various motions in different planes. Matlab2016b software was used to calculate joint angles from measurements collected by Kinect.

The participant was instructed to sit with the back supported by the back rest and feet supported on the floor. If the participant's height was ≤174 cm an additional backrest was used to assure that participants feet reach the floor comfortably. The flexion angles of right hip and knee joint were manually measured by physiotherapist as reference values. Thereafter, the participant was instructed to remain seated the same way, the physiotherapist retreated from the recording area of Kinect and the static parameters of hip and knee joint angle were recorded during the initial static sitting position before the initiation of sit-to-walking performance assessed with modTUG test (further explained later).

Kinect sensor has been previously proven to be reliable in detecting gross motor movements (Galna et al.,2014). Kinect enables to record enormous amount of data. As the movement of sitting to walking requires the greatest extent of movement in sagittal plane in two major joints of the lower limb - hip and knee joints were chosen. More specifically, the

right hip and knee joints were chosen for data analysis in order to compare Kinect measurements with angles taken with goniometry.

3.3 Analysis of differences between men with and without PD in lower limb kinematics and temporal parameters of sit to walking performance

Modified version of TUG test was selected for data collection for the current master thesis for analysis of differences between men with and without PD in lower limb kinematics and temporal parameters of sit to walking performance.

Standard version of the TUG tests measures the time that is required for a patient to stand up from a supported sitting position, walk forwards to a cone 3 meters away, turn around the cone over the preferred shoulder and walk back to the chair and sit again (Herman et al., 2011).

TUG test was used as a modified version due to restrictions by Kinect sensor sensitivity: Lissenko, (2015) found that there is an optimal distance where Kinect can accurately detect movements. In current study, Kinect was placed at a height of 90cm, 3.35m away from the chair, facing the participant to meet the optimal distance requirements. Due to that the normal 3m test length was changed to 2.08m.

To record the dynamic parameters of interest with Kinect, participants were seated on a standard chair (same chair described above). The chair that was attached to the floor. It was done so for safety reasons, as for example during five-times-sit-to-stand-test, which was also measured during this study, but was not included in this paper, the chair could have moved. As for the modTUG used in current master thesis, the test was recorded with Kinect once as a sequence of three successive modTUG performances: The participant was instructed to perform three attempts of standing up, walking around the cone over the dominant shoulder and return back to sitting (back supported) before starting next attempt. The examiner could not be directly by the patient, as Kinect system “assumes” that everything that moves in its test area is the same Kinect model. That means that one person can be in the “recording area” of the Kinect.

As mentioned above, the movement was continuously recorded by Kinect located in frontal plane (in front of the participant). Five “markers” were manually set by one person for Kinect during all three attempts.

Marker 1 the participant was sitting

Marker 2 the participant has reached standing position

Marker 3 the participant has walked to the cone and starts turning

Marker 4 the participant has ended the turn

Marker 5 the participant has walked back to the chair (facing it)

Marker 1 (start of new attempt) the participant has sat back down (back against the chair)

In current study marker 1, 2, 3 were used as the focus of this study was set to sit-to-walking transition. During data analysis the markers were manually adjustable to improve coinciding with measurements of Kinect for example to prevent mistakes due to reaction speed of the tester.

As mentioned previously, Kinect enables to collect a large amount of data. A subset from the original data was extracted for further analysis (see Appendix 3 as an example of one participant). The main focus was on temporal and postural characteristics of modTUG test sub-phase: sitting (marker 1) and sit-to-walking (marker 1 to marker 3). The sub-phase sit-to-walking was further broken down to two phases: sit-to-stand (STS) (marker 1 to marker 2) and walking (marker 2 to marker 3). The extraction of data of the sub-phases was possible due to the markers explained. Appendix 4 illustrates the movements of the Kinect model during sitting, STS and walking.

For lower limb kinematics minimum and maximum joint angles (measured in degrees) demonstrated by the participant during total motion of sit-to-walking were used. As due to rigidity and bradykinesia the range of motion is often reduced in PD (Keus et al., 2014) total range of motion (ROM, joint excursion) was analysed (defined as maximum angle minus minimum joint angles). The ROMs was used as it was not possible to record specific dynamic angles during the motion of sit-to-walking due to restrictions of software used. Also, a maximum joint angles were used to clarify if there is a deficiency in extension, as PD patients are known to be characterised by stooped posture (Falup-Pecurariu et al., 2017).

Knee distance was another postural parameter recorded during sit-to-walking motion to characterise step width and base of support. The maximum and minimum knee distances used during sit-to-walking were measured in cm by Kinect and separately phases of sitting and walking was analysed. With every postural characteristic, the average of three attempts were calculated.

The last also applied for temporal characteristics. The time to perform the previously mentioned phases - sit-to-walking, STS and walking was recorded.Additionally, gait speed was calculated (m/s) – the data on walking speed (henceforward referred as gait speed (GS)) was obtained as an average of three trials that the participant required to walk 2.08m.

All of the data on postural and temporal characteristics of modTUG test were collected with Kinect, with one exception. Namely, the number of steps required to perform the modTUG was counted by physiotherapist. The steps were counted starting from the first step the participant took after had had stood up, and the last step was counted as the participant had walked back to the chair, but was still facing it. The average of three trials was used for analysis

of calculated average step length – as a quotient of 4.16m (walking distance and number of steps). PD-group and CG group were compared.

3.4 Analysis of associations between disease severity and spatiotemporal parameters in men with Parkinson disease

To analyse the associations between disease severity and spatiotemporal parameters of gait in men with Parkinson disease information about current neurological condition needed to be obtained. For that neurological assessment was conducted and it included the assessment of disease severity of the participants with PD in the means of disease stage according to H&Y and MDS-UPDRS (described in short in the literature review of this thesis). It was done by two 5th year medical students, previously trained to perform such an assessment.

Additionally, all participants (n=16) were tested with MMSE, to ensure that participants have sufficient cognitive function to understand the instructions for the assessments. MMSE is a widely used method of assessment for cognitive impairment. The MMSE consists of 6 different sub parts and has a maximum score of 30. The cut-off-score for abnormal cognition is 24 (Folstein et al., 1975) Cognitive assessment was led by physiotherapists and medical students. Neurological status is illustrated in Table 2.

Table 2. Neurological status of participants (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
MDS-UPDRS score	60.3±18	N/A
H&Y score	2.2±0.7	N/A
MMSE score	26.9±3.3	26.6±2.0

PD - Parkinson's disease, CG - Control, n - number of participants in the group, MDS-UPDRS - Movement Disorder Society - Sponsored Revision of the Unified Parkinson´s Disease Rating Scale, H&Y- Hoehn and Yahr, MMSE - Mini Mental State Examination, N/A - not acquired

The association between GS, step length, previously mentioned temporal characteristics and disease severity and staging was further investigated in men with PD.

3.5 Methods of statistical analysis

Statistical analysis was performed with two commercially available statistical software. Descriptive analysis (mean±standard deviation) was performed, using Microsoft Excel (2016). R-Studio software was used for normality testing with Shapiro-Wilk test. In case of normal distribution of the data, the differences between PD and CG groups were analysed using student-t, otherwise Wilcoxon test was used. The associations between disease severity and spatiotemporal parameters of the gait in PD group were analysed using Pearson correlation. The level of statistical significance was set to p-value equal or less than 0.05.

4. RESULTS

4.1 Differences between goniometric and Kinect-based assessments of lower limb angles while sitting in men with and without PD

First, differences in static sitting position of the lower limbs was of interest. The results on comparing groups with Kinect are illustrated in Table 3.

Table 3. Lower limb joint angles while sitting measured with Kinect in degrees (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
RHJ angle	131.7±10.6	126.1±15.6
RKJ angle	122.4±12.8	125.0±15.3

PD - Parkinson's, CG - Control, n - number of participants in the group, RHJ - right hip joint, RKJ - right knee joint.

The groups did not differ according to Kinect in sitting position. Same applies to the goniometric measurements of hip and knee joint. However – when comparing the Kinect and goniometry, it was found that static angles of lower limbs registered by Kinect while sitting were significantly bigger than the goniometric measurements (see Figure 1). Only the knee joint of CG group was not significantly different when comparing Kinect and goniometric measurements (p= 0.07).

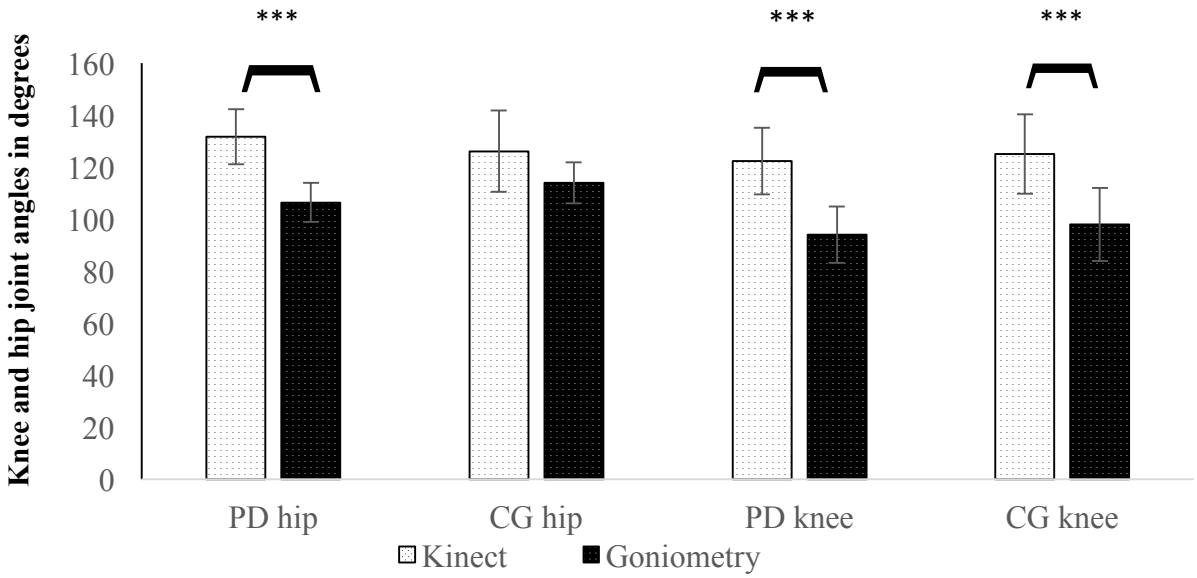

Figure 1. Parkinson's disease (PD) and Control (CG) knee and hip joint angles in degrees, differences between measurements taken by Kinect and Goniometry while sitting, ***p< 0.001

4.2 Differences between men with and without PD in lower limb kinematics of sit to walking performance

ROM in hip and knee joint was examined with Kinect during sit-to-walking motion. No statistically significant difference in joint excursion was found between CG group and participants with PD in the total motion of sit-to-walking. Illustrated in Table 4.

Table 4. Range of motion while performing sit-to-walking measured with Kinect in degrees (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
RHJ ROM	59.8±8	57.8±8.2
RKJ ROM	64.5±8.4	64.5±8

PD - Parkinson's disease, CG - control, n- number of participants in the group, ROM - range of motion, RHJ - right hip joint, RKJ - right knee joint

Data on the level of extension in hip and knee joints of the participants during sit-to-walking is shown in table 5.

Table 5. Maximum joint angles while performing sit- to-walking measured with Kinect in degrees (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
RHJ max	175.0±3.3	175.0±3.3
RKJ max	179.0±0.6	178.7±1.2

PD - Parkinson's disease, CG - control, n - number of participants in the group, RHJ - right hip joint, RKJ - right knee join, RHJ - right hip joint, RKJ - right knee joint, max – maximum

No significant difference between two groups was found. While looking at the maximum angles reached in hips and knees it can be seen that both groups have almost a full extension while performing sit-to-walking motion based on recordings from Kinect.

4.3 Differences between men with and without PD in distances between knees of sit to walking and its sub-phases

The data on the results of comparing maximum and minimum distance between knees used during sit-to-walking transfer was collected. During the whole sit-to-walk movement the PD participants did not reach the same maximum knee distances ($p<0.001$). Additionally, the distance between knees was compared in PD and CG groups during sitting and walking and the results are illustrated in figure 2.

As can be seen, during sitting the maximum distance between knees as well as the minimum distances between knees were significantly smaller in PD group compared to CG

group. During walking sub-part of sit-to-walking the minimum and maximum distances used did not differ between groups.

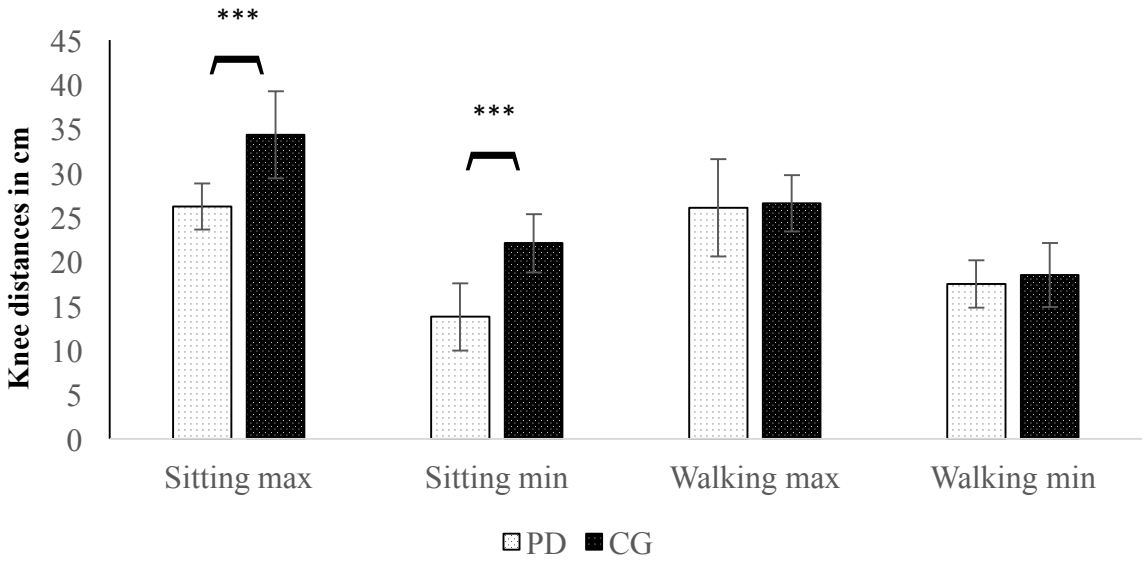

Figure 2. Minimum (min) and maximum (max) knee distances in cm of Parkinson's disease (PD) and Control (CG) group used during sitting and walking, ***p< 0.001

While looking at the differences between minimum and maximum measurements (that is "maximum minus minimum") inside groups, it was found that on average the change in distance between knees (max-min) was 12.4 cm in PD group and in CG group 12.2 cm while sitting. During walking, the variation between knee distance was 9 cm and 8.3 cm, respectively. The difference inside the group between variation of knee distance while sitting (max-min sitting) and walking (max-min walking) was statistically significant in CG group ($p<0.001$), but not in PD group, showing that there is a bigger variation in knee distances used during sitting compared to walking in CG group as expected. There was no difference between groups in these parameters.

4.4 Differences in men with and without PD spatiotemporal characteristics of sit to walking and its sub-phases

When comparing the PD and CG in means of temporal characteristics of sit-to-walking, it was found that it took PD group significantly longer (4.2±1 sec) to stand up and walk 2.08m than control group (3±0.5 sec, $p<0.01$). A more detailed look into sit-to-walking duration, revealed that the time of total duration was mainly increased in PD group due to slower walking phase of the movement. There is no difference between STS transfers between the PD and control group (see Figure 3).

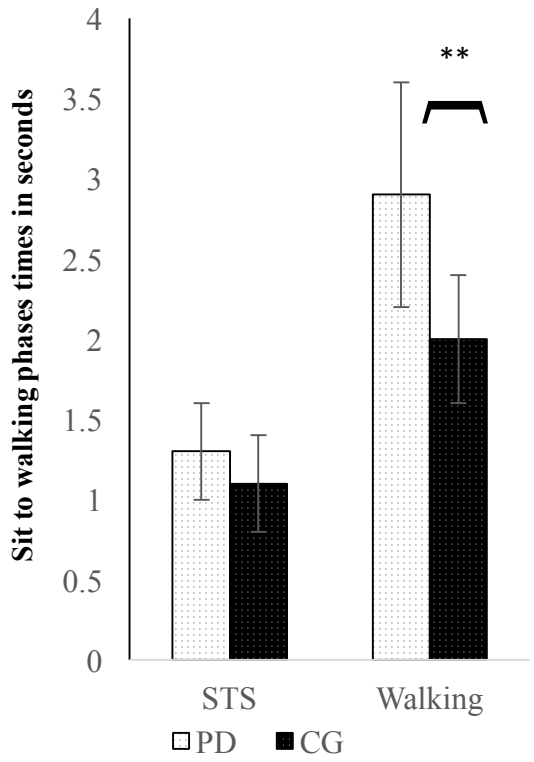

Figure 3. Sit to walking motion in two phases: sit to stand (STS) and walking, between Parkinson's disease (PD) and Control group (CG) **p<0.01

Lastly, groups were compared in means of number of steps and average step length. It was found that participants suffering from PD took significantly more steps than CG while performing modTUG (14.04±3.3 and 9.7±1.1 steps, respectively $p < 0.05$). In addition, also the average step length of PD participants was shorter and the speed of stand-to-walking slower. The results are shown in table 6.

Table 6. Gait speed and step length while performing modTUG test (mean±standard deviation)

	PD group (n=8)	CG group (n=8)
GS (m/s)	0.77±0.2	1.08±0.2**
Step length (cm)	31.2±8	36.3±4*

PD - Parkinson's disease, CG - control, n - number of participants in the group, GS - Gait Speed, modTUG – modified Timed Up and Go, **$p < 0.01$, * $p < 0.05$

4.5 The association between disease severity and spatiotemporal characteristics in men with Parkinson disease

No significant associations were found in current study. Negative moderate correlation ($r=-0.60$, $p<0.1$) between step length and H&Y and STS and H&Y ($r=-0.63$, $p<0.1$) was found, but level of significance set in current study was not met. Also, no significant associations were found between MDS-UPDRS score and any other spatiotemporal characteristics (sit-to-walking, STS and walking times, GS).

5. DISCUSSION

The aim of this study was to analyse the differences of selected postural and temporal characteristics detectable by Kinect during specific phases of modTUG test in male individuals with Parkinson's disease compared to healthy men. Altogether, sixteen men participated in the study, which of whom two groups were performed- PD group (n=8) and control group (n=8).

The ability to move effectively, safely and efficiently is a major part of functional and independent life. Sit-to-walking is a basic transfer commonly used for activities of daily living (Chen et al., 2013). It includes the sequential tasks of standing up and starting to walk. Many PD patients first fear, when diagnosed, is the loss of ability to walk or maintain upright position while sitting or standing (Giladi et al., 2013). Problems with gait and mobility are often present in early stages of the disease, but often remain clinically undetectable until the moderate to advanced stages. However, motion analysis techniques have been found to be able to detect deficits already in early stages of PD (Zampieri et al., 2010). One example of motion analysis systems previously used to assess mobility of people with PD is Kinect (Eltoukhy et al., 2017, Galna et al., 2014), potentially allowing to objectivise motion assessment compared to functional tests classically used in clinical setting (eg TUG).

5.1 Differences between goniometric and Kinect-based assessments of lower limb angles while sitting in men with and without PD

In sitting, no difference between two groups were found in any of the parameters assessed neither with Kinect nor with goniometry. Cachia (2008) found similarly no differences in hip and knee joints during sitting between PD and healthy elderly. The number of participants and the stage of the disease in PD groups were comparable to present study.

When comparing the joint angles obtained with goniometric angles in current thesis with the results of Cachia (2008), then knee angles were found to be similar. Hip joint angle was somewhat different being higher in previous study (hip CG group - 120.2, PD groups - 129.8 by Cachia (2008); in current study 114.0 and 106.4 degrees respectively). The difference can probably be attributed to the differences of chairs used. Cachia (2008) used an adjustable chair without a backrest. A standard non-adjustable chair with a backrest was used in current study as also in clinical setting standard chairs are used.

However, when comparing the same measurements from Cachia (2008) to findings from Kinect, hip joint angles were similar, but knee angles obtained with Kinect were bigger. The reason behind different measurements of Kinect detected, might be due to the accuracy of Kinect sensor.

In current study, the hip and knee joint angles differed significantly when Kinect measurements were compared to goniometry ones. On average, 19 degrees' larger angles detected by Kinect while sitting indicate that the Kinect placed in frontal plane "sees" greater extent of extension (sagittal plane). Similar findings were established by Galna et al (2014), who measured static and dynamic postural characteristics with Kinect in comparison to a gold standard Vicon motion assessment system with a similar Kinect set up to current study (sensor in frontal plane, 3m away in the height of 1m). Kinect was found to overestimate static angles in sagittal plane compared to Vicon. This could explain the differences between goniometry and Kinect measurement found in current thesis. The only exception in which the goniometric and Kinect-based measurements did not differ was the CG group hip joint angles. But as also there the results revealed a tendency to differ it is possible that in case of bigger sample size all the Kinect-based measurements would have been significantly higher in all the joints and in both groups. Although, future studies must keep in mind that as Eltoukhy et al (2017) found that Kinect is less accurate in assessing distal structures.

5.2 Differences between men with and without PD in lower limb kinematics of sit to walking performance

During modTUG test sub-phases, the dynamic angles of hip and knee joints (found as ROM) in sagittal plane were measured and compared between groups. ROM was used as the Kinect software does not able the detection of specific gait phases.

No difference between groups were found, similar to previous findings (Eltoukhy et al., 2017; Van Uem et al. 2016). In two recent studies ROMs of participants with mild to moderate PD and CG group were found to be similar while performing sit-to-walking of iTUG (Van Uem et al., 2016) and straight line walking (Eltoukhy et al., 2017).

While looking at the dynamic angles in sagittal plane Galna et al (2014) found that Kinect significantly underestimated hip kinematics while side stepping in frontal plane and forward stepping in sagittal plane and knee distance while foot tapping exercises.

As one characteristic of bradykinesia is reduced movement amplitude was assumed that individuals with PD group demonstrates smaller ROMs compared to CG group, but it was not the case in current study. Moreover, both of the groups showed reduced ROMs when compared to normative values.

Rowe et al (2000) who assessed transfers and gait parameters of healthy elderly, found that in order to stand up from a standard chair a knee ROM of 91.1 degrees is necessary. While walking, a ROM of 65.2 degrees is needed in knee joints. The ROMs measured by Kinect were substantially smaller in current study, one of the reason being potentially previously mentioned

Kinect sensor inaccuracy.

Another possible explanation for this is that CG participants might have had deficits in their mobility and functioning they did not report during participant interview. The research group did not have access to the participants' medical record so we had to rely on information from the participant. In addition to possible effect of unreported comorbidities, the result might have been affected by general deconditioning or sedentary lifestyle, which is known to be high among elderly (Davis et al., 2011).

In addition to static sitting and ROMs of sit-to-walking, we measured the maximum hip and knee joint angles as a characteristic of whether participants were able to reach a full extension during the test. Both groups achieved a full extension in hip and knee joints. Nugis (2016) reported similarly that PD participants reached an almost full extension during five-times-sit-to-stand test. This also is in concordance with Cachia (2008) who established similar findings when comparing PD participants to healthy elderly. The reason behind similar results probably lies in similar stage of the PD participants (mild- to- moderate in all the studies). Additionally, PD participants were assessed while they were on on-period of their medication cycle and their potential symptoms like bradykinesia were better managed due to that. It is however possible that when patients with moderate-to-severe PD were to be investigated and compared to healthy counterparts, also reduced joint excursions would have been detected in PD group.

The European Physiotherapy Guideline (EPG) of PD states that changes in posture like increased flexion (and reduced movement amplitude) in neck, trunk, upper and lower limbs are often associated with rigidity and usually develop in the later stages of the disease (Keus et al., 2014). Nonetheless, it is important to maintain and assess ROM by increasing awareness and educating patients as the disease progresses together with increase in rigidity (Falup-Pecurariu et al., 2017; Keus et al., 2014) in order to prevent any loss in ROM in the future.

In current study also distance between knees was measured during sit-to-walking movement. Measuring the distance between knees can give information about lower limb placement during sit-to-walking and from that information about width of the step and base of support used. In current study PD participants did not reach the same maximum distance between knees while performing sit-to-walking. When looking at the separate parts of the movement- sitting and standing, no differences in distances between knees was found during walking. These findings are supported by previous study, where also no difference between step width while walking between PD and CG group was detected (Bovonsunthonchai et al., 2014; Eltoukhy et al., 2017).

So, the difference found between groups results from sitting position, were the distance between knees was smaller in PD participants. Taking into account the previously established findings that an optimal base of support is needed for safe STS movement to decrease risk of falling (Janssen et al., 2002), the results show that participants with PD in current study potentially are not using an optimal base of support and could be at higher risk of falling due to that while performing STS movement.

One of the aspect of smaller distance between knees in PD group might be muscle strength. It is known that PD participants are prone to have weakness in muscles surrounding hip and knee joints (Mak & Hui-Chan, 2004) which would make it more difficult to maintain a stable distance between knees. Later aspect should be considered when planning therapy: targeted muscle strengthening to hip abductors and adductors and practising optimal base of support during transfers could help to decrease the risk of falling in people with PD.

5.3 Differences in spatiotemporal characteristics of sit to walking and its sub-phases and correlations with disease severity in men with and without PD

Chen et al (2013) established that compared to non-fallers, elderly who had recurrent falls, performed sit-to-walk movement slower during TUG test. 70-87% of people with PD will fall at one point during their disease (Hely et al., 2008). In current study participants with PD were slower to perform sit-to-walking movement of modTUG test ($p<0.01$). These findings are supported by previous study by Van Uem et al (2016) who found that PD participants were significantly slower in sit-to-walking part of iTUG.

Assessing sit-to-walking movement of PD patients can therefor give information about risk of falling already in early stages of the disease. It is important maintain the movement and practise it therapy as sit-to-walking transfer is a frequently required movement of everyday-life (Van Uem et al., 2016) and is a basic transfer needed for functionality and mobility (Janssen et al., 2002) Additionally, people with PD are known to struggle with that (Keus et al., 2014).

A more detailed look into sit-to-walking duration revealed that the duration of total performance of sit-to-walking was mainly increased in PD group due to slower walking phase of the movement. Previous studies have similarly found that PD participants are slower in walking tasks compared to healthy elderly (Eltoukhy et al., 2017).

There were no differences found in STS part of sit-to-walking between PD and CG groups. These findings are supported by previous study where PD participants were able to perform STS transfer during five-time-sit-to-stand test with same times compared to healthy elderly (Nugis, 2016).

Moreover, Galna et al (2014) found Kinect sensor to be accurate in measuring temporal

characteristics, with excellent correlations ($r>0.9$) in all movements (inc. STS, walking on the spot) compared to Vicon 3D analysis system, indicating that Kinect is accurate in detecting temporal parameters.

A total time of modTUG test was not measured as due to the modification of length from classical 3m to 2.08m (because of Kinect does not measure if the Kinect model is "too near" or "too far" – distance 2.08 was optimal for Kinect to measure both sitting, standing up and walking forward). Therefor it is not possible to compare our results on total modTUG performance with the findings from previous and standard TUG tests.

However, we used the calculated GS to compare results from previous studies. PD participants in current study had a significantly slower GS comparing to control group ($p<0.01$). These findings are supported by previous research as it is well established that patients with PD have slower GS when compared to healthy elderly (Falup-Pecurariu et al., 2017). GS can be affected and linked to many factors in people with PD like previous falls, increased risk of falls, decreased mobility, clinical severity of the disease among other (Parker et al., 2015).

However, the GS calculated in current thesis was 0.77m/s, which is considerably lower comparing to GS of 0.94 m/s measured in previous study of Parker et al (2015). Parker and co-authors (2015) studied the GS of 50 participants with PD with a mean H&Y score similar to current study. Findings of current are closer to average GS of 0.88 m/s detected in PD participants with more progressed disease - H&Y scoring of 3-4 (Hass et al., 2012). The GS in current study is also slower comparing to international standards for GS needed to gross pedestrian grossing of 0.94- 1.2 m/s (Keus et al., 2014) indicating that participants with PD in current study are potentially not coping with outdoor mobility efficiently and safely.

Potential reason why the GS of our PD participants was slower could be due to the fact that it was recorded during a functional activity of sit-to-walking in a short distance, which includes acceleration (post standing up and starting to walk) and decelerating part (prior to turning), comparing to previous studies were GS has been measured while straight line walking where often acceleration and deceleration has been excluded (Hass et al., 2012; Parker et al., 2015). However, as CG performed under same circumstances the difference might potentially arise from other PD characteristics symptoms like bradykinesia or start hesitation (Keus et al., 2014).

Another reason could be the use of a non-specific room. Gait speed is often measured in gait laboratories (Parker et al., 2015). Zampieri et al (2011) found that PD patients walk slower in home setting compared to a gait laboratories setting while performing iTUG test. The room used in current thesis is comparable to home-environment due to its size.

In addition to GS, number of steps was measured while performing modTUG test and from there average step length was calculated. It was found that participants with PD perform more steps comparing to control group ($p<0.05$) and have shorter step length ($p<0.05$). As it is known that the gait of a person with PD is characterised with small and shuffling steps (Falup-Pecurariu et al., 2017) the results are expectable. These finding are also in concordance previous studies where participants with PD performed more steps while performing iTUG (Zampieri et al., 2011) and used smaller steps while walking measured with Kinect and Vicon (Eltoukhy et al., 2017) compared to healthy elderly (Eltoukhy et al., 2017; Zampieri et al., 2011)

Chen et al (2013) found that elderly fallers use shorter steps while performing sit-to-walking motion as a strategy to maintain balance compared to elderly non-fallers. Indicating that higher number of steps during modTUG among elderly could predict higher falls risk. In current study due to the limited size of the study sample, fallers and non-fallers were not distinguished. Future studies should look into this aspect, as it is well known that PD participants are at increased risk of falling (Nocera et al.,2013).

When comparing the step length detected in current study to normative spatiotemporal parameters of older people, the average step length used by participants in current study is much smaller. Hollmann et al (2011) found that healthy elderly males aged 70-74 years' average step length is 69±8 cm, which is twice as much as the step length used by both groups in current study. A potential reason of smaller step length might be due to the fact that it was measured on a short distance (like home environments) - PD patients perform more steps while performing modTUG in smaller environments, indicating smaller step length (Zampieri et al., 2011).

Another reason could be that the step length was calculated based on step count which included also180 degree turn during modTUG test and participants with PD are known to perform turning part of iTUG slower (Van Uem et al., 2016). Distance however was taken from straight line walking, making the calculation less accurate. Taking that into account, future studies could differentiate turning steps from straight line walking steps to avoid inaccuracy in the calculations.

The step length was however still calculated as the current version of program used with Kinect was unable to detect spatiotemporal characteristics like step length. Nonetheless, calculated step length from modTUG test can still be informative as it mimics everyday transfers in a home environment, which often include turns or manoeuvring past furniture as it is found that home environments are more cluttered (Zamiper et al., 2011).

Lastly we looked into associations between assessed parameters of sit-to-walking and the

stage of the disease. No correlations between spatiotemporal characteristics and H&Y or MDS-UPDRS scores was found. These findings differ from previous study conducted by Parker et al (2016) who found negative correlation between GS and H&Y Therefor on reason behind not finding associations in current study is probably mostly due to small sample size – The sample size in the study by Parker et al (2015) exceeded current study considerably (n=50).

Findings in current study indicate that physiotherapy should be concentrating on gait related activities and transfers, especially on temporal characteristics like time taken to stand up or speed of walking in mild to moderate PD. Furthermore, it is important not to concentrate on postural characteristics like ROM or posture exercises as it was found not to be limited in early stages of PD, but on gait characteristics like step length and width used while performing functional activities and base of support while performing STS. This is supported by EPG for PD, that indicate that physiotherapy for people with PD staging 2-4 should concentrate on maintain and improving activities like balance, manual activities and gait together with transfers. Moreover, is it established that gait limitations arise already in early stages of the disease (Keus et al., 2014).

The main limitation of the study was the relatively small sample size. Additionally, the inability for several people to be in the view of the Kinect currently limits the assessment of PD patients with more advanced disease.

The use of non-adjustable chair, making it not possible to standardize initial position for data collection, potentially making static siting position less accurate due to differences in anthropometrics, can be counted as the weaknesses of the study. However, using a non-adjustable chair allows to mimic clinical or home setting.

Future studies could concentrate on the turning and stand to sit phase of TUG test and find connections between self-reported functionality and TUG test findings. Additionally, a study comparing PD participants with and without a falls history and fear of falling, while performing TUG test measured with Kinect, could give an understanding into the relationship between functional tests and falls risk and how accurate Kinect sensor is in predicting this. Kinect sensor sensitivity and accuracy should be targeted in future developments of Kinect. Additionally, Kinect sensors sensitivity detecting tremor as it is one of the main symptoms of PD (Kalia & Lang, 2015) could be of interest together with accuracy of the motion analysis in future studies.

The strengths of current thesis are the use of a relatively new method Kinect for analysis of a classical functional test like modTUG for data collection. Use of cost effective alternative for gold standard 3D motion analysis systems and using more flexible environments comparing to gait lab like home (Zampieri et al., 2011; Van Uem et al., 2016) or clinical settings like

consultation room. Additionally, analysing temporal characteristics of specific phases with Kinect made it possible to objectivise a classical test TUG. Assessing postural characteristics with Kinect however need further development prior to using it in clinical settings as Kinect accuracy was indicated to be poor in some parameters, with the software currently not allowing to look at specific dynamic joint angles or some spatiotemporal characteristics.

Current thesis has given an insight to the use of Kinect sensor in assessing sit-to-walking performance in people with PD and in comparison, to healthy counterparts. Using Kinect made it possible to assess the sub-phases of the test, giving information about the specific part of a functional activity of sit-to-walking which usually would not be possible in clinical setting. Future development of the Kinect-based movement analysis and studies on their accuracy are needed to guide management of PD.

6. CONCLUSIONS

1. During goniometric and Kinect-based measurements men with PD and healthy men demonstrate similar static sagittal plane hip and knee joint angles
2. During sitting Kinect records higher, potentially false, sagittal plane angles in lower limbs compared to goniometry
3. The hip and knee joint range of motion and extent of extension recorded with Kinect are similar in men with and without PD during sit-to-walking performance
4. Kinect is likely to be underestimating joint excursions during dynamic movement in sagittal plane both men with PD and healthy men
5. Men with mild to moderate PD have similar distance between knees while walking, but use smaller distances while sitting, resulting in smaller distances used during sit-to-walking part of modTUG
6. Men with mild to moderate PD perform the STS phase of modTUG test with similar duration than healthy men, but are slower in walking phase, resulting also in lower sit-to-walking transition
7. Men with mild-to-moderate PD demonstrate reduced GS during sit-to-walking performance and reduced step length while performing modTUG compared to heathy men.
8. Disease severity and spatiotemporal characteristics of modTUG test are not associated in men with PD

REFERENCES

1. Bloem RB, de Vries MN, Ebersbach G. Nonpharmacological Treatments for Patients with Parkinson's Disease. Movement Disorders 2015;30:1504-1520.
2. Bovonsunthonchai S, Vachalathiti R, Pisarnpong A, Khobhun F, Hiengkaew. Spatiotemporal Gait Parameters for Patients with Parkinson's Disease Compared with Normal Individuals. 2014;19:158-165
3. Cachia C. A biomechanical analysis of the sit-to-stand transfer in Parkinson's disease. Master's thesis. Kingston, Kanada: Queen's University; 2008.
4. Chen T, Chang CC, Chou L-S. Sagittal plane centre of mass movement strategy and joint kinetics during sit-to-walk in elderly fallers. Clinical Biomechanics 2013;28:807-812.
5. Connolly BS, Large AE. Pharmacological Treatment of Parkinson Disease: A review. The Journal of American Medical Association 2014;311(16):1670-1683.
6. Davis MG, Fox KR, Hillsdon M, Sharp DJ, Coulson JC et al. Objectively measured physical activity in a diverse sample of older urban UK adults. Medical Science of Sports Exercise 2011;43(4):647–54.
7. Delval A, Rambour MI, Tard C, Dujardin K, Devos D, et al. Freezing/Festination During Motor Tasks in Early-Stage Parkinson's Disease: A Prospective Study. Movement Disorders 2016; 31:1837-1845.
8. Eltoukhy M, Kuenze C, Oh J, Jacopetti M, Wooten S et al. Microsoft Kinect can distinguish differences in over-ground gait between older persons with and without Parkinson's disease. Medical Engineering and Physics 2017;000:1–7.
9. Espay AJ, Schwarzschild MA, Tanner CM, Fernandez HH, Simon DK, et al. Biomarker-Driven Phenotyping in Parkinson's Disease: A Translational Missing Link in Disease-Modifying Clinical Trials. Movement Disorders 2017;32:319-324.
10. Falup-Pecurariu C, Ferreira J, Martinez-Martin P, Chaudhuri KR. Movement Disorder Curricula. Wien: Springer-Verlag; 2017
11. Folstein MF, Folstein SE, McHugh PR. Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research 1975;12:189-198.
12. Galna B, Barry G, Jackson D, Mhiripiri D, Olivier P et al. Accuracy of the Microsoft Kinect sensor for measuring movement in people with Parkinson's disease. Gait & Posture 2014:39: 1062–1068.

13. Giladi N, Horak FB, Hausdorff JM. Classification of Gait Disturbances: Distinguishing Between Continuous and Episodic Changes. Movement Disorders 2013; 28: 1469-1473.
14. Goetz CG, Poewe W, Rascol O, Sampio C, Stebbins GT et al. Movement Disorder Society Task Force Report on the Hoehn and Yahr Staging Scale: Status and Recommendations. Movement Disorders 2004; 19:1020 –1028.
15. Goetz CG, Tilley BC, Shaftman SR, Stebbins GT, Fahn S, et al. Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale Presentation and Clinimetric Testing Results. Movement Disorders 2008;23(15):2129–2170.
16. Hass CJ, Malczak P, Nocera J, Stegemoller EL, Wagle SA, Malaty I et al. Quantitative normative gait data in a large cohort of ambulatory persons with Parkinson's disease. Public Library of Science One 2012; 7. https://doi.org/10.1371/annotation/d4b5158e-0dd1-4e14-b03a-1af4d5f06c0e
17. Hely MA, Reid WG, Adena MA, Halliday GM, Morris JG. The Sydney multicenter study of Parkinson's disease: the inevitability of dementia at 20 years. Movement Disorder 2008; 23:837–844.
18. Herman T, Giladi N, Hausdorff JM. Properties of the Timed Up and GO Test: More than Meets the Eye. Gerontology 2011;57:203-210.
19. Hollman JH. McDade EM, Petersen RC. Normative Spatiotemporal Gait Paramteters in Older Adults. Gait and Posture 2011; 34;111-118.
20. Janssen, WGM, Bussmann, HBJ, Stam, HJ. Determinants of the Sit-to-Stand Movement: A Review. Physical Therapy 2002; 82: 866-879.
21. Kalia LV, Lang AE. Parkinsons's disease. The Lancet 2015;386:896-912
22. Keus SHJ, Nieuwboer A, Bloem BR, Borm GF, Munneken M. Clinimetric analyses of the Modified Parkinson Activity Scale. Parkinson Related Disorders 2009; 15: 263-269.
23. Keus SHJ, Munneke M, Graziano M, Paltamaa J, Pelosin E. European Physiotherapy Guideline for Parkinson's disease. 2014; KNGF/ParkinsonNet, the Netherlands.
24. Lissenko H. Mitme Kinecti kasutamine pööramisliigutuse registreerimiseks. Master thesis. Tallinn. Tallinna Tehnikülikool; 2015
25. Lun R, Zhao W. A survey of application and human motion recognition with Microsoft Kinect. International Journal of Pattern Recognition and Artificial Intelligence 2015: 8. DOI: 10.1142/S0218001415550083
26. Mak MKY, Hui-Chan CMY. Audiovisual cues can enhance sit-to-stand in patients with

Parkinson´s disease. Movement Disorders 2004; 19: 1012-1019.

27. Medijainen K, Pääsuke M, Lukmann A, Taba P. Functional Performance and Associations between Performance Tests and Neurological Assessment Differ in Men and Women with Parkinson's Disease. Behavioural Neurology 2015. http://dx.doi.org/10.1155/2015/519801
28. Mellone S, Tacconi C, Chiari L. Validity of a Smartphone-based instrumented Timed Up and Go. Gait & Posture 2012; 36:163–165.
29. Morris ME, Huxham F, McGinley J, Dodd K, Iansek R. The biomechanics and motor control of gait in Parkinson disease. Clinical Biomechanics 2001;16:459-470.
30. Nocera JR, Stegemöller EL, Malaty IA, Okun MS, Marsiske M. Using the Timed Up & Go Test in a Clinical Setting to Predict Falling in Parkinson's Disease. Archives of Physical Medicine and Rehabilitation 2013; 94: 1300–1305.
31. Nugis M. Istest püstitõusu testi sooritus hinnatuna tavapäraselt ja Microsoft Kinectiga Parkinsoni tõvega meestel ja naistel enne ja pärast ühekordset füsioterapeutilist sekkumist. Master's thesis. Tartu, Estonia: University of Tartu; 2016
32. Parker N, Bugdayci D, Goksenoglu G, Demircioglu DT, Kesiktas N. Gait speed and related factors in Parkinson's disease. Journal of Physical Therapy Science 2015;27: 3675-3679.
33. Perissinotto E, Pisent C, Sergi G , Grigoletto F, Enzi G. Anthropometric measurements in the elderly: age and gender differences. British Journal of Nutrition 2002;87:177–186.
34. Pringsheim T, Jette N, Frolkis A, Thomas, Steeves DL. The Prevalence of Parkinson's Disease: A Systematic Review and Meta-analysis. Movement Disorders 2014; 29: 1583-1590.
35. Rascol O. Pharmacological Insights into Levodopa- induced Motor Fluctuations in Patients with Parkinson's Disease. Wiley Inter Science 2016: 523-526. doi:10.1002/mdc3.12389
36. Rochester L, Espay AJ. Multidisciplinary Rehabilitation in Parkinson's Disease: A Milestone With Future Challenges. Movement Disorders 2015; 30:1011-1013.
37. Rowe PJC, Myles MWalker C, Nutton R. Knee joint kinematics in gait and other functional activities measured using flexible electrogoniometry: how much knee motion is sufficient for normal daily life? Gait and Posture 2000;12:143–155
38. Shulman LM, Armstrong M, Ellis T, Gruber-Baldini A, Horak F et al. Disability Rating

Scales in Parkinson's Disease: Critique and Recommendations. Movement Disorder 2016; 31:1455-1465.

39. Taba P, Asser T. Parkinsoni tõbi Eestis. Eesti Arst 2003; 82(6): 400-405.
40. Zampieri C, Salarian A,Carlson-Kuhta P, Nutt JG, Horak BF. Assessing mobility at home in people with early Parkinson's disease using an instrumented Timed Up and Go test. Parkinsonism and Related Disorders 2011;12: 277-280.
41. Zampieri C, Salarian A, Carlson-Kuhta P, Aminian K, Nutt JG. The instrumented Timed Up and Go test: Potential outcome measure for disease modifying therapies in Parkinson's disease. The Journal of Neurology Neurosurgery and Psychiatry 2010; 81(2):171–176.
42. Van Uem JMT, Walgaard S, Ainsworth E, Hasmann SE, Heger T et al. Quantitative Timed-Up-and-Go Parameters in Relation to Cognitive Parameters and Health- Related Quality of Life in Mild-to-Moderate Parkinson's Disease 2012: DOI:10.1371/journal.pone.0151997
43. Viccaro LJ, Perera S, Studenski SA. Is Timed Up and Go Better Than Gait Speed in Predicting Health, Function, and Falls in Older Adults? Journal of American Geriatric Society 2011; 59(5): 887–892.
44. Xia J, Siochi A. A real-time respiratory motion monitoring system using KINECT: Proof of concept. Medical Physics 2012;39(5):2682-2685.

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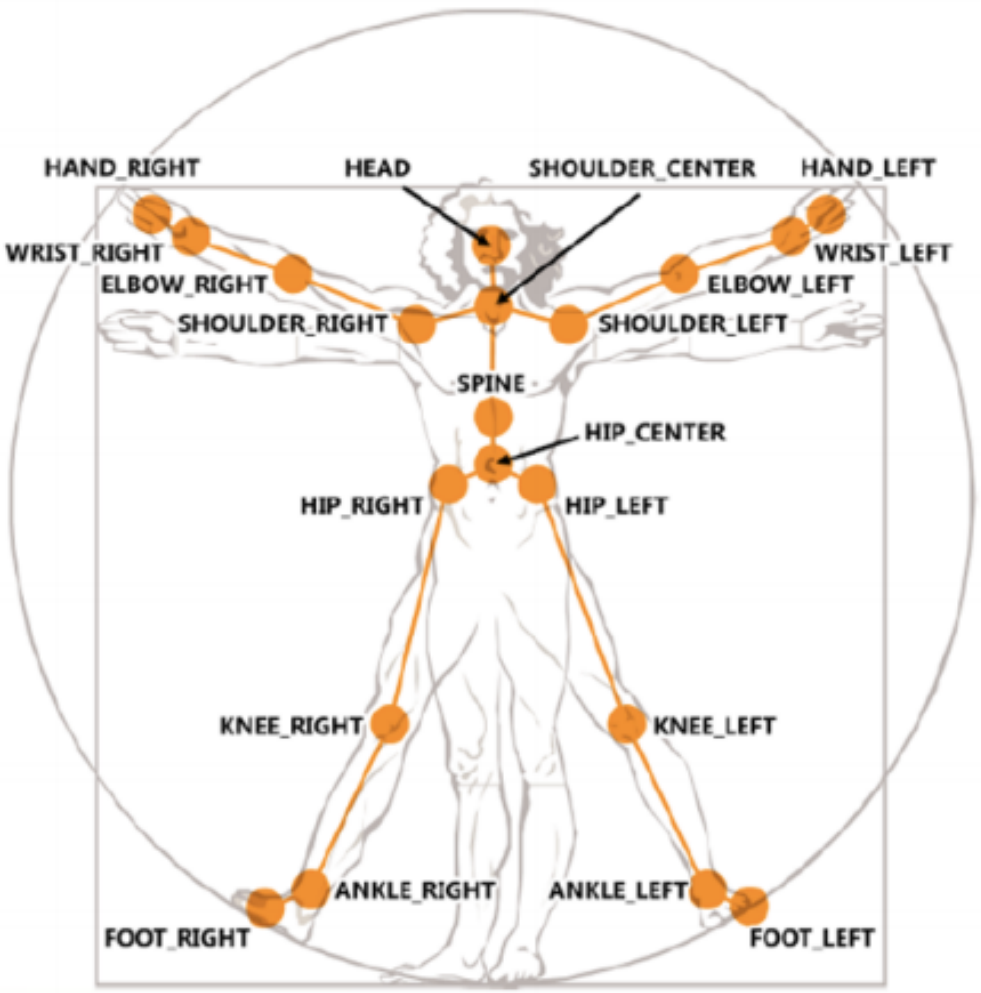
Appendix 1 Classification of severity of Parkinson's disease according to modified Hoeh and Yahr scale (Goetz et al., 2004).

Stage	Signs and symptoms
0	No signs of disease
1.0	Unilateral symptoms only
1.5	Unilateral and axial involvement
2.0	Bilateral symptoms. No impairment of balance
2.5	Mild bilateral disease with recovery on pull test
3.0	Balance impairment. Mild to moderate disease. Physically independent
4.0	Severe disability, but still able to walk or stand unassisted
5.0	Needing a wheelchair or bedridden unless assisted

Appendix 2 Model constructed by built-in Kinect software with 20 joint points (Lissenko, 2015).



Appendix 3 Raw data extracted from Kinect

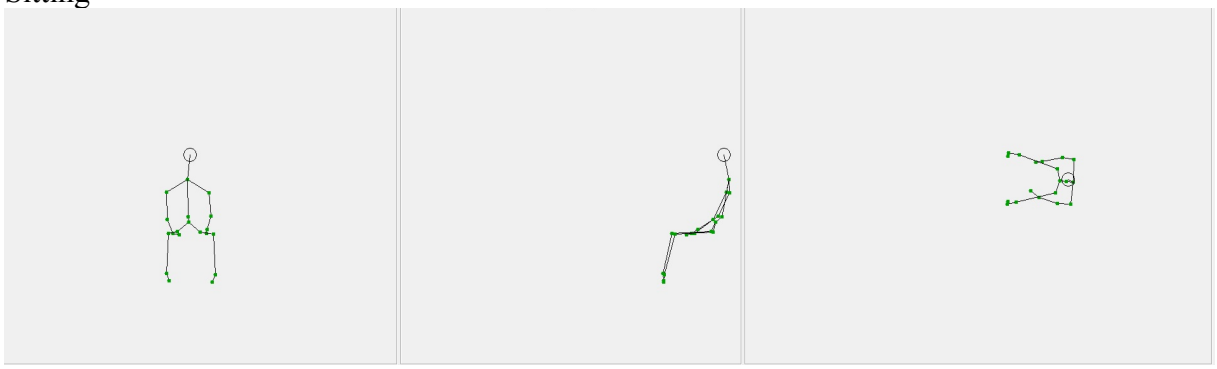
	A	B	C	D	E	F	G	H
1								
2			Sitting					
3			Abs. time	1 4 18	1 4 14	17 18 19	13 14 15	Knee dist.
4	Attempt 1	Marker 1	1.236	126.5132	127.6559	127.3157	123.8034	0.258187
5			2.136	164.1479	161.8536	177.379	171.5095	0.178095
6	Attempt 2	Marker 1	13.376	128.0261	127.575	126.9855	126.2536	0.220906
7			14.712	161.7134	168.5503	172.9001	172.5376	0.223396
8	Attempt 3	Marker 1	25.516	128.3524	125.3041	124.2235	117.8149	0.217592
9			26.516	157.703	168.3795	173.062	174.4464	0.240814
10	Min			124.1996	124.9527	124.2235	114.9211	0.178095
11	Max			164.1479	168.5503	179.2605	174.4464	0.258187

	J	K	L	M	N	O	P	Q
1								
2			Walking					
3			Abs. time	1 4 18	1 4 14	17 18 19	13 14 15	Knee dist.
4	Attempt 1	Marker 2	2.172	165.5199	163.4585	175.0938	172.7223	0.17682
5		Marker 3	4.108	173.5541	158.5436	162.7164	173.6128	0.210079
6	Attempt 2	Marker 2	14.744	162.6591	168.9854	173.4586	172.7778	0.223399
7		Marker 3	17.044	163.2554	163.4314	164.6634	167.0721	0.235688
8	Attempt 3	Marker 2	26.553	159.9495	169.2985	167.606	174.545	0.237659
9		Marker 3	28.252	173.724	159.0697	171.188	178.6706	0.186728
10	Min			159.6294	157.2702	152.3601	150.3137	0.17682
11	Max			174.4527	171.2735	179.3301	178.6706	0.237659

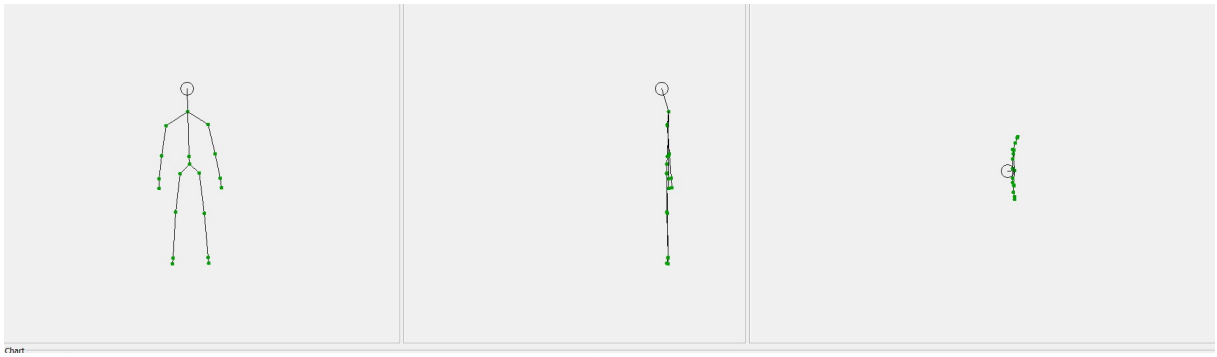
Abs. time - absolute time continuously recorded in seconds; 1 4 18 - right hip angle recorded by Kinect converted into degrees; 1 4 14 - left hip angle recorded by Kinect converted into degrees; 17 18 19 - right knee angles recorded by Kinect converted into degrees;; 13 14 15 - left knee angles recorded by Kinect converted into degrees; knee dist – distance between knee joints recorded by Kinect in in meters, Min - minimum joint angle of total movement of sit-to-walking recorded by Kinect, converted into degrees; Max - maximum joint angle of total movement of sit-to-walking recorded by Kinect, converted into degrees.

Appendix 4 Kinect 3D figure while different phases of sit-to-walking

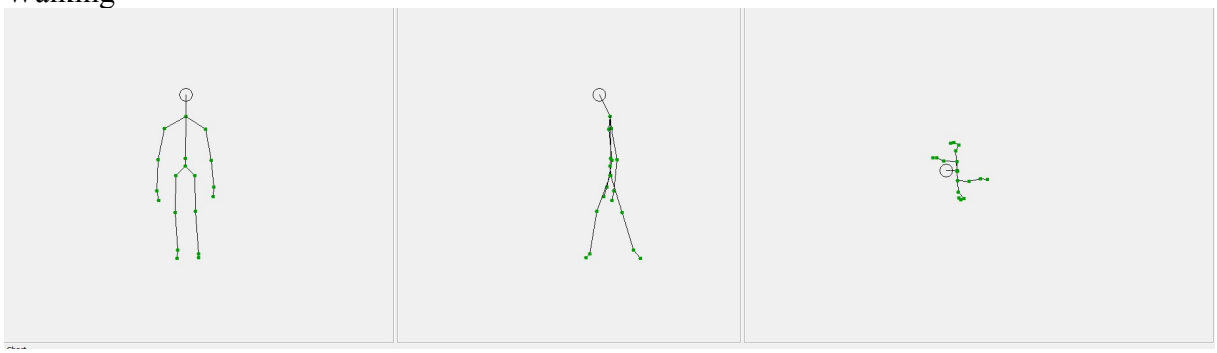
Sitting



Sit-to-stand



Walking



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Mina Hedi Kähär (sünnikuupäev 09.07.1992)

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Microsoft Kinectiga hinnatavad posturaalsed ja ajalised erinevused istest kõndima minekul modifitseeritud Tõuse- ja-Mine testi sooritusel Parkinsoni tõvega ja tõveta meestel,

mille juhendajad on Kadri Medijainen, MSc ja Pille Taba, MD, PhD,

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